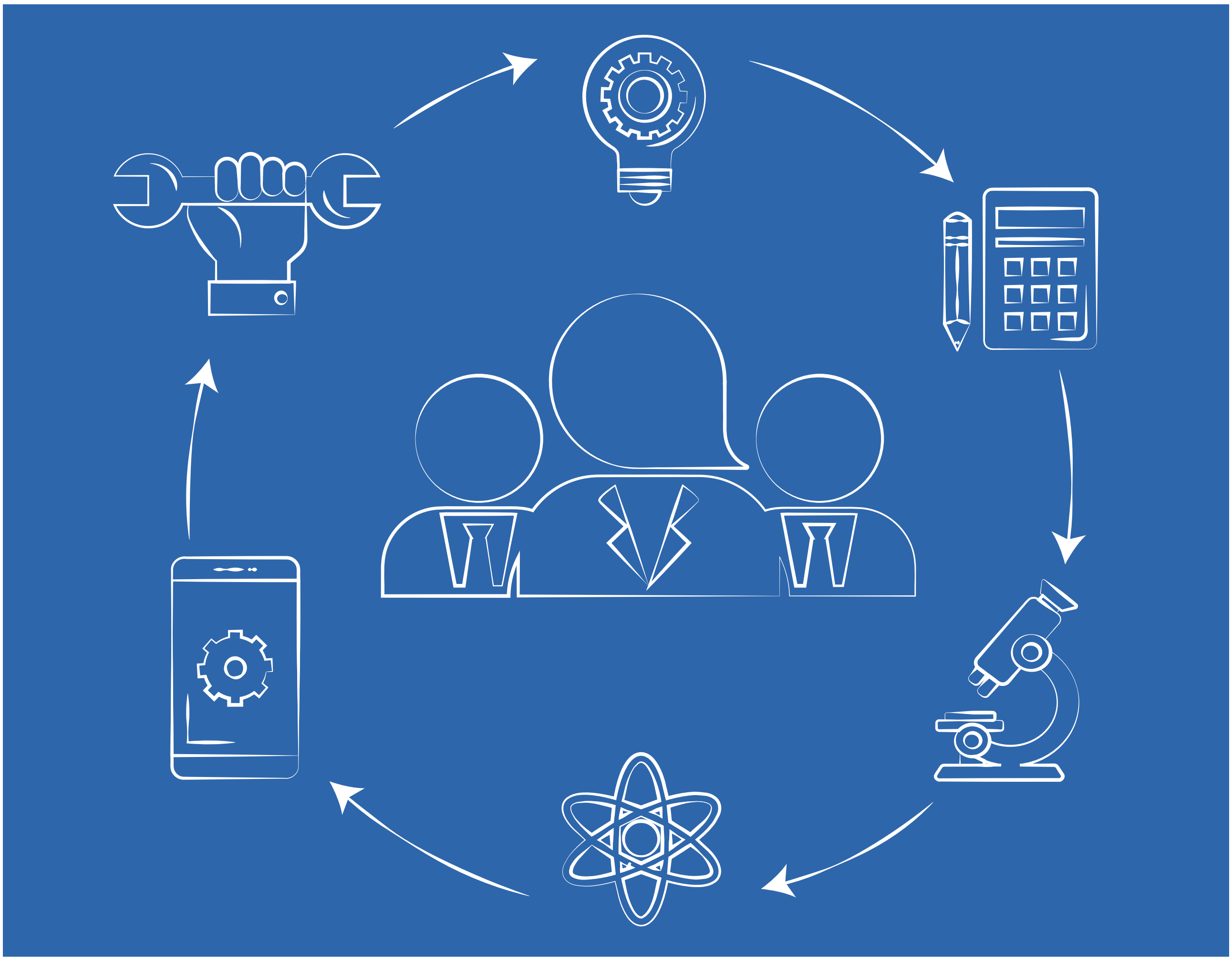
tecnología
Glosas de innovacion aplicadas a la pyme

Ed.44 | Vol.12 | N.2
April - June 2023

ISSN: 2254-3376



https://doi.org/10.17993/3ctecno.2023.v12n2e44

3C Tecnología. Glosas de innovación aplicadas a la pyme.

Quarterly periodicity.

Edition 44, Volume 12, Issue 2 (April - June 2023).

National and internacional circulation.

Articles reviewed by the double blind peer evaluation method.

ISSN: 2254 - 4143
Legal: A 268 - 2012
DOI: https://doi.org/10.17993/3ctecno.2023.v12n2e44

Edita:
Área de Innovación y Desarrollo by UP4 Institute of Sciences, S.L.
info@3ciencias.com _ www.3ciencias.com

https://doi.org/10.17993/3ctecno.2023.v12n2e44

https://doi.org/10.17993/3ctecno.2023.v12n2e44

EDITORIAL BOARD

https://doi.org/10.17993/3ctecno.2023.v12n2e44

AIMS AND SCOPE

PUBLISHING GOAL

3Ciencias wants to transmit to society innovative projects and ideas. This goal is reached thought the publication of original articles which are subdue to peer review or thorough the publication of scientific books.

TEMATIC COVERAGE

3C Empresa is a scientific - social journal, where original works are spread, written in English, for dissemination with empirical and theoretical analyzes on financial markets, leadership, human resources, market microestructure, public accounting and bussines management.

OUR TARGET

- Research staff.
- PhD students.
- Professors.
- Research Results Transfer Office.
- Companies that develop research and want to publish some of their works.

SUBMISSION GUIDELINES

3C Empresa is an arbitrated journal that uses the double-blind peer review system, where external experts in the field on which a paper deals evaluate it, always maintaining the anonymity of both the authors and of the reviewers. The journal follows the standards of publication of the APA (American Psychological Association) for indexing in the main international databases.

Each issue of the journal is published in electronic version (e-ISSN: 2254-3376), each work being identified with its respective DOI (Digital Object Identifier System) code.

STRUCTURE

The original works will tend to respect the following structure: introduction, methods, results, discussion/conclusions, notes, acknowledgments and bibliographical references.

The inclusion of references is mandatory, while notes and acknowledgments are optional. The correct citation will be assessed according to the 7th edition of the APA standards.

PRESENTATION WORK

All the information, as well as the templates to which the works must adhere, can be found at:

https://www.3ciencias.com/en/journals/infromation-for-authors/

https://www.3ciencias.com/en/regulations/templates/

ETHICAL RESPONSIBILITIES

Previously published material is not accepted (they must be unpublished works). The list of signatory authors should include only and exclusively those who have contributed intellectually (authorship), with a maximum of 4 authors per work. Articles that do not strictly comply with the standards are not accepted.

STATISTICAL INFORMATION ON ACCEPTANCE AND INTERNATIONALIZATION FEES

- Number of accepted papers published: 8.
- Level of acceptance of manuscripts in this number: 66,7%.
- Level of rejection of manuscripts: 33,3%.
- Internationalization of authors: 3 countries (India, Spain, China).

Guidelines for authors: https://www.3ciencias.com/en/regulations/instructions/

INDEXATIONS

INDEXATIONS

/SUMMARY/

3C tecnología
Glosas de innovacion aplicadas a la pyme

/01/

METRIC COMPARISON BETWEEN GOOGLE SCHOLAR AND RESEARCH GATE FOR RATED SCIENTISTS IN SOUTH AFRICA

Arthur James Swart*

Central University of Technology

drjamesswart@gmail.com

Reception: 21/02/2023 **Acceptance**: 21/04/2023 **Publication**: 10/07/2023

Suggested citation:

Swart., A. J. (2023). **Metric comparison between Google Scholar and Research Gate for rated scientists in South Africa**. 3C Tecnología. Glosas de innovación aplicada a la pyme, *12(2)*, 15-29. https://doi.org/10.17993/3ctecno.2023.v12n2e44.15-29

https://doi.org/10.17993/3ctecno.2023.v12n2e44.15-29

ABSTRACT

The successful promotion of an academic at an institution of higher learning is affected, to a large degree, by the publication record of the applicant. This record is usually updated in a resume, portfolio, or an online database, such as Google Scholar, Research Gate, or LinkedIn. The purpose of this article is to present a metric comparison between Google Scholar and Research Gate for rated scientists who are employed at universities of technology in South Africa. This may help to establish notable similarities or differences between rated scientists from specific universities and identify which platform they prefer to maintain their publication records. A snapshot quantitative study is used where the total number of citations, h-index values, and Research Gate scores were collected and analyzed. Results indicate that Research Gate has the highest number of authors present from the six universities of technology, with Google Scholar recording the highest number of h-index values for these authors. Only 134 out of the 181 (sample size) authors maintain their records on both databases. It is recommended that researchers in higher education use at least one online database to maintain a record of their publications, thereby enhancing the visibility of the research done at a university and enabling a more valid snapshot of the performance achieved by each researcher.

KEYWORDS

Quantitative, data analytics, citations, h-index

INDEX

https://doi.org/10.17993/3ctecno.2023.v12n2e44.15-29

1. INTRODUCTION

“It takes 20 years to build a reputation and five minutes to ruin it. If you think about that, you'll do things differently” [3]. Warren Buffet, a successful American businessman, uttered these words that indicate that it takes time to build a good reputation. For researchers and academics in Higher Education, these words ring true. They need time to complete publications, successfully supervise postgraduate students, contribute to curriculum development, provide evidence of good teaching, serve on various committees, and engage in community development as part of their key performance agreement. This usually contributes to career development, as they progress through the ranks to a full professor. Being a full professor means not only having a wealth of experience but also status and institutional power that can be put to positive use [9]. However, the progression from a junior lecturer to a full professor takes time (12 years or more) in which individuals build a reputation that identifies them among the leaders in their fields of expertise who constantly produce high-quality research outputs.

This reputation is what the National Research Foundation (NRF) in South Africa (SA) seeks to evaluate. The rating of individuals is based primarily on the quality and impact of their research outputs over the past eight years, taking into consideration the evaluation made by local and international peers [13]. This evaluation aids the NRF in identifying an appropriate category into which researchers may be placed (Categories A, B, C, P and Y). Category Y is for promising young researchers while Category A is for leading international researchers. They are called “rated researchers” in SA, with the term “rated scientist” also applicable as used in this article. Their research outputs may include peer-reviewed journal articles, conference papers, research monographs, and patents. An important requirement for applicants is the inclusion of their h-index values from three different databases, namely Web of Science, Scopus and Google Scholar.

These databases usually include a list (which may not be complete) of the research outputs of a researcher and may also serve as a repository for some of them. For example, Google Scholar (GS) is a searchable database that allows users to access information, cross reference that information with other sources and keep up with new research as it is released. It also allows users to access journal articles, conference papers, academic books, pre-prints, theses and dissertations, abstracts and other scholarly literature [4]. Research Gate (RG) is a similar database that places more emphasis on social networking among researchers. It allows users to share their research publications, find collaborators, access job boards and ask and answer questions in real-time [19]. The metrics (citations, h-index, scores) of these databases should not be considered as the pinnacle of one’s reputation, but should rather be considered as an initial stepping-stone to establishing the reputation [17]. Although both databases may provide similar publication ranks [18], great differences have been found between the number of citations present on GS and RG [14]. This is partly due to which database is regularly maintained by the researcher, who often has to

https://doi.org/10.17993/3ctecno.2023.v12n2e44.15-29

manually add his or her latest outputs. The following research questions are therefore posed:

1. What percentage of NRF-rated scientists from universities of technology in South Africa use either Google Scholar or Research Gate to maintain their research publication record?

2. What correlation exists between the annual output-to-input ratio of students to the number of rated scientists present at the six universities in South Africa?

3. What correlation exists between the h-index values present on Google Scholar and Research Gate for specific NRF-rated scientists?

4. What correlation exists between multiple and single authorship for specific NRF-rated scientists when considering their highest citation count for these publications?

The purpose of this article is therefore to present a metric comparison between GS and RG for rated scientists who are employed at universities of technology in SA. This may help to establish notable similarities or differences between rated scientists from specific universities and identify which platform they prefer to maintain their publication records. A quantitative study is used where the total number of citations, h-index values and RG scores were collected and analyzed. A snapshot quantitative study is used to gather and analyze this data from both databases. The article starts with a brief discussion of the rating application submitted to the NRF, followed by the context of the study. Results, discussions and conclusions follow.

2. NRF RATING APPLICATION IN SOUTH AFRICA

The NRF of SA was established on 1 April 1999 with the mandate to contribute to the national development of research and human capacity, national facilities, national science system and science engagement. The NRF rating system is a key driver to build a globally competitive science system in SA. It is a valuable tool for benchmarking the quality of researchers against the best in the world where the rating categories are allocated based on a researcher's recent research outputs (primarily publications from the past eight years) and impact as perceived by international reviewers [13].

Researchers from institutions of higher learning and science councils are invited to apply, with the submission deadline usually around 15 February of each year. The outcome of the rating process is usually communicated at the end of the calendar year. Unsuccessful applications require applicants to wait three years before re-applying. Successful applicants are required to re-apply every 5 years, thereby providing them with the opportunity to improve their rating towards A Category researcher.

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.15-29

A predefined template needs to be populated, which includes a detailed resume and publication list. Four key critical sections of the application are discussed in the paragraphs below. Possible reviewers must also be suggested by the applicant, where the majority should be international peers.

The section called "The Best Research Outputs in Last 8 years" requires the applicant to list his or her top 5 research outputs for the past 8 years, substantiating each one. This motivation should feature quantitative results such as the top-ranked conference in one's field where a paper was presented, the number of current citations for a book chapter, the impact factor of the journal that published an article and which universities or institutions are making use of an output in a specific way. If the research output was multi-authored, then an explanation of the applicant's contribution is required.

The applicant must highlight his or her niche area of research in the section called "Brief Description of Completed Research". This requires the applicant to focus in on a specific field of research, thereby enabling the acquisition of expertise within it. Having multiple focus areas does not contribute to a successful application. A chronological discussion of the progress made over the past 8 years is required, with the niche area featured in each paragraph. Specific achievements for each year should be listed in separate paragraphs, with quantitative results or achievements taking precedence.

The "Self-assessment of Research Outputs" section involves a brief personal discussion of the top 5 selected research outputs for the past 8 years. In this section, the applicant needs to indicate how the outputs have contributed to the niche area of the researcher and what personal development (e.g., new knowledge or skill) occurred in each case.

The final section entitled "Ongoing and Planned Future Research" calls on the applicant to again mention his or her niche area. The importance of this area should be noted here, and what further contributions to it are envisioned by the applicant. This section would typically become the "Brief Description of Completed Research" in 5 years when the applicant re-applies to the NRF for the rating (only valid if the initial application is successful).

Several key benefits accrue to rated scientists in SA [17]. Firstly, they receive a once-off financial grant from the NRF that must be used towards their future research. Secondly, they may receive an additional financial incentive from their institution. Thirdly, they become more valuable and marketable within the sphere of higher education. Fourthly, they improve their research reputation among their peers and colleagues. Fifthly, university students can benefit from exposure to rated scientists, who are usually motivated, dedicated and well-informed in their field of study.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.15-29

3. STUDY CONTEXT

The context of this study is limited to six universities of technology in SA that seek to improve the number of NRF-rated scientists at their institutions (see Table 1). Two key benefits are derived from this, including additional research funding from the NRF and greater awareness of the research ability and capacity of academics at an institution.

Table 1. Data from four online databases for the six universities

Acronym	Full university name	Enrol-ments in 2020	Gradua-tions in 2020	Ratio	No. of NRF Scientists	Scientist-to-student ratio
CPUT	Cape Peninsula University of Technology	32383	7593	0,23	58	558
CUT	Central University of Technology	21103	4622	0,22	19	1111
DUT	Durban University of Technology	33933	10034	0,30	41	828
MUT	Mangosuthu University of Technology	14652	2805	0,19	6	2442
TUT	Tshwane University of Technology	62482	14897	0,24	47	1329
VUT	Vaal University of Technology	20293	3566	0,18	10	2029

This table lists the acronym of the university that will be used in this article along with the number of enrolments and graduations for 2020, as indicated on the NRF website. The Department of Higher Education and Training (DHET) in SA provides the NRF with aggregated staff and student data collected through its HEMIS (Higher Education Management Information Systems) database [11].

These statistics help to provide an output-to-input ratio of students (which may also be termed the efficiency of a system by dividing the output by the input and multiplying by 100%) that may be correlated to the number of rated scientists present at the institutions. This can help to determine if a statistically significant relationship exists between these two variables which could indicate that a higher number of rated scientists may lead to a higher output-to-input ratio for an institution. The number of enrolments may also be divided by the number of rated scientists to obtain a scientist-to-student ratio. The expression lecturer-to-student ratio is more common in the literature and can be affected by large classes, inadequate infrastructural facilities and poor management support. One study from Nigeria listed a very poor lecturer-to-student ratio of 1:800 [6], which can impact the quality of teaching and student academic success. These last two factors may also be influenced by the scientist-to-student ratio at an institution, as scientists are motivated, dedicated and experts within their profession, who can easily respond to related questions from their students. Wood and Su [20] emphasize that an excellent lecturer is someone who is committed and dedicated to their profession while Mardiana [8] states that lecturers must have a teaching competency certificate related to performance. Subsequently, an excellent

https://doi.org/10.17993/3ctecno.2023.v12n2e44.15-29

lecturer may be defined as one who holds a teaching qualification and who is regarded by his or her peers as an expert in a specific field of study. A rated scientist fulfills 50% of this definition, providing students with a wealth of expertise to draw from, thereby improving their professional knowledge.

4. QUANTITATIVE RESEARCH METHODOLOGY

A snapshot quantitative study is used where the total number of citations, h-index values and RG scores were collected and analyzed. A snapshot is used to create a static image of dynamic content that may be used as a benchmark for future research. This was done in the month of April 2022. Present-day data would not correlate to the results presented in this article, as this type of data is dynamic with new citations and publications regularly being recorded. MS EXCEL was used to manually capture and process the data. This included the total amount of citations per author, the highest citation count for a sole and multi-author publication, and the h-index value from the GS database. From the RG database, the RG score, h-index values and h-index values excluding self-citations were captured. The author names were obtained from the NRF website which provides a downloaded EXCEL sheet of all rated scientists (researchers) in SA [12]. The search feature available in GS and RG was used to obtain the required data for each researcher.

Before the static images could be generated, the data had to be processed. A table listing all six universities of technologies with the number of rated scientists per institution was first generated. This table also included the number of student graduations and enrolments for the six universities for the year 2020. The number of rated scientists per category where then determined along with a scientist-to-student ratio. GS citations and RG scores were processed for each university (maximum, mean and median values being calculated). The maximum value represents the highest total citation count for a single researcher while the median helps to evaluate the contribution to the research culture of the institution by all the researchers as a collective.

The h-index values between GS and RG were then compared using the maximum and median values along with a Pearson correlation value. This correlation required that researchers be present on both databases which equated to 134 out of the 181 rated scientists (total sample size). The h-index from RG was further analyzed by contrasting the difference between including self-citations to the exclusion thereof. Finally, a comparison between the highest citation count for a sole and multiple-author publication was processed using data from GS.

5. RESULTS AND DISCUSSIONS

Figure 1 presents the number of rated scientists listed on the NRF website according to five different categories of registration. No researchers from the six universities are currently rated in Categories A and P. This indicates that these

https://doi.org/10.17993/3ctecno.2023.v12n2e44.15-29

researchers are still progressing toward being recognized as leading international researchers within their field of study. It also indicates that there are no researchers younger than 35 years of age (Category P).

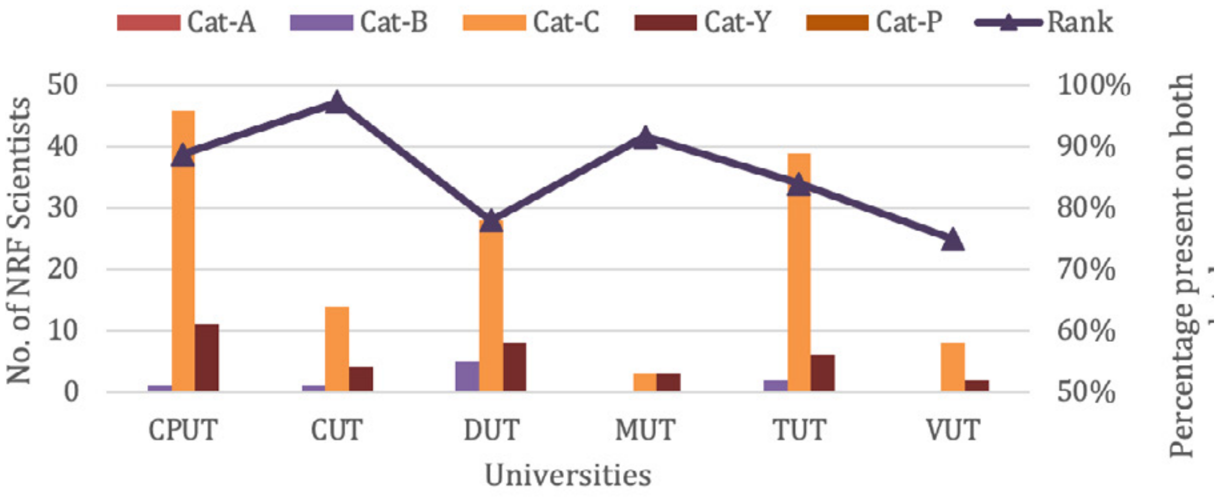


Figure 1. NRF Scientist categories for the six universities along with a ranking percentage of scientists present on both platforms (average value between GS and RG)

The dominant category is C, with a total number of 138 out of the possible 181 rated scientists. This category is for established researchers with a sustained recent record of productivity in their field who are recognized by their peers as having produced a body of quality work (being coherent and ongoing) and have demonstrated the ability to conceptualize problems and apply research methods to investigate them [13]. Noteworthy is the percentage of rated scientists who are present on GS and RG. CUT ranks first in this regard, with 97% of their researchers present on both databases. The lowest presence (75%) is currently found with VUT. High-profile publications of scholars may provide a glimpse of the quality and relevance of an institution's research regarding global trends [16], which may be enhanced by using more than one online database. Figures 2 and 3 show the results of the GS citations and RG scores.

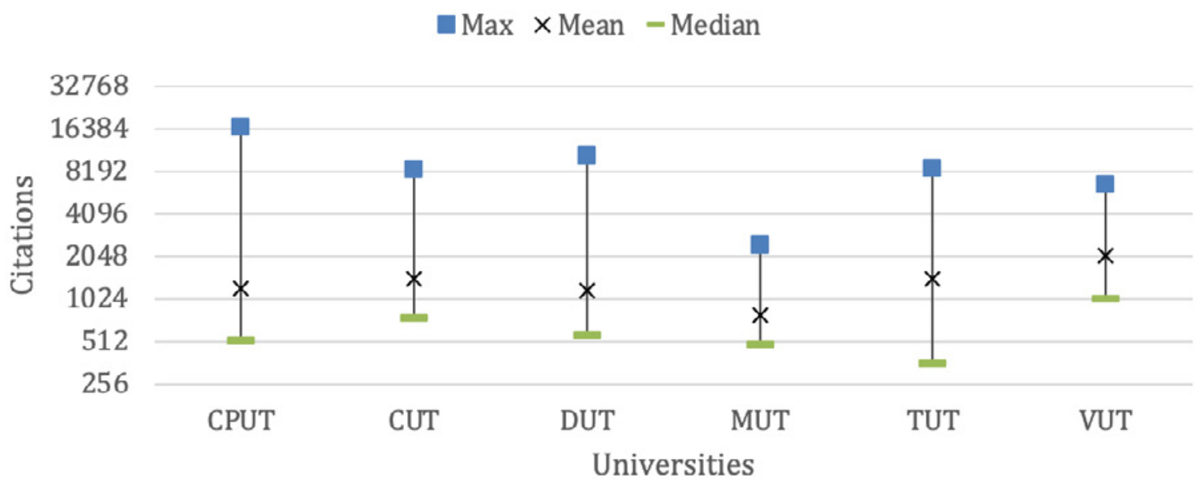


Figure 2. Google Scholar citations

https://doi.org/10.17993/3ctecno.2023.v12n2e44.15-29

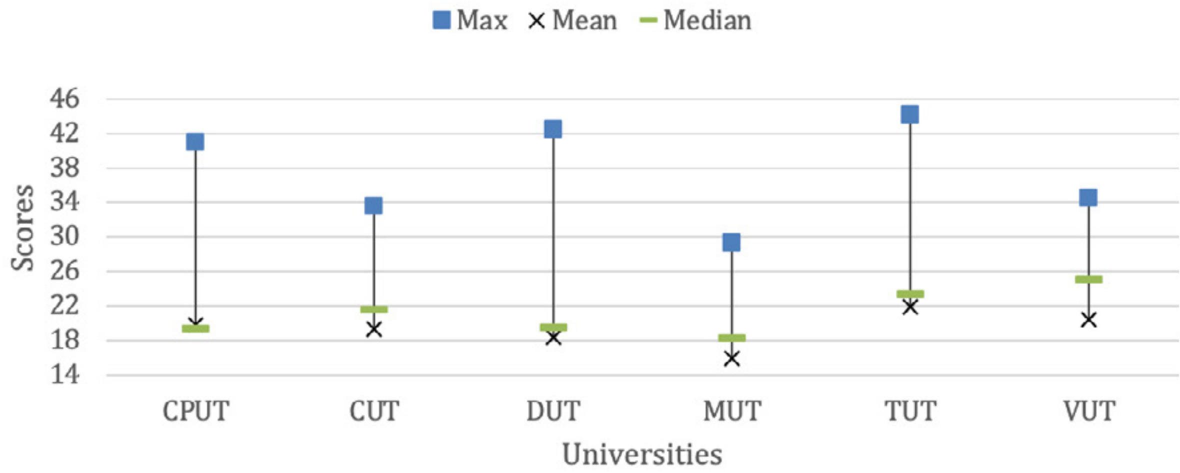


Figure 3. Research Gate scores

From Figure 2 it is evident that individual researchers from four out of the six universities have produced several high-profile publications that have resulted in a maximum total citation count of more than 8192 times (see the Max value). MUT has a researcher with the lowest maximum total citation count (just over 2048) when considering all the universities. This may be correlated to Table 1, which shows that MUT also has the lowest number of rated scientists with the highest scientist-to-student ratio. A possible reason for this low maximum total citation count may be that the university is still trying to establish a good research culture among its academics. Developing positive, supportive, and productive research cultures is a complex and progressively important component of institutional and academic lives [7]. The establishment of increasing productivity and quality metrics, as well as frameworks for measuring impact and research environment, means that the important role of a good research culture should not be ignored. The low median value for TUT is ascribed to the fact that 11 of their rated scientists do not maintain a profile on GS. However, the median is consistently smaller than the mean thereby indicating a positive skew.

A similar profile is noted in Figure 3, where MUT again has a researcher with the lowest maximum RG score of 29. This suggests a similarity between the two databases. However, where GS registered the highest total citation count with CPUT, RG registers its highest score with TUT. Noteworthy also is the gap differences between the mean and median scores between the two databases. GS consistently shows a higher mean-to-median value for its citations, while this is reversed for the RG scores. One must bear in mind that the RG score is calculated using several variables, whereas the GS citation count is purely based on the total of citations to all the published work of a researcher. It has been noted that the RG score should not be used to compare institutions on research quality [5], as is evident by the negatively skewed distribution of data in Figure 3 (median greater than the mean). This infers that the distribution of scores is not symmetrical and there are more extreme scores in the bottom 50% than in the top 50%. Figure 4 considers the h-index.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.15-29

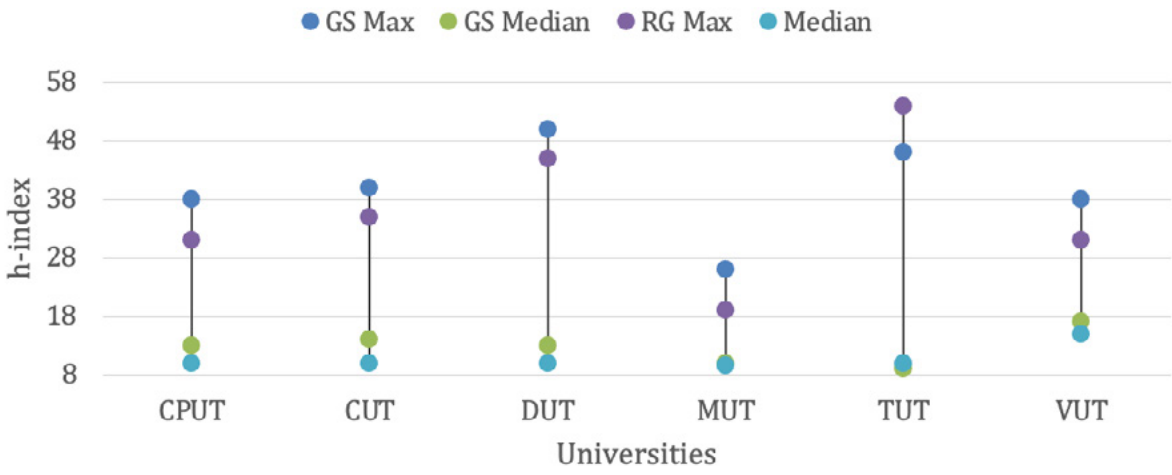


Figure 4. Google Scholar (GS) to Research Gate (RG) h-index comparison

A comparison between the h-index values of GS and RG is done using the highest h-index for a single researcher (see GS Max) and the median for all the researchers as a collective. In this case, five out of the six universities have the potential to gain at least one Category A NRF researcher in the future, as their h-index lies above 38 according to GS. RG paints a similar picture. The question of what number to categorize as a good h-index is controversial [1]. However, it is generally accepted that a h-index of 20 over 20 years of scientific work is considered good while a score of >40 in the same career duration would be outstanding. A statistically significant relationship (p = 0,893) was found between the h-index values present on GS and RG for 134 scientists present in both databases. All median values are above 8, which suggests that at least 50% of all rated scientists at the six universities are contributing to the research culture of the institution.

Figure 5 illustrates the results of the h-index values from GS when considering self-citations. The maximum number (Max) represents a decrease in the h-index for a single researcher if his or her publications that include self-citations are excluded from the analysis. In this case, the maximum is 8 from CUT. It is encouraging to see that all six universities have a low median value of 0 or 1, thereby indicating that at least 50% of their rated scientists do not overly engage in the use of self-citations. Self-citations can be a means for researchers to place their ongoing research in the context of their prior research [15] or they can be manipulated by a researcher to affect their influence and recognition [2].

https://doi.org/10.17993/3ctecno.2023.v12n2e44.15-29

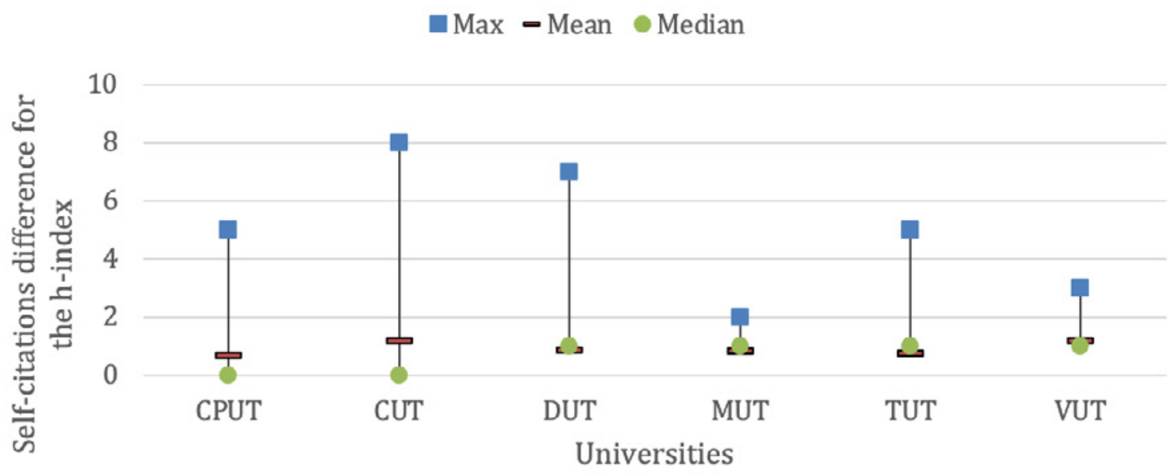


Figure 5. Google Scholar h-index difference when considering self-citations

Figure 6 portrays a comparison between the highest citation count for a sole-author publication versus a multi-author publication for all 181-rated scientists. Consider two examples highlighted with enlarged black circles. The first example is of a researcher who has a sole-author publication with 8 citations and a multi-author publication with 3 citations. The second example shows a researcher with a sole-author paper with 1 citation and a multi-authored paper with 4096 citations. Recall that these values represent the highest citation count for publications from individual researchers. The first example could suggest that the researcher is balancing their research between multi-author (collaborating with fellow researchers) and sole-author (working independently) publications. The second example suggests that this researcher is primarily producing multi-authored publications (engaging only in collaborative work). Ideally, a researcher should be balancing sole and multi-author publications that result in a citation count for both that reside within the box that is shown in the figure. This is currently not the case, as no statistically significant relationship (p = 0,148) was found between the highest citation count for a single-author and multi-author publication.

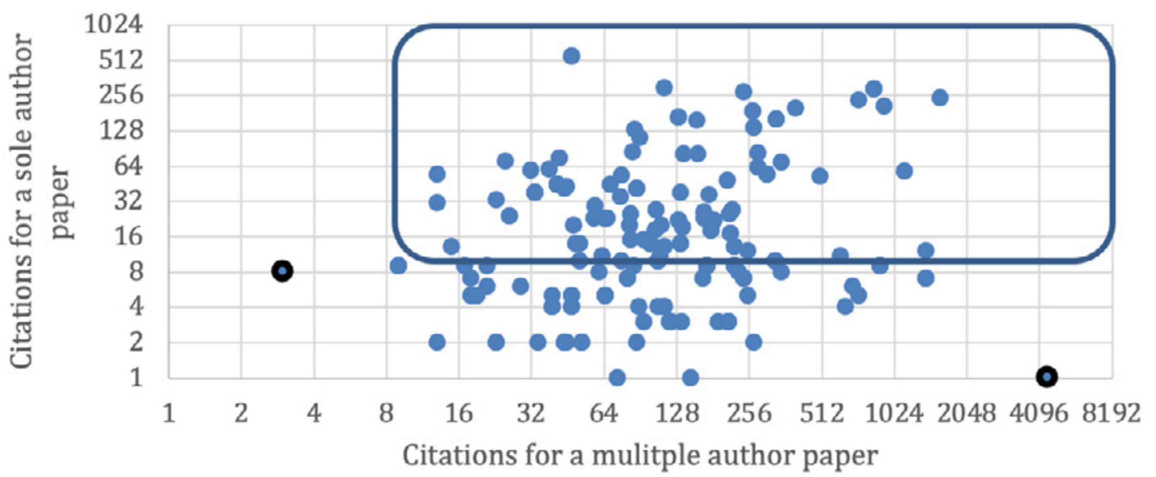


Figure 6. Google Scholar comparison for the highest citation count for a multiple-author publication versus a sole-author publication

https://doi.org/10.17993/3ctecno.2023.v12n2e44.15-29

It must be noted that a researcher needs to demonstrate the ability to publish on his or her own. This demonstrates the ability of the researcher to conceptualize, synthesize and analyze a research publication. Engaging solely in collaborative work does not convey this demonstration, as co-authors may have conceptualized the publication or even gathered all the data. Being a sole author does represent a significant responsibility, as it means that one has full autonomy and accountability for producing papers worthy of publication. It also enables one to avoid engaging in the somewhat contested space of author order negotiation [10]. It also removes the debate of what contribution each author made to the publication as a percentage that needs to be described in the NRF rating applications.

6. CONCLUSIONS

The purpose of this article was to present a metric comparison between GS and RG for rated scientists who are employed at universities of technology in SA. This helped to establish several notable similarities and differences between rated scientists from specific universities and helped identify which platform they prefer to maintain their publication records. Answers to the original four questions posed under the introduction are now presented.

1. What percentage of NRF-rated scientists from universities of technology in South Africa use either Google Scholar or Research Gate to maintain their research publication record?

From Figure 1, it was shown that CUT ranks first in this regard, with 97% of their researchers present on both databases. A further breakdown of the percentages shown in this figure indicates that 85% of the 181-rated scientists maintain a GS profile, while 87% of them maintain an RG profile. It was further found that the citations from GS provide a positively skewed distribution while the RG scores indicate a negatively skewed distribution (see Figures 2 and 3). This suggests that at least 50% of the rated scientists are achieving a higher citation count while their RG score remains low. However, maintaining at least one profile may improve international awareness of the quality and relevance of an institution's research regarding global trends.

2. What correlation exists between the annual output-to-input ratio of students to the number of rated scientists present at the six universities in South Africa?

Table 1 indicated that DUT achieved a superior output-to-input ratio in 2020 of 0.30 while having the lowest scientist-to-student ratio of 828. A statistically significant relationship (p = 0,694) was found between the number of rated scientists and the output-to-input ratio of students at the universities. This suggests that student academic success can be influenced by a higher number of rated scientists at an institution, as these scientists are usually motivated, dedicated and experts within their profession, who can easily respond to related questions from their students.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.15-29

3. What correlation exists between the h-index values present on Google Scholar and Research Gate for specific NRF-rated scientists?

From Figure 4 it was shown that the h-index values from both databases follow a similar trend. A statistically significant relationship (p = 0,893) was found between the h-index values present on GS and RG for 134 scientists present in both databases. This indicates a measure of reliability where rated scientists can make use of either database to maintain their publication record.

4. What correlation exists between multiple and single authorship for specific NRF-rated scientists when considering their highest citation count for these publications?

No statistically significant relationship (p = 0,148) was found between the highest citation count for a single-author and multi-author publication for the 181-rated scientists. Ideally, a researcher should be balancing sole and multi-author publications that can enable one to demonstrate independent learning and collaborative work, which is currently not the case as seen in Figure 6. Figure 5 further indicated that at least 50% of the rated scientists from all six universities do not overly engage in the use of self-citations. This would lend credibility to the data presented in this article, as well as to the databases, as the majority of the citations have not been self-inflated by the researchers but represents the active interest of peers in the quality of their work.

A limitation of this study relates to the use of data from only six universities of technology in SA. However, the results of this study can serve as a benchmark for future research-related metric comparisons between GS and RG. The metrics on these two databases should not be considered as the pinnacle of one's research achievement or reputation but should rather be considered as an initial stepping-stone to establishing the reputation. It is further recommended that researchers try to find a balance between multi-authored and sole-authored publications, as this can simply be the application process for rating where different author contributions need to be explained.

Furthermore, it is recommended that management at universities mandate that their academic staff maintain their publication record on at least one of the many available databases in this regard. This can enhance the visibility of the research done at the university and enable an easier review of the achievements of staff for personal performance management purposes and promotion.

REFERENCES

(1) Ali, M. J. (2021). Forewarned Is Forearmed: The h-Index as a Scientometric. Seminars in Ophthalmology, 36(1-2), 1-1.

(2) Bayram, A. (2021). Author Self-Citation in the Turkish Otorhinolaryngology Literature. Turkish Archives of Otorhinolaryngology, 59(3), 210.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.15-29

(3) Brainy Quote. (2020). Homepage. Retrieved from http://www.brainyquote.com/quotes/

(4) Delfino, D. (2019). 'What is Google Scholar?': What you need to know about Google's database for students, researchers, and other curious minds. Business Insider. Retrieved from https://www.businessinsider.com/what-is-google-scholar?IR=T

(5) Iatsyshyn, A. V., Popov, O., Kovach, V., Iatsyshyn, A. V., Artemchuk, V., Radchenko, O., … Kovalenko, V. (2021). Formation of the scientist image in modern conditions of digital society transformation. Paper presented at the Journal of Physics: Conference Series.

(6) Ifedili, C. J., & Ofoegbu, F. (2011). Managing entrepreneurship education in Nigerian universities. European Journal of Educational Studies, 3(1), 101-109.

(7) Khoo, T. (2021). Creating spaces to develop research culture. International Journal for Academic Development, 1, 1-13.

(8) Mardiana, H. (2021). Lecturers in Adopting Digital Literacy towards Innovation Technological Change. Zien Journal of Social Sciences and Humanities, 1(1), 36-48.

(9) McDaniel, K. N. (2019). You're a Full Professor. Now What? The Chronicle of Higher Education, 65, 21.

(10) Merga, M. K. (2015). Thesis by publication in education: An autoethnographic perspective for educational researchers. Issues in Educational Research, 25(3), 291-308.

(11) National Research Foundation. (2022a). HEMIS Students. Retrieved from https://www.nrf.ac.za/information-portal/hemis-students/

(12) National Research Foundation. (2022b). NRF Rated Researchers. Retrieved from https://www.nrf.ac.za/information-portal/nrf-rated-researchers/

(13) National Research Foundation. (2022c). NRF Rating. Retrieved from https://www.nrf.ac.za/rating/

(14) Orduna-Malea, E., & Delgado López-Cózar, E. (2017). Performance behavior patterns in author-level metrics: a disciplinary comparison of Google Scholar Citations, ResearchGate, and ImpactStory. Frontiers in Research Metrics and Analytics, 2, 14.

(15) Sandnes, F. E. (2020). A simple back-of-the-envelope test for self-citations using Google Scholar author profiles. Scientometrics, 124(2), 1685-1689.

(16) Swart, A. J. (2018). An Analysis of Master Dissertations: A Case Study of Central University of Technology, South Africa. AJLAIS, African Journal of Library, Archives and Information Sciences, 28(2), 211-223.

(17) Swart, A. J. (2022). Metric Comparison Between Google Scholar And Research Gate For Engineering Academics. Webology, 19(3), 1025-1036.

(18) Thelwall, M., & Kousha, K. (2017). ResearchGate versus Google Scholar: Which finds more early citations? Scientometrics, 112(2), 1125-1131.

(19) University of Melbourne. (2019). Researcher Profiles, Identifiers and Social Networks: Maximise your Impact. Retrieved from https://unimelb.libguides.com/researcher_profiles/rg

(20) Wood, M., & Su, F. (2017). What makes an excellent lecturer? Academics' perspectives on the discourse of 'teaching excellence' in higher education. Teaching in Higher Education, 22(4), 451-466.

ABOUT THE AUTHOR

James Swart received his DTech: Electrical: Engineering degree in 2011 from the Vaal University of Technology. His research interests include engineering education development and energy monitoring of PV modules. He is currently an Associate Professor at the Central University of Technology.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.15-29

/02/

A NOVEL TDEF1.0 FOR MAKING TWITTER ACCESSIBLE FOR PEOPLE WITH DISABILITIES

Namrata Aggarwal

Dept. of Computer Science and Applications. Bharati Vidyapeeth's Institute of Computer Applications and Management (BVICAM). Delhi, India

aggarwalnamrata644@gmail.com

Ritika Wason*

Dept. of Computer Science and Applications. Bharati Vidyapeeth's Institute of Computer Applications and Management (BVICAM). Delhi, India

ritika.wason@bvicam.in

Parul Arora

Dept. of Computer Science and Applications. Bharati Vidyapeeth's Institute of Computer Applications and Management (BVICAM). Delhi, India

paruldevsum@gmail.com

Aruna Tomar

Dept. of Computer Science and Applications. Bharati Vidyapeeth's Institute of Computer Applications and Management (BVICAM). Delhi, India

tomar07aruna@gmail.com

Devansh Arora

Indraprastha Institute of Information Technology (IIIT). Delhi, India

devansh2005@iiitd.ac.in

Reception: 20/02/2023 **Acceptance**: 21/04/2023 **Publication**: 10/07/2023

Suggested citation:

Aggarwal, N., Wason, R., Arora, P., Tomar, A. and Arora, D. (2023). **A Novel TDEF1.0 for Making Twitter Accessible for People with Disabilities**. *3C Tecnología. Glosas de innovación aplicada a la pyme, 12(2)*, 31-47. https://doi.org/10.17993/3ctecno.2023.v12n2e44.31-47

https://doi.org/10.17993/3ctecno.2023.v12n2e44.31-47

ABSTRACT

This manuscript introduces a novel framework to extend the accessibility of Twitter users' timelines to people with disabilities. Our proposed framework is designed with iconic speaker and information functionalities which will enable transcription of multi-media content and provide users the opportunity to read and hear the translated transcripts depending upon the user's primary language.

This work is one of its kind that opens Twitter's user timeline completely to people with disabilities.

KEYWORDS

Disabled people, Accessibility, Twitter, Transcription, TDEF1.0.

INDEX

https://doi.org/10.17993/3ctecno.2023.v12n2e44.31-47

1. TWITTER FOR EVERYONE

Among the various social media platforms [8], Twitter is considered one of the popular microblogging services on the internet which allow users to post (tweet), like, comment and share (retweet) [2].

Twitter has over 3.5 billion monthly active users [4],[18]. This number is growing each day as Twitter is continuously improving its global accessibility to share real-time information among members of the public and is thus widely impacting business, politics, communities, social groups, etc [10],[18].

At the basic, Twitter makes its features accessible to all its users with options to create content in audio, video, text, image, or URL formats [3]. This feature is included with the purpose to widen the outreach of Twitter content among a wide audience including the blind or people with vision abnormalities [20].

Twitter being an internationally recognizable platform, follows a format for appropriate appearances and limited functionality [3]. It also introduced certain features to improve its content accessibility, like [21].

1. In 2017, the limit of text-tweet got doubled from 140-character-limitation to 280.

2. As of May 2020, Alt-Text for captioning images to improve the accessibility of Twitter timelines for visually impaired people is enabled by default on Web, iOS and Android app users [5].

3. Voice tweets were rolled out as an experiment, which was limited to iOS devices to improve the accessibility of content to the audience [29].

However, as per analysis, the new Twitter features are either extended versions of existing features or are limited to several users [25].

Hence, though efforts are being made to open the boundaries of Twitter to people with disabilities, challenges remain [17],[21].

This manuscript proposes a novel solution to widen the feature functionality of Twitter, ensuring easy access to all potential users with varied types and degrees of disability.

The manuscript proposes to increase the participation of people with disability through the inculcation of novel features like text-to-speech (Read out loud tweet), image captioning (Image summarization), speech-to-text (Video/Audio tweet captioning), etc. To highlight the same, the rest of this manuscript is structured as follows. Section ii analyses the existing Twitter framework concerning the timeline features. Section iii outlines the proposed Twitter Data Extraction Framework (TDEF). Section iv details the implementation details of the same. Section v reports the results of testing the same while Sections vi and vii conclude the manuscript by elaborating our understanding of the same and our future course of action to address further research challenges.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.31-47

2. AN ANALYSIS OF THE CURRENT TWITTER FRAMEWORK

Twitter is one of the most popular global social networking platforms [4]. Hence before suggesting any enhancements to its features, it is first important to understand its current capabilities [8]. We review the same in this section, especially concerning the timeline feature.

2.1. CURRENT TIMELINE FEATURES

Twitter displays a structured timeline with a stream of real-time tweets from the accounts that are followed by any user [18]. It also provides options to view the top tweets or the latest tweets first in the timeline [2]. The major goal of the user timeline is to display the content the user is most interested in and would contribute to the same [7].

As per their most popular historical features –comments and retweets made a huge success in the engagement of potential users with the content [3]. To further improve accessibility, recently the timeline got an extension with follow-up features, like [21]:

1. Anonymous Bookmark [26]: Introduced to avoid the problem of liking, retweeting and spamming. Enabled users to purposely refer to the tweets later. Bookmarked content remains private as no one can see who saved and what is saved.

2. Direct Message (DM) [11]: Allows private sharing of tweets through DM (Direct message) or any social platform. It applies the copy link feature to copy the URL into the clipboard. The reach of tweets is now amplified to varied platforms like SMS, Email, etc outside of Twitter to stabilize its online presence.

3. Twitter Fleets [23]: Enables sharing transitory thoughts through your tweet, text, videos, gifs, and photos for 24 hours. Inspired by Instagram and Facebook, it is a dynamic, personalized approach rolled out to share moments for a short period and see who viewed the content.

4. Voice Tweets [16],[27]: Enabled tweets to be published with audio options that people could play.

The above-listed features are only a few of the most notable ones [12],[16]. However, we noticed that the Alt-text option, which enabled limited image description for visually impaired people expanded the number of potentially active users on Twitter [12],[22],[24] Hence, the current updated timeline of Twitter supporting people with disabilities is detailed in Table 1 below:

https://doi.org/10.17993/3ctecno.2023.v12n2e44.31-47

Table 1. Twitter support for people with disabilities

Disability	Voice	Video with Speech	Image	Text
Visual (Blind/ Colour Blind/ Visually Impaired)	-	Under Trial	Alt-Text (optional)	Alt-Text (optional)
Voice (Deaf/ Hearing Imapired)	Under Trial	Under Trial	-	-
Reading (Dyslexia)	-	-	-	-
Language (non-natives)	-	-	-	Text Translation (through Google)

As is clear from Table 1, for people with disabilities, Twitter has made some inbuilt support [24]. For multi-lingual users, auto-translation for text tweets is also rolled out powered by Google to help users to engage with translated content in a meaningful way [16]. The same is depicted in Fig.1 below:

Figure 1. A tweet featuring Auto-translation into the user's primary language

Popular platforms like Facebook and LinkedIn have already implemented multiple features to increase the ability to access content like text, voice, video image/gif [10]. Thus, it is time Twitter should keep in mind that Twitter is for everyone and it is a room where potential users engage with content and raise their voice [21]. Thus, as one of its first, we have designed and implemented a novel Twitter Data Extraction Framework we have coined as TDEF1.0. This framework is intended to support

https://doi.org/10.17993/3ctecno.2023.v12n2e44.31-47

people with disabilities to join and use Twitter. The details of the same are elaborated in the following section.

3. PROPOSED TWITTER DATA EXTRACTION FRAMEWORK (TDEF 1.0)

As discussed in section ii, Twitter has various accessibility features for normal people [11],[12],[21],[23],[26],[27],[14],[18]. However, it is well realized that Twitter should improve its accessibility among physically challenged prospective users [17].

In the past for many years, Twitter limited its use to traditional features for content creation [13]. However, soon it began rolling out effective and engaging features to allow more users to interact with real-time information in a more meaningful way [21]. In 2015, Twitter introduced many extensions to its timeline to leverage usage and increase the number of active users [18]. However, after thorough timeline analysis we realized that despite efforts, Twitter has as yet failed to introduce any timeline enhancements that could bring people with disabilities easily on board. Though many disabled have been absorbed by Twitter, many still hesitate [17].

Thus, we propose a real-time approach to include disabled people on Twitter. Taking cue [15] and amplifying Twitter values for the people, our research majorly focussed on the accessibility of Voice, Video, Images and Text to support people with different challenges and allow them to express and present their opinions without any technical barriers. We now briefly explain our approach for different kinds of tweets:

3.1. VOICE TWEET

After Twitter's recent experiment of Voice tweets for the iOS app [11], users could tweet their voice using the voice icon. Users could initially record up to 140 seconds of audio. If the audio message was longer than 140 seconds, it will be automatically threaded up to 25 audio tweets. We realized that the feature could be made more inclusive for the disabled community through transcription and translation.

Through transcription, the user could read the text from the transcribed audio. Through automated translation captions, users could also read the text in different languages which would make audio tweets accessible to the hearing-impaired audience.

3.2. VIDEO TWEET

To make video tweets accessible, we performed operations to generate a vocal summary of video tweets with speech and without speech. Summarized text will help the users to engage with content in a short period in more customized ways.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.31-47

3.3. IMAGE/GIF TWEET

When users tweet images there is an additional feature to compose descriptions to make the photos more accessible to people with disabilities including people who are blind and have low vision.

In the alt-text feature for photos, add a short description under the limitation of 1000 characters for the audience to understand the type of content and increase engagement in a personalized way. If posted, the description of the image won't be visible and edited but visually impaired people will have access to the alt-text description through screen readers [12].

To increase access to images globally, we developed the feature of vocal summary for the image on the timeline which will help the audience with disabilities to listen to the summary of activity performed in the images. This image summary will support people understand the background without depending on the audience to let them add descriptions in the alt-text feature.

3.4. TEXT TWEET

Traditional text tweeting was the historical feature launched by Twitter, the micro-blogging platform in 2006 [13]. The product emerged with the limitation of text tweets up to 140 characters which allowed the potential users to compose the content on the social media platform and interact with relevant audiences.

In 2017, Twitter doubled its character limit from 140 to 280 for the audience to share their real-time information in a more meaningful way with the support of 40 languages except for Japanese, Chinese and Korean (JCK) [18].

Using the 280-character tweet feature should not be limited to the audience without any physical challenges. Consider the audience globally with different languages and different disabilities. We thus developed Vocal Reading to let users listen to the tweet they wish for. This will enhance the accessibility creatively without focusing to see on the device. The feature shall also save the eyes from longer screen time.

4. IMPLEMENTATION DETAILS

Twitter has played a vital role in the field of content creation platforms and significantly attracted millions of users in the past two decades all over the world [9]. The world has witnessed the power of Twitter where leaders to teenagers have actively participated with tweets and led the reach of tweets to the trending section [15],[19],[20].

In the following section, we will propose a model where the visibility of the tweets will have a high reach to the potential audience which also includes people with disabilities like visually impaired, hearing impaired, etc.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.31-47

Our model targeted videos, audio, text, photos, and gifs where we fetched real-time tweets from Twitter and stored them in the database using .CSV files containing text, media and URLs. Figure 2 below depicts a sample of the same.

We trained our model on the real-time tweets where we scrapped data in November 2020 and stored 1000 tweets which majorly included tweets including text, URL and media attachments.

4.1. EXTRACTION OF TWEETS

Real-time Tweets were extracted from Twitter using Twitter API (Application Programming Interface) to analyze and learn behavior, direct interaction, locations and other significant resources [28].

To analyze whether the multimedia and non-multimedia content will have more access to people with disability, we sampled 1000 real-time tweets using our 3-way technique described below in Figure 2.

As seen in Figure 2., Twitter API was used to generate authenticate credentials including keys and tokens. After successfully generating Twitter API V2 endpoints, real-time tweets are fetched to examine in the further model and stored in .CSV files.

The tweets were filtered based on their content type and data was cleaned of non-relevant information like emoji, incomplete links, unwanted symbols, extra spaces and retweets. Once cleaned, the significant labeled non-media information was stored in respective CSV files and media files were maintained separately.

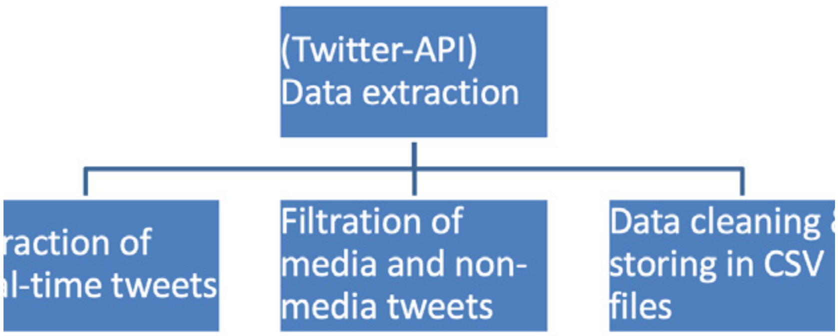


Figure 2. The 3-way technique for Data extraction using Twitter API

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.31-47

Table 2. The Statistic of extracted real-time Tweets – November 2020

Tweet Type	Number of tweets
Texts (iOS and Android)	400
Audios (iOS only)	30
Videos (iOS and Android)	230
Images (iOS and Android)	180
GIF (iOS and Android)	45
Text with URL (iOS and Android)	115

Table 2 above lists the statistic to better understand the behavior of extracted tweets, we have filtered the random sample of 1000 tweets from November 2020 according to the type of content where 400 tweets are text without any media attachments and 600 tweets are text with embedded multimedia where 30 tweets are audios by iOS users only, 230 tweets are videos with speech and without speech, 180 tweets are images, 45 tweets are GIF, 115 tweets are text with clickable URL.

4.2. TRANSCRIPTION

To explore the extent of Google services and API (Application Programming Interface), the most popular Google Cloud Speech-to-text API was used to convert Audio tweets and video tweets with speech into text which will be output as captions and subtitles respectively.

Separating tweets after data cleaning summed up to 260 tweets in total where 30-audio tweets and 230 video tweets were taken into consideration. The URL of the audio and video (with speech) were imported from the CSV files and after researching the frequency of media type, 5 different categories were observed to see which type of content significantly added value to reach visually impaired audiences.

Table 3. Frequency of different categories of video -230 Tweets

Categorical Video content	Frequency
Videos	55.5 %
Speechless Video	7.8 %
Short Video Tweets	9.3 %
Advertisements	25.2 %
Videos with text/quotes	2.2 %

We examined different video contents where out of 230 tweets, Table 3 describes the frequency of occurrence of different tweets where 55.5 % of the potential audience

https://doi.org/10.17993/3ctecno.2023.v12n2e44.31-47

generally tweeted videos with an average length of 1 minute, 7.8 % of videos have no speech, 9.3% videos are short with an average length less than 1 minute,25.2% videos are advertisement which is promoted by social brands and companies for global users, 2.2% are videos which are either quotes or universal facts/texts.

Considering video and audio tweets, noise filtration was performed to remove the unwanted audio and differentiate the original voice of the person.

Using the Google Speech-to-text API, the audio and videos were transcribed into text and displayed in the form of captions and subtitles to the user. This technique is thus proposed to increase the reach to hearing-impaired people where earlier the videos were less accessible to people with hearing and vision problems. Our code also facilitates Google translation with the support of almost 108 languages that can translate the captioned transcribed text into their native language.

4.3. IMAGE CAPTIONING

Image captioning is one of the most popular features in the open-source communities and Industry [9]. Caption generation is an implementation of Deep Learning in which the model is processed and generates captions or short descriptions concerning the trained model. There is a huge probability that the model will not return accurate captions or descriptions and for better results, a huge amount of labelled dataset is required.

Separating 180 real-time image tweets which were stored in CSV files in the form of tweet URLs, our model was prepared using open-source tools to caption different categorical images.

The model aimed to not depend on the author of the original tweet containing media contents to write a short description under a character size of 1000 in the ALT-TEXT feature. The image captioning model is an independent feature that will facilitate over millions of active users and remove the barrier of limited access and networking opportunities.

To examine which part of the photo is detected to generate the caption, an Attention-deep learning model which is similar to the 'Show, Attend and Tell' paper was used [1],[30]. The model was trained using the MS-COCO dataset [6] with 40,000 images.

The deep learning InceptionV3 model was used as the feature extractor and then an encoder-decoder model was trained for the generation of desired captions/ descriptions for new images.

4.4. TEXT SUMMARIZATION

Twitter is experimenting with media tweets containing audio and video for auto-captioning. Considering the testing feature of Audio tweets by Twitter for iOS users

https://doi.org/10.17993/3ctecno.2023.v12n2e44.31-47

and Video tweets for iOS and Android, our Text Summarization model is designed in support of the above Transcription model where audio and videos from tweets will be summarized into different language short sentences.

Open-source Python library, pysummarization is used that implements Encoder/ Decoder based on LSTM (Long Short-Term Memory) for improving the accuracy of the desired summarization by Sequence-to-Sequence (Seq2Seq) learning.

Our proposed model is coded in a 3-step format which considered 260 tweets from CSV files.

1. The script reads the generated video/audio tweet transcript.
2. Summarize in not more than three sentences.
3. Display the summary to the audience.

The Text summarization model in support of the transcription model will work together to deliver the summary of the transcribed video/audio tweets. This will encourage active users to understand the content in the form of a summary and lead to meaningful interaction with other users.

5. RESULTS

The results obtained from the above experiment were motivating enough to infer that our model can significantly make an impact to fill the gap of content accessibility for people with disability.

The experiment has also removed the linguistic barrier by making the social media platform available to all in their specific native language.

As the current framework of Twitter supports features to the potential audience globally with an average of 6000 tweets per second which is approximately 200 billion tweets per year.

Further, our model is simple to operate as it can be implemented with a simple interface of only 2 buttons, namely: speaker icon (Read Out Loud) and information icon (transcript) which will help the disabled user to listen to the text tweets and read out the transcripts of multi-media contents like audio, video, image captioning and summaries. A simulation of the same is depicted in Fig. 3, 4 and 5 below.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.31-47

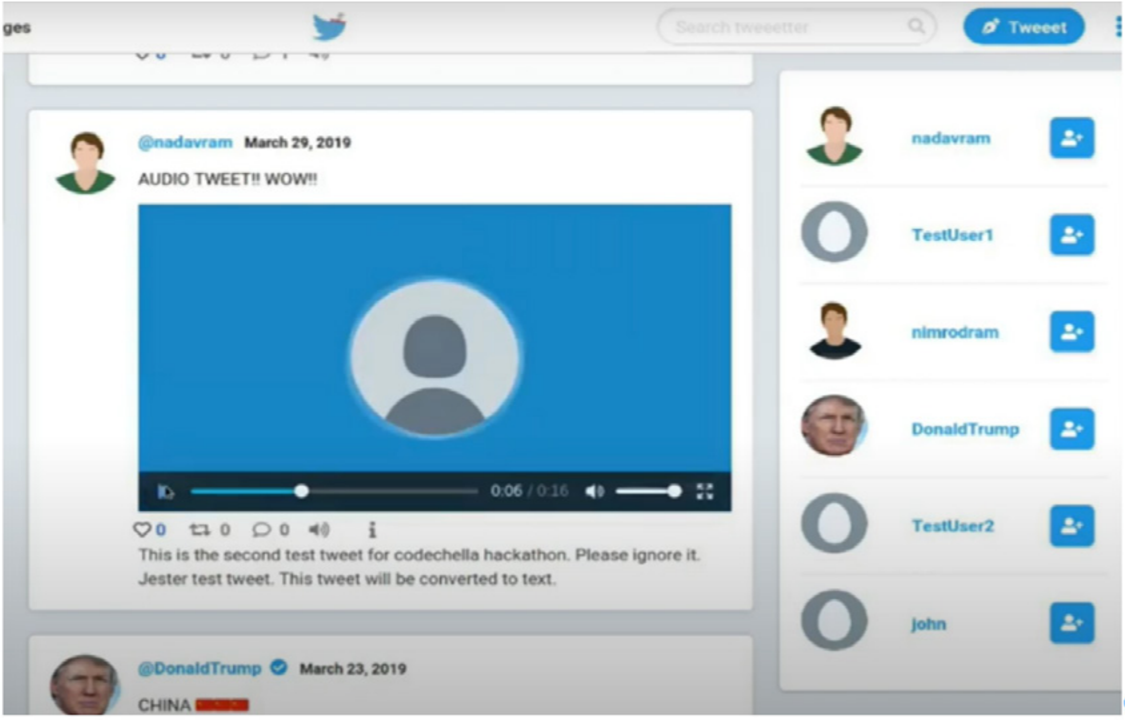


Figure 3. Transcription of Audio Tweet using Information Button ('i')

Figure 4. Transcription of Video Tweet followed by Summarization using the 'i' button.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.31-47

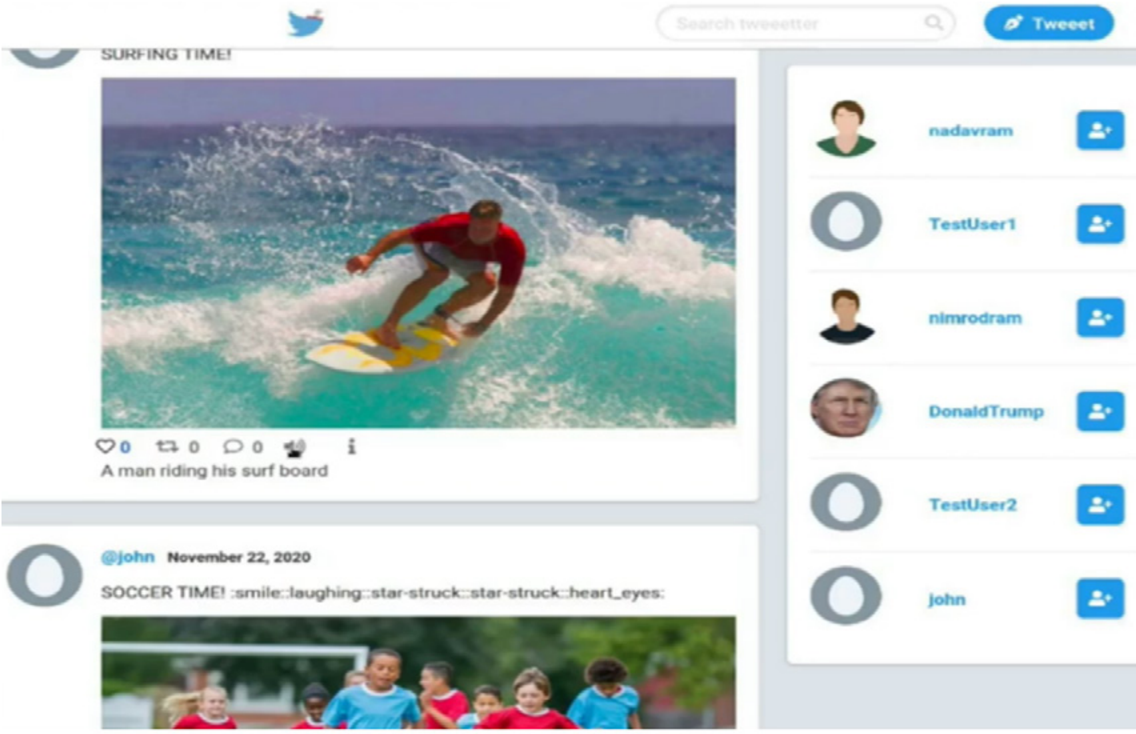


Figure 5. Read Out Loud Image caption using the speaker button

The above figures simulate our proposed framework for better accessibility of user timelines on Twitter. Two major icons knowingly as the speaker and information button support the proposed model which will leverage the open-source community along with communities for disabled people.

In Figure 2. the iconic information button will generate the transcript of the audio tweet and make it accessible majorly for hearing impaired people and other potential audiences. In Figure 3, a video tweet is transcribed through the information button followed up by a summary of the user's primary language. The transcribed text generated in Figure 4. after image captioning can be read out loud through the iconic speaker button which is also compatible in Figure 2 and Figure 3 respectively.

However, after obtaining results from our proposed model which implements Natural Language Processing, Transcription, Translation, and Summarization our approach of using the open-source library for transcript summarization may not yield better performance but there is always room for improvement and global contribution in the community.

6. CONCLUSION

In this research, we analyzed different types of disabled people who need access to Twitter with the advancement of technology and compared the existing features in the current framework of user's timeline with our proposed model which is specialized to fill the gap for disabled people community and leverage the value of inclusion and diversity.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.31-47

The proposed model we coined as TDEF1.0, allows immediate access to the content and works independently without any indulgence of other people.

Concerning the current usage of Twitter by millions of active users, we have examined the pattern of tweets from our dataset of 1000 tweets that infer that people can improve their content creation style while keeping accessibility criteria in their mind.

Our study also suggests that people should be aware of some DOs and DON'T while creating and uploading content on social media platforms.

1. Active users should use camel case during Hashtags so that the screen reader can read the words separately like #EasyToRead.

2. Avoid using different fonts for a tweet as the screen reader will mess with the font name and actual word during screen reading.

3. Try to avoid using unnecessary emoji, special characters, abbreviations, GIFS, extra spaces, etc.

4. Always add an Alt-Text short description if any image is uploaded on Twitter.

7. FUTURE SCOPE

After researching Twitter for everyone, a possibility arises to make Twitter better every day with the advancement of technology and open-source tools. Our goal is to bring diversity and inclusion to the micro-blogging platform and uplift the power of disabled people.

In the future, we would want to bring focus on maintaining a dashboard for insights and statistics on the total number of accounts registered for people with disabilities to track their activities like the number of multi-media/ non-media tweets, retweets, replies, comments, likes in a year to generate overall usage of the product.

Twitter is filled with millions of bot accounts and a bot account can be advantageous to expand our support to the disabled people community by creating a support bot that will exclusively work during accessibility issues and prepares a report of the technical issues faced by the users on time.

Our research is supported by open-source technologies and considering the perspective of different audiences, more advancement and modifications can be done to make Twitter for everyone possible.

REFERENCES

(1) Allahyari, M., Pouriyeh, S., Assefi, M., Safaei, S., D., E., B., J., & Kochut, K. (2017). Text Summarization Techniques: A Brief Survey. International Journal of

https://doi.org/10.17993/3ctecno.2023.v12n2e44.31-47

Advanced Computer Science and Applications, 8(10). https://doi.org/10.14569/ijacsa.2017.081052

(2) Ayo, F. E., Folorunso, O., Ibharalu, F. T., & Osinuga, I. A. (2020). Machine learning techniques for hate speech classification of twitter data: State-of-The-Art, future challenges and research directions. In Computer Science Review (Vol. 38, p. 100311). Elsevier Ireland Ltd. https://doi.org/10.1016/j.cosrev.2020.100311

(3) Boyd, D. M., & Ellison, N. B. (2007). Social network sites: Definition, history, and scholarship. Journal of Computer-Mediated Communication, 13(1), 210–230. https://doi.org/10.1111/j.1083-6101.2007.00393.x

(4) Chatziadam, P., Dimitriadis, A., Gikas, S., Logothetis, I., Michalodimitrakis, M., Neratzoulakis, M., Papadakis, A., Kontoulis, V., Siganos, N., Theodoropoulos, D., Vougioukalos, G., Hatzakis, I., Gerakis, G., Papadakis, N., & Kondylakis, H. (2020). TwiFly: A data analysis framework for Twitter. Information (Switzerland), 11(5), 1–14. https://doi.org/10.3390/INFO11050247

(5) Chiarella, D., Yarbrough, J., & Jackson, C. A. L. (2020). Using alt text to make science Twitter more accessible for people with visual impairments. Nature Communications, 11(1), 10–12. https://doi.org/10.1038/s41467-020-19640-w

(6) COCO Dataset | Papers With Code. (n.d.). Retrieved February 18, 2023, from https://paperswithcode.com/dataset/coco

(7) Desselle, S. P. (2017). The use of Twitter to facilitate engagement and reflection in a constructionist learning environment. Currents in Pharmacy Teaching and Learning, 9(2), 185–194. https://doi.org/10.1016/j.cptl.2016.11.016

(8) Ellis, K., & Kent, M. (2010). Community Accessibility : Tweeters Take Responsibility for an Accessible Web 2.0. Fast Capitalism, 7(1), 39–46.

(9) Gleason, C., Carrington, P., Cassidy, C., Morris, M. R., Kitani, K. M., & Bigham, J. P. (n.d.). “ It ’ s almost like they ’ re trying to hide it ": How User-Provided Image Descriptions Have Failed to Make Twitter Accessible. 549–559. https://doi.org/10.1145/3308558.3313605

(10) Hellemans, J., Willems, K., & Brengman, M. (2020). Daily Active Users of Social Network Sites: Facebook, Twitter, and Instagram-Use Compared to General Social Network Site Use (pp. 194–202). Springer, Cham. https://doi.org/10.1007/978-3-030-47595-6_24

(11) How to Direct Message (DM) on Twitter | Twitter Help. (n.d.). Retrieved May 13, 2021, from https://help.twitter.com/en/using-twitter/direct-messages

(12) How to make images accessible for people. (n.d.). Retrieved May 13, 2021, from https://help.twitter.com/en/using-twitter/picture-descriptions

(13) jack on Twitter: “just setting up my twttr” / Twitter. (n.d.). Retrieved May 14, 2021, from https://twitter.com/jack/status/20

(14) Khan, I., Naqvi, S. K., Alam, M., & Rizvi, S. N. A. (2017). An efficient framework for real-time tweet classification. International Journal of Information Technology (Singapore), 9(2), 215–221.

(15) Khatua, A., Khatua, A., & Cambria, E. (2019). A tale of two epidemics: Contextual Word2Vec for classifying twitter streams during outbreaks. Information Processing and Management, 56(1), 247–257. https://doi.org/10.1016/j.ipm.2018.10.010

(16) Little-known Twitter feature can help blind and visually impaired people use the site | The Independent | The Independent. (n.d.). Retrieved May 13, 2021, from https://www.independent.co.uk/life-style/gadgets-and-tech/news/twitter-blind-users-alt-text-accessibility-features-ios-android-app-website-compose-image-descriptions-a8143391.html

(17) Morris, M. R., Zolyomi, A., Yao, C., Bahram, S., Bigham, J. P., & Kane, S. K. (2016). "With most of it being pictures now, I rarely use it": Understanding Twitter's evolving accessibility to blind users. Conference on Human Factors in Computing Systems - Proceedings, 5506–5516. https://doi.org/10.1145/2858036.2858116

(18) Sujay, R., Pujari, J., Bhat, V. S., & Dixit, A. (2018). Timeline Analysis of Twitter User. Procedia Computer Science, 132, 157–166. https://doi.org/10.1016/j.procs.2018.05.179

(19) Talbot, C. V, Dwyer, S. T. O., Clare, L., & Heaton, J. (2021). The use of Twitter by people with young-onset dementia : A qualitative analysis of narratives and identity formation in the age of social media. https://doi.org/10.1177/14713012211002410

(20) Tang, Y., & Hew, K. F. (2017). Using Twitter for education: Beneficial or simply a waste of time? Computers and Education, 106, 97–118. https://doi.org/10.1016/j.compedu.2016.12.004

(21) The Top Twitter Updates You Need to Know: January 2021. (n.d.). Retrieved May 13, 2021, from https://blog.hootsuite.com/twitter-updates/

(22) Twitter apologies for not making voice tweets accessible to deaf people | The Independent | The Independent. (n.d.). Retrieved May 13, 2021, from https://www.independent.co.uk/life-style/gadgets-and-tech/news/twitter-voice-notes-deaf-accessible-ios-iphone-app-update-a9574966.html

(23) Twitter Fleets Introduced to Encourage More Tweets. (n.d.). Retrieved May 13, 2021, from https://www.searchenginejournal.com/twitter-fleets/387927/

(24) Twitter invited a deaf person to test out Spaces – here's what they think… – Liam O'Dell. (n.d.). Retrieved May 13, 2021, from https://liamodell.com/2021/01/16/twitter-spaces-deaf-captions-clubhouse-audio/

(25) Twitter just rolled out a feature that's inaccessible to disabled users. (n.d.). Retrieved May 13, 2021, from https://slate.com/technology/2020/06/twitter-voice-tweets-accessibility.html

(26) Twitter launches Bookmarks – an anonymous way to save tweets - The Courier. (n.d.). Retrieved May 13, 2021.

(27) Twitter voice Tweets – how to Tweet with your voice or audio. (n.d.). Retrieved May 13, 2021, from https://help.twitter.com/en/using-twitter/voice-tweet

(28) Ugochi, O., Prasad, R., Odu, N., Ogidiaka, E., & Ibrahim, B. H. (2022). Customer opinion mining in electricity distribution company using twitter topic modeling and logistic regression. International Journal of Information Technology (Singapore), 14(4), 2005–2012.

(29) Valencia, S., Kirabo, L., Carter, E. J., Bennett, C. L., & Pavel, A. (2020). Disability and the COVID-19 Pandemic Using Twitter to Understand Accessibility during Rapid Societal Transition. i. https://doi.org/10.1145/3373625.3417023

(30) Yadav, A. K., Singh, A., Dhiman, M., Vineet, Kaundal, R., Verma, A., & Yadav, D. (2022). Extractive text summarization using deep learning approach. International Journal of Information Technology (Singapore), 14(5), 2407–2415.

ABOUT THE AUTHORS

Ms. Namrata Aggarwal

Ms. Namrata Aggarwal is currently working as an Analyst at KPMG and post-graduated with a Master of Computer Application (M.C.A) from Bharati Vidyapeeth's Institute of Computer Applications and Management (BVICAM) in June 2022. Passionate about learning new things every day for career and life. She is an acclaimed researcher in Artificial Intelligence who has also won #WomenHackAI, 5XHackathons and also been a Gold Microsoft Learn Student Ambassador.

Dr. Ritika Wason

Dr. Ritika Wason is working as Associate Professor with Bharati Vidyapeeth's Institute of Computer Applications and Management (BVICAM), New Delhi. She is also the managing editor for the International Journal of Information Technology (IJIT), an official Journal of Bharati Vidyapeeth’s Institute of Computer Applications and Management (BVICAM) co-published with Springer and UGC-Care Indexed and Scopus indexed. An avid researcher, she is also the editor for CSI Communications, a monthly magazine published by the Computer Society of India (CSI). A certified mendeley trainer she has trained several professionals and scholars on mendeley. A researcher she has also authored many books and papers published by many leading publishers.

Dr. Parul Arora

Dr. Parul Arora is working as Associate Professor with Bharati Vidyapeeth's Institute of Computer Applications and Management (BVICAM), New Delhi. An avid researcher she has many research papers published in many renowned journals and conferences.

Ms. Aruna Tomar

Ms Aruna Tomar is working as an Assistant Professor with Bharati Vidyapeeth's Institute of Computer Applications and Management (BVICAM), New Delhi. An avid researcher she has many research papers published in many renowned journals and conferences.

Mr. Devansh Arora

Mr. Devansh Arora is a student at Indraprastha Institute of Information Technology (IIIT), Delhi. An artificial intelligence and machine learning enthusiast he has many projects and papers to his credit.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.31-47

/03/

AN EMPIRICAL ANALYSIS OF TRAJECTORY PREDICTION TECHNIQUES FOR MOTION PREDICTION IN WAYMO DATASET

Devansh Arora

Indraprastha Institute of Information Technology (IIIT) Delhi, India

devansh20053@iiitd.ac.in

Parul Arora

Dept. of Computer Science and Applications. Bharati Vidyapeeth's Institute of Computer Applications and Management (BVICAM). Delhi, India

paruldevsum@gmail.com

Ritika Wason*

Dept. of Computer Science and Applications. Bharati Vidyapeeth's Institute of Computer Applications and Management (BVICAM). Delhi, India

ritika.wason@bvicam.in

Reception: 15/02/2023 **Acceptance**: 21/04/2023 **Publication**: 10/07/2023

Suggested citation:

Devansh, A., Parul, A. And Ritika, W. (2023). **An Empirical Analysis of Trajectory Prediction Techniques for Motion Prediction in Waymo Dataset.** *3C Tecnología. Glosas de innovación aplicada a la pyme, 12(2)*, 49-63. https://doi.org/10.17993/3ctecno.2023.v12n2e44.49-63

ABSTRACT

The Waymo is the prime and most varied autonomous driving dataset that improves and enhances itself every year. Motion Prediction is a considerable challenge in 2023. This manuscript analyses five considerable methods namely MTR-A, Wayformer, DenseTNT, Golfer and MultiPath++ for their technology applied. The analysis revealed that the Transformer network could achieve a state of the art trajectory prediction as well as scale to many workloads.

KEYWORDS

Trajectory Prediction, Waymo Dataset, Motion Prediction, Transformer Network, Autonomous Driving.

INDEX

https://doi.org/10.17993/3ctecno.2023.v12n2e44.49-63

1. INTRODUCTION

Google, Uber, Tesla, Mobileye, and numerous automakers have lately made substantial investments in autonomous driving systems, a futuristic use [7]. The autonomous driving technology permits the car to drive itself without human assistance [15]. The car with autonomous driving capacity detects its surroundings, determines its position, and drives itself safely to the given target without human intervention [27]. Demand for this solution continues to rise, resulting in increased industry investment [17]. Mobileye is a pioneer in computer vision-based autonomous driving technology, and Intel just purchased the company for $15.3 billion. Forecasts indicate that by 2035, the market for driverless vehicles will be worth $77 billion [4]. The number of autonomous vehicles is expected to reach 18 million by 2035, which represents 25% of the market [3].

From robot axes to self-driving trucks, it is anticipated that autonomous driving technology will enable a vast array of applications with the potential to save numerous lives [1],[18]. The public availability of large-scale datasets and yardsticks has led to substantial growth in the fields of image categorization, object recognition, object trailing, semantic segmentation, and instance segmentation. Images obtained from numerous high-resolution cameras and sensor readings from numerous high-quality LiDAR scanners installed on a convoy of autonomous vehicles make up the Waymo open data set, the largest and most diversified multimodal autonomous driving dataset to date [6]. When compared to other autonomous driving datasets, ours captures a far wider geographical range, both in terms of overall area covered and allotment of that coverage across geographies [13]. Several cities, including San Francisco, Phoenix, and Mountain View, were sampled across a variety of environmental circumstances, and a vast geographical area was sampled within each city [5],[13],[20]. The dataset demonstrates that the disparities in these regions result in a significant domain gap, hence opening up intriguing potential for research in the field of domain adaptation [6]. Both 3D ground truth bounding boxes for the LiDAR data and 2D bounding boxes that closely fit the camera images are included in the Waymo dataset, which has a large number of them [12]. Track IDs are present in all ground truth containers to assist object tracking [26]. Finally, with our provided rolling shutter aware projection software, scientists can derive 2D a modal camera boxes from 3D LiDAR boxes [2]. Studies involving LiDAR and camera annotations are bolstered by the multimodal ground truth. There are about 12 million camera box annotations, 12 million LiDAR object tracks, and about 250 thousand camera image tracks [10]. Professional labelers used labelling tools suitable for production to make and verify all annotations. It captured all of the sensor data in our dataset using an industrial-strength sensor suite consisting of numerous high-resolution cameras and multiple high-quality LiDAR sensors. Moreover, we provide camera and LiDAR synchronization, which enables exciting cross-domain learning and transfer [2]. Every pixel in the range images we supply also includes accurate information about the vehicle's attitude, in addition to sensor attributes like as elongation. Since this is the original synchronized dataset with such low-level information, it will facilitate studies of alternative LiDAR input formats to the

https://doi.org/10.17993/3ctecno.2023.v12n2e44.49-63

standard 3D point set format [6],[8]. Now, there are 1000 scenarios used for training and validation, along with 150 scenes used for testing; every scene lasts for 20 seconds [6]. To see how effectively the models, we've trained on our dataset generalize to new environments, we might choose test set scenarios from a geographical holdout area [24],[26].

2. ADDING LABELS AND CHALLENGES TO WAYMO OPEN DATASET.

To broaden the scope of academic inquiry, new labels have been added to the Waymo Open Dataset [6]. The following are included in the extension: The evaluation of central features and spatial context can be a useful extension of models for predicting perception and behavior. Subtle cues, such as a bicycle signaling a turn, are not lost on them. The key point label release is the largest dataset of its kind that is freely accessible for research into autonomous vehicles. We're energized to see how the research neighborhood at large puts it to use to progress the field of human posture evaluation.

Although segmentation has long been recognized as a valuable tool in the academic world, the vast majority of publicly available datasets for autonomous driving only provide bounding boxes to characterize and categorize objects, which might lead to the absence of critical information. In order to identify and categorize each pixel in an image or LiDAR point cloud as part of a certain object, segmentation labelling is employed [11]. This remarkable level of granularity is made possible by the insertion of 3D segmentation labels for 23 classes and 1,150 segments of the Waymo Open Dataset [6],[17].

It could be confusing or time-consuming to match up the bounding boxes from a 2D camera with their 3D equivalents in LiDAR labels. In order to promote further research on sensor fusion for object recognition and detection, we have added labels based on the standard 2D-to-3D bounding box correspondence.

Along from all these new tools, Waymo has also launched the 2023 Waymo Open Dataset Challenges, which will have participants forecast the whereabouts of up to eight agents eight seconds into the future using only the agents' historical one-second tracks on an associated map [14],[23],[25].

3. WAYMO OPEN DATASET: MOTION PREDICTION CHALLENGE

The capacity to predict the behavior of other drivers is essential for safe and successful driving [25]. Important questions can be: Is that the sound of a pedestrian trying to cross? How close is that car to entering my lane, and is it parallel parked? Is the speeding car going to roll through the stop sign? One of the most demanding

https://doi.org/10.17993/3ctecno.2023.v12n2e44.49-63

aspects of autonomous driving is accurately predicting the behavior of other road users. There are also serious safety concerns; being able to precisely predict the actions of other drivers is crucial for avoiding collisions. While researchers in the ground of autonomous vehicles have made significant strides in recent years in solving the problem of motion prediction, the industry would benefit from having access to even more high-quality open-source motion data.

To the best of our knowledge, the Waymo Open Dataset motion challenge is the largest interactive dataset released to date for study of behavior prediction and motion forecasting for autonomous driving, and we've expanded it in this work. In order to help any research group looking into how to construct its own high-quality motion data, we are reviewing all the articles describing the state-of-the-art research perception method used to annotate the motion dataset. This is especially true of high-quality motion data, which can be difficult to come by and sometimes costs a lot of money to obtain.

An advanced perception system is needed to build a motion dataset with high-quality labels, as this requires the ability to reliably identify agents and objects from camera and LidaR data, as well as track their movement within the image. The collection of compelling motion data is similarly difficult. Most commutes are uneventful, therefore there is little to no useful information to use in developing a system to anticipate what can happen on the road under extreme circumstances. As a result, there are usually just a few of interesting interactions included in the datasets that are publicly available.

The Waymo Open Dataset is designed to address these issues. Predict the positions of up to eight agents eight seconds into the future, given their 1 second-ago tracks on a comparable map. The ground truth future data for the test set is concealed from challenge participants in order to facilitate the motion prediction task. As a result, the test sets only include one second of historical data. The validation sets contain the actual future ground truth data for use in model building. In addition, the test and validation sets include a list of up to eight predicted object tracks in the scene. They are chosen for their engaging behavior and variety of object types.

4. LEADERBOARD BEST SOLUTIONS

Each Scenario Predictions proto within a motion prediction submission corresponds to a single scenario in the test set and contains up to eight predictions for the objects indicated in the tracks to predict field of the scenario [19],[9]. While these are distinct forecasts, each Joint Predictions proto comprises a prediction for a single item. Each Multi Modal Prediction prototype will include a maximum of six trajectory predictions, each accompanied by a confidence rating. Trajectory forecasts must include precisely 16 position samples, each corresponding to the next 8 seconds and sampled at a rate of 2 Hz. Wayformer's attention-based scene encoder/decoder is modest [16]. Nigamaa Nayakanti and all study scene encoder early, late, and hierarchical input

https://doi.org/10.17993/3ctecno.2023.v12n2e44.49-63

fusion [16]. Factorized or latent query attention balances efficiency and quality for each fusion type. Nigamaa Nayakanti and all design philosophy proves that early fusion, despite its simplicity, is modality neutral and performs at the top of the Waymo Open Motion Dataset (WOMD) and Argoverse leaderboards. Shaoshuai Shi and all offer a distinctive Motion Transformer framework for multimodal motion prediction, which initiates a restricted set of novel motion query pairs for producing superior multimodal future trajectories by conducting intention localization and iterative motion refining simultaneously [19]. Balakrishnan Varadarajan and all in their manuscript directly uses agent state information and compact polylines to describe road features (e.g., position, velocity, acceleration) [22]. Balakrishnan Varadarajan et. al. examines pre-defined, static anchors and develop a model to discover latent anchor embeddings end-to-end. Balakrishnan Varadarajan et. al. use ensembling and output aggregation approaches from other ML areas to find appropriate probabilistic multimodal output representations. Yueming Zhang introduces a real-time 2D object detection algorithm from photos [25]. Yueming Zhang aggregate multiple common one-stage object detectors and train various input strategy models independently to improve multi-scale identification of each category, notably small objects. TensorRT optimizes detection pipeline inference time for model acceleration. Junru Gu offer an anchor-free model, dubbed DenseTNT, which performs opaque goal probability estimate for trajectory prediction [9]. Without relying on the value of heuristically set goal anchors, its performance vastly improves. In the next section we will compare and analyze the leaderboard solutions and understand the research areas where work can be done.

5. RESULTS

Table 1 below highlights the research gaps we discovered of our analysis of the five above methodologies. These gaps lay the ground for considerable future research.

TABLE 1. Comparison of Considerable Leaderboard Solutions for Motion Prediction in Waymo Dataset

https://doi.org/10.17993/3ctecno.2023.v12n2e44.49-63

S. No.	Title	Ref.	Methodology	Findings	Research Gaps
1	MTR-A: 1st Place Solution for 2022 Waymo Open Dataset Challenge - Motion Prediction	[19]	We introduce the Motion Transformer, a novel architecture for multimodal motion prediction that uses simultaneous intention localization and iterative motion refinement to generate better multimodal future trajectories. To further improve the performance of the final model, a basic model ensemble technique with non-maximal suppression is employed.	Approach came in first on the leaderboard and did better than all the other submissions in terms of Soft mAP, mAP, and the miss rate. This means that their method is better at predicting multimodal future trajectories.	Agent-centric modelling forecasts the multimodal future trajectories of a single interested agent while redundantly encoding the situation for additional interested actors. So, it is an upcoming problem to build a multimodal motion prediction system for several actors. Even when using a rule-based post-processing method, accuracy in predicting the minADE/minFDE can be low. If you want a more solid structure, it's worth your time to learn how to generate 6 possible future trajectories using multimodal predictions (e.g., 64 predictions).

https://doi.org/10.17993/3ctecno.2023.v12n2e44.49-63

2	DenseTNT: Waymo Open Dataset Motion Prediction	[9]	DenseTNT is a model without anchors that conducts dense goal probability estimate for trajectory prediction. The author extracts sparse scene context characteristics before employing a dense probability estimation to construct the probability distribution of the goal candidates. A trajectory completion module then generates trajectories depending on a set of selected objectives.	The objective candidates are densely dispersed over the map in DenseTNT. We display the probability of the dense goals and the anticipated trajectories based on the specified goals. DenseTNT provides different predictions, including travelling straight, making left/right turns, and U-turns.	Complex trajectory generation in dense TNT is computationally intensive and time consuming, especially in dynamic environments with moving obstacles. As a result, its usefulness in real-time contexts may be hampered. In addition, Dense TNT is highly sensitive to the initial conditions, with even a small shift in the robot's or the obstacles' starting position leading to a dramatically different path. In applications where the initial conditions are uncertain or may change during the plan's execution, this can be problematic.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.49-63

3	Wayformer: Motion Forecasting via Simple & Efficient Attention Networks	[16]	Wayformer is a simple and unified family of attention-based architectures for motion prediction introduced in this paper. A scene encoder and decoder that is based on attention are the meat and potatoes of Wayformer's model description. We explore the use of early, late, and hierarchical input fusion in the scene encoder. We look into methods of achieving a happy medium between speed and accuracy, using either factorized or latent query attention, for every possible combination of	The results obtained by Wayformer on the Waymo Open Motion Dataset (WOMD) and the Argoverse leaderboards validate the effectiveness of our design philosophy and show that early fusion is not only modality agnostic but also delivers state-of-the-art outcomes.	The following are the limits placed on the scope of this investigation: Processing the same data over and again is a burden for egocentric modelling in complex settings. This can be avoided by encoding the scene only once, in a world-at-once reference frame. The input to the system is a vague and generalized description of the world, which leaves out important details in complex situations, such as indications from human eyes or fine-grained contour or wheel angle information for vehicles. Gaining an all-encompassing understanding of perception and prediction could pave the way for progress. Each agent's distribution over possible futures is modelled separately in time and space, and each agent's distribution over possible futures is modelled conditionally independently in time and space given their goal.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.49-63

4	Golfer: Trajectory Prediction with Masked Goal Conditioning MnM Network	[21]	For the purpose of AV trajectory prediction, authors provide a universal Transformer-like architectural module MnM network with innovative masked goal conditioning training methods.	It has been demonstrated that the resulting MnM network, which consists of solely MnM blocks stacked on top of one another, is superior since it can predict trajectories given point-like agent and road inputs. On May 23, 2022, authors golfer-named trajectory prediction model, which was enhanced with the new masked goal conditioning and MnM network, was rated second on the Waymo Open Motion Dataset leaderboard.	In order to learn cross-correlations between items in a set, the proposed Mix and Match (MnM) block, a broad kind of set transformation, has been shown to be particularly useful. This building block may not be suitable for use in all circumstances, though.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.49-63

5	Multipath++: efficient information fusion and trajectory aggregation for behavior prediction	[20]	The MultiPath framework can cope with the problem of a multimodal output space by using a Gaussian Mixture Model to characterize the extremely multimodal output distributions. With the help of static trajectory anchors, an external input to the model, this method can overcome the common problem of mode collapse in the learning process. This useful technique provides experts with a fundamental strategy for guaranteeing consistency and an extra measure of control for modelers through the creation of such anchors.	The provided model performs at the state-of-the-art level in both the Argoverse Motion Forecasting Competition and the Waymo Open Dataset Motion Prediction Challenge. Sparse encoding, efficient fusion methods, control-based approaches, and learned anchors were all shown to be crucial by the authors. Furthermore, we provided a practical guidance for implementing different training and inference procedures to enhance robustness, diversity, missing data handling, and training convergence speed.	Multipath++ is only capable of predicting a path a few seconds into the future. While this may be sufficient for some applications, others may necessitate more advanced prediction techniques.

6. CONCLUSION

MTRA, Golfer and Wayformer underlined that Transformer can be trained substantially faster than recurrent or convolutional layer-based designs. The Transformer utilizes multi-headed focus in three distinct ways. In an encoder-decoder architecture, the memory's keys and values are produced by the encoder, while queries are passed down from the previous decoder layer. This allows the decoder's input positions to process the entire sequence. This is similar to the focus mechanisms of encoder-decoder models used in sequence-to-sequence models. The encoder has layers for introspective processing. In a self-attention layer, the output of

https://doi.org/10.17993/3ctecno.2023.v12n2e44.49-63

the previous layer's encoder is used as the source for all keys, values, and queries. The encoder's architecture allows for all of the previous layer's positions to be serviced from any given place. Like the encoder, the decoder has self-attention layers that allow any location in the decoder to pay attention to all other positions. The auto-regressive property can only be preserved by blocking leftward information flow in the decoder.

7. FUTURE SCOPE

Based on what we learned from our analysis, we conclude that Transformers networks, modified to improve their baseline architecture of input encodings and overall models, produce the best results. With transformers, one can interpret which parts of the input sequence are most crucial to generating the output thanks to their attention mechanisms. This allows transformers to achieve state-of-the-art results in the case of trajectory prediction and scale to a wide range of tasks.

REFERENCES

(1) Bansal, P., & Kockelman, K. M. (2017). Forecasting Americans' long-term adoption of connected and autonomous vehicle technologies. Transportation Research Part A: Policy and Practice, 95, 49–63. https://doi.org/10.1016/J.TRA.2016.10.013

(2) Chong, Y. L., Lee, C. D. W., Chen, L., Shen, C., Chan, K. K. H., & Ang, M. H. (2022). Online Obstacle Trajectory Prediction for Autonomous Buses. Machines, 10(3), 1–19. https://doi.org/10.3390/machines10030202

(3) Clements, L. M., & Kockelman, K. M. (2017). Economic Effects of Automated Vehicles. Https://Doi.Org/10.3141/2606-14, 2606(1), 106–114. https://doi.org/10.3141/2606-14

(4) Cohen, T., & Rabinovitch, A. L. (2017). Intel's $15 billion purchase of Mobileye shakes up driverless car sector | Reuters. Technology, Media & Telecom-Innovation. https://www.reuters.com/article/us-intel-mobileye-idUSKBN16K0ZP

(5) CVPR 2020 Open Access Repository. (n.d.). Retrieved March 20, 2023, from https://openaccess.thecvf.com/content_CVPR_2020/html/Sun_Scalability_in_Perception_for_Autonomous_Driving_Waymo_Open_Dataset_CVPR_2020_paper.html

(6) Ettinger, S., Cheng, S., Caine, B., Liu, C., Zhao, H., Pradhan, S., Chai, Y., Sapp, B., Qi, C., Zhou, Y., Yang, Z., Chouard, A., Sun, P., Ngiam, J., Vasudevan, V., McCauley, A., Shlens, J., & Anguelov, D. (2021). Large Scale Interactive Motion Forecasting for Autonomous Driving: The WAYMO OPEN MOTION DATASET. Proceedings of the IEEE International Conference on Computer Vision, 9690–9699. https://doi.org/10.1109/ICCV48922.2021.00957

(7) Fagnant, D. J., & Kockelman, K. (2015). Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. Transportation Research Part A: Policy and Practice, 77, 167–181. https://doi.org/10.1016/J.TRA.2015.04.003

(8) Gressenbuch, L., Esterle, K., Kessler, T., & Althoff, M. (2022). MONA: The Munich Motion Dataset of Natural Driving. IEEE Conference on Intelligent Transportation Systems, Proceedings, ITSC, 2022-Octob, 2093–2100. https://doi.org/10.1109/ITSC55140.2022.9922263

(9) Gu, J., Sun, Q., & Zhao, H. (2021). DenseTNT: Waymo Open Dataset Motion Prediction Challenge 1st Place Solution. 1–5. http://arxiv.org/abs/2106.14160

(10) Hu, X., Zheng, Z., Chen, D., Zhang, X., & Sun, J. (2022). Processing, assessing, and enhancing the Waymo autonomous vehicle open dataset for driving behavior research. Transportation Research Part C: Emerging Technologies, 134(December). https://doi.org/10.1016/j.trc.2021.103490

(11) Hula, A., de Zwart, R., Mons, C., Weijermars, W., Boghani, H., & Thomas, P. (2023). Using reaction times and accident statistics for safety impact prediction of automated vehicles on road safety of vulnerable road users. Safety Science, 162. https://doi.org/10.1016/j.ssci.2023.106091

(12) LaMondia, J. J., Fagnant, D. J., Qu, H., Barrett, J., & Kockelman, K. (2016). Shifts in long-distance travel mode due to automated vehicles: Statewide mode-shift simulation experiment and travel survey analysis. Transportation Research Record, 2566, 1–10. https://doi.org/10.3141/2566-01

(13) Leon, F., & Gavrilescu, M. (2021). A review of tracking and trajectory prediction methods for autonomous driving. Mathematics, 9(6), na. https://doi.org/10.3390/math9060660

(14) Mahmoud, A., Hu, J. S. K., & Waslander, S. L. (2023). Dense Voxel Fusion for 3D Object Detection (pp. 663–672).

(15) May, A. D., Shepherd, S., Pfaffenbichler, P., & Emberger, G. (2020). The potential impacts of automated cars on urban transport: An exploratory analysis. Transport Policy, 98, 127–138. https://doi.org/10.1016/j.tranpol.2020.05.007

(16) Nayakanti, N., Al-Rfou, R., Zhou, A., Goel, K., Refaat, K. S., & Sapp, B. (2022). Wayformer: Motion Forecasting via Simple & Efficient Attention Networks. 1–20. http://arxiv.org/abs/2207.05844

(17) Notz, D., Becker, F., Kuhbeck, T., & Watzenig, D. (2020). Extraction and Assessment of Naturalistic Human Driving Trajectories from Infrastructure Camera and Radar Sensors. IEEE International Conference on Automation Science and Engineering, 2020-Augus, 455–462. https://doi.org/10.1109/CASE48305.2020.9216992

(18) Shaheen, S. A., Cohen, A. P., & Martin, E. (2010). Carsharing parking policy. Transportation Research Record, 2187, 146–156. https://doi.org/10.3141/2187-19

(19) Shi, S., Jiang, L., Dai, D., & Schiele, B. (2022). MTR-A: 1st Place Solution for 2022 Waymo Open Dataset Challenge -- Motion Prediction. http://arxiv.org/abs/2209.10033

(20) Sun, P., Kretzschmar, H., Dotiwalla, X., Chouard, A., Patnaik, V., Tsui, P., Guo, J., Zhou, Y., Chai, Y., Caine, B., Vasudevan, V., Han, W., Ngiam, J., Zhao, H., Timofeev, A., Ettinger, S., Krivokon, M., Gao, A., Joshi, A., … Anguelov, D. (2020). Scalability in Perception for Autonomous Driving: Waymo Open Dataset (pp. 2446–2454). http://www.waymo.com/open

(21) Tang, X., Eshkevari, S. S., Chen, H., Wu, W., Qian, W., & Wang, X. (2022). Golfer: Trajectory Prediction with Masked Goal Conditioning MnM Network. 1–4. Retrieved from http://arxiv.org/abs/2207.00738

(22) Varadarajan, B., Hefny, A., Srivastava, A., Refaat, K. S., Nayakanti, N., Cornman, A., Chen, K., Douillard, B., Lam, C. P., Anguelov, D., & Sapp, B. (2022). MultiPath++: Efficient Information Fusion and Trajectory Aggregation for Behavior Prediction. Proceedings - IEEE International Conference on Robotics and Automation, 7814–7821. https://doi.org/10.1109/ICRA46639.2022.9812107

(23) WACV 2023 Open Access Repository. (n.d.). Retrieved March 20, 2023, from https://openaccess.thecvf.com/content/WACV2023/html/Mahmoud_Dense_Voxel_Fusion_for_3D_Object_Detection_WACV_2023_paper.html

(24) Wang, J. (2019). Estimation And Tracking Algorithm For Autonomous Vehicles And Humans.

(25) Wang, Y., Chen, S., Huang, L., Ge, R., Hu, Y., Ding, Z., & Liao, J. (2020). 1st Place Solutions for Waymo Open Dataset Challenges -- 2D and 3D Tracking. c, 1–8. Retrieved from http://arxiv.org/abs/2006.15506

(26) Ward, E. (2018). Models Supporting Trajectory Planning in Autonomous Vehicles [KTH Royal Institute of Technology]. In Doctoral Thesis. Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-224870

(27) You, C., Lu, J., Filev, D., & Tsiotras, P. (2019). Advanced planning for autonomous vehicles using reinforcement learning and deep inverse reinforcement learning. Robotics and Autonomous Systems, 114, 1–18. https://doi.org/10.1016/j.robot.2019.01.003

ABOUT THE AUTHORS

Mr. Devansh Arora

Mr Devansh Arora is a student at Indraprastha Institute of Information Technology (IIIT), Delhi. An artificial intelligence and machine learning enthusiast he has many projects and papers to his credit.

Dr. Parul Arora

Dr Parul Arora is working as Associate Professor with Bharati Vidyapeeth's Institute of Computer Applications and Management (BVICAM), New Delhi. An avid researcher she has many research papers published in many renowned journals and conferences.

Dr. Ritika Wason

Dr Ritika Wason is working as Associate Professor with Bharati Vidyapeeth's Institute of Computer Applications and Management (BVICAM), New Delhi. She is also the managing editor for International Journal of Information Technology (IJIT), an official Journal of Bharati Vidyapeeth's Institute of Computer Applications and

Management (BVICAM) co-published with Springer and UGC-Care Indexed and Scopus indexed. An avid researcher, she is also the editor for CSI Communications, a monthly magazine published by the Computer Society of India (CSI). A certified Mendeley trainer she has trained several professionals and scholars on Mendeley. A researcher she has also authored many books and papers published by many leading publishers.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.49-63

/04/

PLANT DISEASE CLASSIFICATION USING AI - SPL DEEP LEARNING AND MACHINE LEARNING

Leena Gupta*

Banasthali Vidyapith, Vidyapith, Rajasthan (India)

Institute of Information Technology and Management, Guru Gobind Singh Indraprastha University, New Delhi (India)

email2leena@gmail.com

Vaibhav Vyas

Banasthali Vidyapith, Vidyapith, Rajasthan (India)

Reception: 27/02/2023 **Acceptance**:21/04/2023 **Publication**: 10/07/2023

Suggested citation:

Gupta, L. and Vyas, V. (2023). **Plant Disease Classification Using AI - Spl Deep Learning and Machine Learning**. *3C Tecnología. Glosas de innovación aplicada a la pyme, 12(2)*, 65-76. https://doi.org/10.17993/3ctecno.2023.v12n2e44.65-76

ABSTRACT

The field of plant disease classification has recently been seen to be a vast area of research. Recent years have witnessed a growing interest in the application of artificial intelligence (AI) and machine learning (ML) techniques for various tasks. Among these techniques, deep learning (DL) algorithms have received significant attention and demonstrated remarkable results. This review article aims to give a comprehensive overview of the current advancements in the field of plant disease classification using AI and ML, with a focus on DL approaches. The paper will cover key literature in the field, including recent advances and challenges, and will discuss the most commonly used algorithms, such as Convolutional Neural Networks (CNNs), Recurrent Neural Networks (RNNs), and Transfer Learning (TL). Additionally, the review will highlight the various applications of AI in plant disease classification, including the use of images, genomic data, and environmental data. The paper will also provide insights into the limitations and opportunities of AI-based plant disease classification, as well as future directions for research in this field. The goal of this paper is to provide a comprehensive overview of the field and to serve as a useful resource for researchers and practitioners in the area of plant disease classification using AI and ML.

KEYWORDS

Plant disease classification, artificial intelligence, machine learning, deep learning, convolutional neural networks, recurrent neural networks, transfer learning

INDEX

https://doi.org/10.17993/3ctecno.2023.v12n2e44.65-76

1. INTRODUCTION

Plant diseases caused by pathogens, environmental factors, or genetic issues have a major impact on global food security, crop yield, and economic stability. Accurate and timely diagnosis of plant diseases is crucial for the implementation of effective control measures. Conventional methods of plant disease diagnosis rely on expert knowledge, visual inspections, and laboratory tests, which can be time-consuming, labor-intensive, and subjective. To overcome these limitations, the field of plant disease classification has increasingly turned to the use of artificial intelligence (AI) and machine learning (ML) techniques [1].

In recent years, deep learning (DL) algorithms have shown significant promise in plant disease classification, particularly in the analysis of image data. Convolutional Neural Networks (CNNs), Recurrent Neural Networks (RNNs), and Transfer Learning (TL) are among the most commonly used DL algorithms in this field. In addition to images, AI has also been applied to the analysis of genomic and environmental data for plant disease classification [2]. The purpose of this literature review is to examine the advancements made in the field of plant disease diagnosis through the use of artificial intelligence and machine learning techniques, particularly highlighting the applications of deep learning methods. The paper will cover key literature in the field, including recent advances and challenges, and will discuss the most commonly used algorithms. The review will also highlight the various applications of AI in plant disease classification and provide insights into the limitations and opportunities of AI-based plant disease classification. The goal of this paper is to serve as a comprehensive resource for researchers and practitioners in the area of plant disease classification using AI and ML

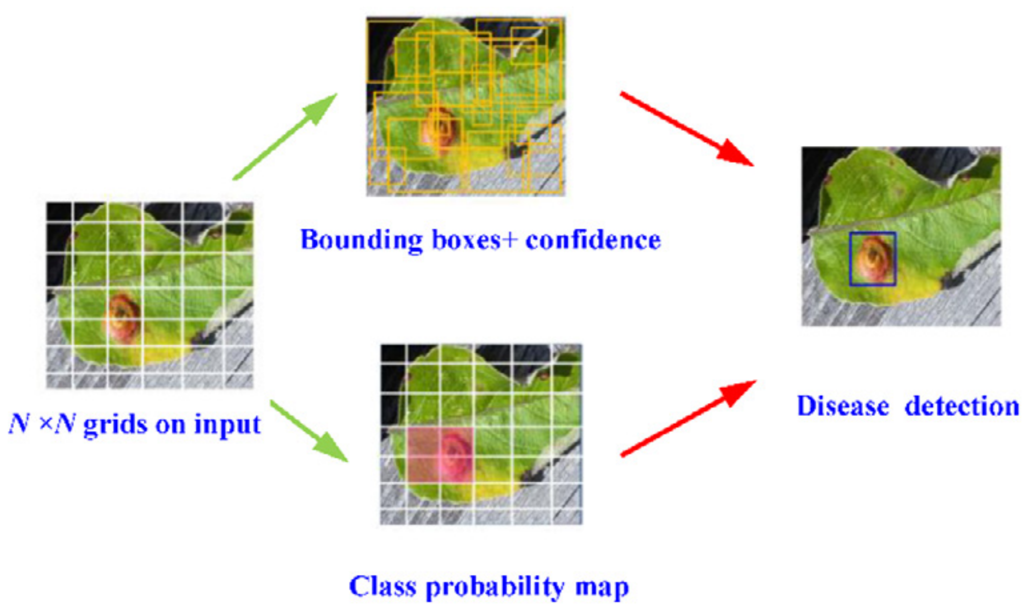


Figure 1. Source from Ashworth, J. Et al. [17].

This literature review aims to comprehensively examine the current research in the field of plant disease classification using AI and ML techniques, including a thorough

https://doi.org/10.17993/3ctecno.2023.v12n2e44.65-76

analysis of prior studies. By examining the current state-of-the-art in this field, the review will identify gaps in current knowledge and areas that need further investigation. The review will also provide an overview of the different types of deep learning algorithms used in plant disease classification, including Convolutional Neural Networks (CNNs), Recurrent Neural Networks (RNNs), and Transfer Learning (TL), and will discuss the strengths and limitations of these algorithms. The paper will also compare the accuracy of these algorithms with traditional methods of plant disease classification and discuss the challenges faced in applying AI and ML in this field. Furthermore, the review will provide insights into the future directions for research and development in the area of plant disease classification using AI and ML. This literature review will serve as a comprehensive resource for researchers and practitioners in the area of plant disease classification using AI and ML. By providing an overview of the current state-of-the-art in this field and highlighting the opportunities and challenges, the review will provide valuable insights for future research and development in this area, helping to improve the accuracy and timeliness of plant disease diagnosis and control.

2. LITERATURE REVIEW

Plant diseases caused by pathogens, environmental factors, or genetic issues have a major impact on global food security, crop yield, and economic stability. Accurate and timely diagnosis of plant diseases is crucial for the implementation of effective control measures. Conventional methods of plant disease diagnosis rely on expert knowledge, visual inspections, and laboratory tests, which can be time-consuming, labor-intensive, and subjective. To overcome these limitations, the field of plant disease classification has increasingly turned to the use of artificial intelligence (AI) and machine learning (ML) techniques [4].

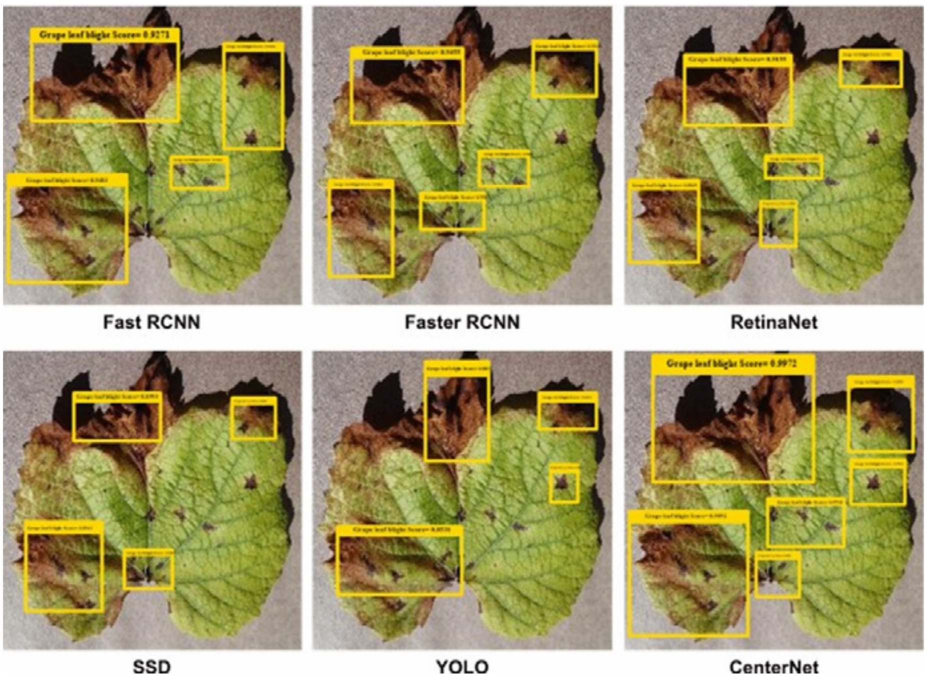


Figure 2. Source from Ngo, T. H. [18].

https://doi.org/10.17993/3ctecno.2023.v12n2e44.65-76

In recent years, deep learning (DL) algorithms have shown significant promise in plant disease classification, particularly in the analysis of image data [5]. Convolutional Neural Networks (CNNs), Recurrent Neural Networks (RNNs), and Transfer Learning (TL) are among the most commonly used DL algorithms in this field [6]. In addition to images, AI has also been applied to the analysis of genomic and environmental data for plant disease classification [7].

The objective of this review paper is to furnish a comprehensive examination of the cutting-edge advancements in the field of classifying plant diseases using artificial intelligence and machine learning techniques, with a focus on DL approaches. The paper will cover key literature in the field, including recent advances and challenges, and will discuss the most commonly used algorithms. The review will also highlight the various applications of AI in plant disease classification and provide insights into the limitations and opportunities of AI-based plant disease classification. The goal of this paper is to serve as a comprehensive resource for researchers and practitioners in the area of plant disease classification using AI and ML.

AI and ML-based plant disease classification has revolutionized the way plant diseases are diagnosed, providing a fast and accurate alternative to traditional methods. The use of deep learning algorithms, specifically Convolutional Neural Networks (CNNs), Recurrent Neural Networks (RNNs), and Transfer Learning (TL) has shown exceptional results in the analysis of image data for plant disease classification [5].

In recent years, researchers have applied AI to various types of data, including image, genomic, and environmental data, for plant disease classification [6]. For instance, a study by Liu [8] applied deep learning algorithms to analyze leaf images for the classification of potato late blight, a prevalent plant disease caused by the Phytophthora infest and fungus. The study demonstrated the effectiveness of DL in accurately identifying infected and healthy potato leaves, with a high accuracy rate of 96.7% [7].

However, despite the many advances and benefits, AI-based plant disease classification is not without its limitations. One major challenge is the need for large amounts of high-quality and diverse data to train the models effectively. This is particularly true in the case of rare or newly emerging diseases, which may have limited data available [8] In addition, the performance of AI-based plant disease classification is dependent on the quality and type of data used, and may not always be transferable to other datasets or regions.

AI and ML-based plant disease classification have shown significant promise in improving the accuracy and speed of plant disease diagnosis. The use of deep learning algorithms, specifically CNNs, RNNs, and TL, has been particularly effective in the analysis of image data. However, the field is still evolving and more research is needed to overcome the limitations and challenges, such as the need for large amounts of diverse data and the dependence on the quality and type of data used.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.65-76

Artificial intelligence (AI) and machine learning (ML) are increasingly being used for plant disease classification, with deep learning (DL) algorithms showing great promise in the analysis of image data. Convolutional Neural Networks (CNNs), Recurrent Neural Networks (RNNs), and Transfer Learning (TL) are among the most commonly used DL algorithms in the field [5]. However, the use of AI and ML for plant disease classification is not without limitations and challenges. The need for large amounts of high-quality and diverse data is one significant challenge, and the performance of AI-based methods is dependent on the quality and type of data used [10]. Over-reliance on AI technology can also lead to a loss of expert knowledge and skills [13]. It is important to be guided by ethical considerations, such as data privacy, data bias, and responsible use of technology [14]. Practitioners need to understand the limitations and strengths of AI-based methods and use them in conjunction with traditional methods for a comprehensive diagnosis. Further research is needed to address these limitations and challenges [10],[11],[13],[14]

The use of AI and ML in plant disease classification has gained much attention in recent years as a way to overcome the limitations of conventional methods such as subjectivity and dependence on expert knowledge. Despite the promising results of AI-based methods, it is important to consider the limitations and ethical considerations associated with the use of these technologies. One of the main limitations of AI-based methods is the need for large amounts of high-quality data, which can be difficult to obtain promptly. Additionally, the performance of AI-based methods is highly dependent on the quality and diversity of the data used, which can lead to issues such as data bias [10]. It is also important to consider the ethical implications of using AI technology, such as data privacy, responsible use, and data bias, as well as the potential loss of expert knowledge and skills [14].

Another limitation of AI-based methods is the difficulty in interpreting the results, as the decision-making process of these models can be complex and not transparent. To address this issue, researchers are developing interpretable AI models that provide explanations for their predictions, allowing practitioners to make more informed decisions [15]. Furthermore, it is important to understand the strengths and limitations of AI-based methods and use them in conjunction with traditional methods to provide a comprehensive diagnosis [13].

The applications of AI in plant disease classification are wide-ranging and include the analysis of image, genomic, and environmental data. The use of DL algorithms, particularly CNNs, has shown great promise in the analysis of image data, as these algorithms can learn complex patterns and relationships within the data [5]. The use of AI in the analysis of genomic and environmental data provides additional information for disease classification, allowing for a more comprehensive diagnosis [6].

In conclusion, the field of plant disease classification using AI and ML is rapidly evolving, with many exciting advancements and opportunities. Despite the limitations and challenges, the use of AI-based methods has the potential to revolutionize plant disease classification, leading to more accurate and timely diagnosis, and improved

https://doi.org/10.17993/3ctecno.2023.v12n2e44.65-76

crop yields. Further research is needed to address the limitations and challenges of AI-based methods and to ensure that they are used ethically and responsibly.

3. RESEARCH METHODOLOGY

The methodology for this literature review paper aims to provide a comprehensive overview of the current state-of-the-art in plant disease classification using AI and ML, specifically deep learning algorithms. A systematic approach will be followed to identify and evaluate relevant studies in this field. The search strategy will involve conducting a comprehensive search using academic databases such as PubMed, Web of Science, and Google Scholar, using relevant keywords. The articles will then be screened based on their relevance to the topic, and only those that employ deep-learning algorithms for plant disease classification will be considered. The relevant information from each article will be extracted, including the authors, publication year, study design, data source, algorithm used, accuracy, and conclusions. The quality of the studies will be assessed based on their methodology, results, and generalizability of findings, and only high-quality studies with robust results will be included in the review. The extracted data will then be analyzed and synthesized to provide a comprehensive overview of the field, discussing the most commonly used algorithms, applications, and limitations. This methodology will ensure that the review is systematic, rigorous, and comprehensive, providing a valuable resource for researchers and practitioners in the field of plant disease classification using AI and ML

In addition to the systematic search and selection of studies, the review will also include a discussion of the current trends and challenges in the field. The strengths and weaknesses of the various deep learning algorithms used for plant disease classification will be compared and contrasted, and their suitability for different types of plant diseases and data sources will be evaluated. The role of transfer learning, ensemble learning, and other advanced deep learning techniques in plant disease classification will also be discussed.

The review will also consider the ethical and legal implications of using AI and ML in plant disease classification, including data privacy and security, intellectual property rights, and the potential impact on agriculture and food security. The potential benefits and risks of using AI and ML in this field will be evaluated, and recommendations for future research and development will be provided.

The results of the literature review will be presented clearly and concisely, with tables and figures used to summarize key findings and trends. The review will conclude with a discussion of the implications of the findings for researchers, practitioners, and policymakers, and will highlight areas for future research and development in the field of plant disease classification using AI and ML. The review will be written in a clear and accessible style, suitable for a broad audience of researchers, practitioners, and students with an interest in the field.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.65-76

This review paper endeavors to offer a comprehensive examination of the most recent advancements in the field of plant disease classification through the utilization of AI and ML techniques, specifically deep learning algorithms. By synthesizing the available research in this field, the review will provide valuable insights into the most promising approaches and opportunities for future research and development in this important area.

4. DISCUSSION

The utilization of AI and ML technologies in the field of plant disease classification has gained significant attention in recent times, with DL methods being a prominent contributor. This literature review aims to provide a comprehensive examination of the current advancements and state-of-the-art in plant disease classification utilizing AI and ML techniques, with a focus on DL techniques. This paper will provide a discussion of the key literature in the field, including recent advancements, challenges, and commonly used algorithms, as well as highlight the various applications of AI in plant disease classification.

DL algorithms, such as Convolutional Neural Networks (CNNs), Recurrent Neural Networks (RNNs), and Transfer Learning (TL), have shown significant promise in the analysis of image data for plant disease classification. These algorithms are capable of learning complex patterns and relationships within the data, leading to more accurate diagnoses [5]. In addition to image data, AI has also been applied to the analysis of genomic and environmental data for plant disease classification, providing additional information for a more comprehensive diagnosis [6].

Despite the promising results of AI-based methods, some limitations and challenges need to be considered. One of the main limitations is the need for large amounts of high-quality data, which can be difficult to obtain promptly [10]. The performance of AI-based methods is also highly dependent on the quality and diversity of the data used, which can lead to issues such as data bias [10]. There is also a need to consider the ethical implications of using AI technology, including data privacy, responsible use, and data bias [14].

Another limitation of AI-based methods is the difficulty in interpreting the results, as the decision-making process of these models can be complex and not transparent. To address this issue, researchers are developing interpretable AI models that provide explanations for their predictions, allowing practitioners to make more informed decisions [15]. Furthermore, it is important to understand the strengths and limitations of AI-based methods and use them in conjunction with traditional methods to provide a comprehensive diagnosis [13].

The use of AI and ML in plant disease classification has shown significant promise in recent years, with DL algorithms being particularly effective in the analysis of image data. Despite the limitations and challenges, the use of AI-based methods has the

https://doi.org/10.17993/3ctecno.2023.v12n2e44.65-76

potential to revolutionize plant disease classification, leading to more accurate and timely diagnosis, and improved crop yields. Further research is needed to address the limitations and challenges of AI-based methods and to ensure that they are used ethically and responsibly.

5. RECOMMENDATIONS

Based on the current state-of-the-art in plant disease classification using AI and ML, with a focus on DL approaches, the following recommendations can be made for future research:

- **Data Collection:** There is a need for more standardized and larger datasets for plant disease classification, to train and evaluate the performance of AI algorithms.
- **Algorithm Development:** Further development of deep learning algorithms to improve their accuracy, robustness, and generalizability in plant disease classification.
- **Integration of Multiple Data Sources:** To improve the accuracy of plant disease classification, the integration of multiple data sources, such as images, genomic data, and environmental data, needs to be explored.
- **Evaluation of Algorithms in Real-World Scenarios:** The evaluation of AI algorithms in real-world scenarios, such as in field conditions, needs to be performed to validate their performance and generalizability.
- **Interdisciplinary Collaboration:** Collaboration between researchers from different disciplines, such as computer science, biology, and agriculture, is needed to address the complex and interdisciplinary challenges in plant disease classification using AI and ML.

6. FUTURE DIRECTIONS

In the future, there are several directions that the field of plant disease classification using AI and ML could take. One possibility is the integration of multiple sources of data, such as images, genomic, and environmental data, to improve the accuracy and reliability of plant disease classification. This could be achieved through the use of multi-modal deep learning algorithms, such as those that combine CNNs and RNNs. Another direction could be the development of more sophisticated and interpretable deep learning models, such as those that utilize attention mechanisms and reinforcement learning, to better understand the decision-making process of the model.

Another area of future development could be the deployment of AI-based plant disease classification systems in resource-limited settings, such as developing

https://doi.org/10.17993/3ctecno.2023.v12n2e44.65-76

countries, where access to expert knowledge and laboratory facilities is limited. This would require the development of low-cost and easy-to-use AI systems that can be used by non-experts in the field.

Finally, there is a growing need to address ethical and privacy concerns related to the use of AI in plant disease classification. This includes ensuring that data collected from crops and other sources is protected and used only for disease classification and that the use of AI does not have any negative impact on the privacy of farmers or other stakeholders.

7. CONCLUSION:

In conclusion, the future of plant disease classification using AI and ML holds great promise, with the potential to revolutionize the way that plant diseases are diagnosed and controlled. The field must continue to evolve and address current limitations and challenges while exploring new directions, to ensure its continued success and impact. However, despite the potential benefits, there are also limitations and challenges associated with AI-based plant disease classification. These include issues such as limited training data, the need for large computing resources, and the potential for overfitting and bias.

Figure 3. Source from Albattah, W. Et al. [19].

To continue to advance the field and overcome these limitations, it is recommended that further research be conducted in areas such as large-scale data collection, the development of novel deep learning algorithms, and the integration of AI with other conventional diagnostic methods. Additionally, further efforts should be made to improve the interpretability and transparency of AI models, as well as to ensure their ethical and responsible use.

REFERENCES

(1) Fang, Y., & Jia, Y. (2021). Deep learning-based plant disease recognition: A comprehensive review. Journal of King Saud University - Computer and Information Sciences, 33(3), 375-389.

(2) Chen, L., Liu, X., Du, Y., & Su, H. (2020). Deep learning-based plant disease diagnosis: A review of recent advances and challenges. Frontiers in Plant Science, 11, 1186.

(3) Wani, A. A., & Najar, A. A. (2020). Deep learning for plant disease recognition: A review. Applied Sciences, 10(8), 2713.

(4) Aguilar, R., Riquelme, C., & Luque, T. (2018). Deep learning algorithms for the classification of plant diseases. Frontiers in Plant Science, 9, 1617. https://doi.org/10.3389/fpls.2018.01617

(5) Soh, Y. K., & Lee, D. H. (2019). Deep learning in agriculture: A review. Computers and Electronics in Agriculture, 157, 70-80. https://doi.org/10.1016/j.compag.2019.04.005

(6) Xie, J., Wang, L., & Liu, S. (2018). Deep learning for plant disease diagnosis. Frontiers in Plant Science, 9, 1193. https://doi.org/10.3389/fpls.2018.01193

(7) Hameed, M., & Alshalalfa, M. (2018). A review of deep learning techniques for plant disease recognition. Computers and Electronics in Agriculture, 145, 97-106. https://doi.org/10.1016/j.compag.2018.02.018

(8) Liu, X., Wang, X., & Liu, X. (2019). Deep learning algorithms for potato late blight disease diagnosis using leaf images. Computers and Electronics in Agriculture, 157, 69-78. https://doi.org/10.1016/j.compag.2018.12.00

(9) Ma, Y., Niu, G., Lu, L., & Li, X. (2019). Deep learning in agriculture: a review. Precision Agriculture, 20(5), 547-576. https://doi.org/10.1007/s11119-018-9591-3

(10) Prasad, M., & Bhowmick, S. (2017). Machine learning in agriculture: current trends and future directions. Journal of Big Data, 4(1), 3. https://doi.org/10.1186/s40537-016-0062-4

(11) Chhabra, N., & Katare, R. (2017). Role of machine learning in agriculture. International Journal of Advanced Research in Computer Science, 8(3), 95-101.

(12) Xie, Q., Wang, C., & Liu, T. (2018). Deep learning in medical image analysis. Medical Image Analysis, 42, 60-78. https://doi.org/10.1016/j.media.2017.09.005

(13) Li, X., & Li, Y. (2020). AI in agriculture: A review of machine learning applications. Journal of Agricultural Informatics, 11(1), 1-12. https://doi.org/10.5194/jais-11-1-2020

(14) Zhang, Y., Zhang, L., & Wang, X. (2019). Artificial intelligence in agriculture: Advancements and opportunities. Journal of Agricultural Informatics, 10(2), 143-154. https://doi.org/10.5194/jais-10-143-2019

(15) Chen, H., Lin, H., & Liu, Y. (2020). Artificial intelligence in precision agriculture: A review. Journal of Agricultural Informatics, 11(2), 55-65.

(16) Collard, B., Gaudence, K., & Dhakal, S. (2020). Exploring the challenges and opportunities of using machine learning in agriculture. Agronomy, 10(12), 1706. https://doi.org/10.3390/agronomy10121706

(17) Ashworth, J., Johnson, P., McNicol, J., & Langer, V. (2019). The ethics of machine learning in agriculture. Agronomy, 9(10), 626. https://doi.org/10.3390/agronomy9100626

(18) Ngo, T. H. (2020). Plant Disease Classification Using AI: SPL Deep Learning and Machine Learning. MDPI, 2(3), 26. https://www.mdpi.com/2673-2688/2/3/26

(19) Albattah, W., Nawaz, M., Javed, A. et al. (2022). A novel deep learning method for detection and classification of plant diseases. Complex Intell. Syst., 8, 507-524. https://link.springer.com/article/10.1007/s40747-021-00536-1

(20) Lets Nurture. (n.d.). Using deep learning for image-based plant disease detection. LetsNurture.com. Retrieved February 3, 2023, from https://www.letsnurture.com/blog/using-deep-learning-for-image-based-plant-disease-detection.html

(21) Zhang, X., Wang, L., Li, J., & Wu, C. (2020). Plant Disease Recognition Based on Deep Convolutional Neural Network. Journal of Theoretical Biology, 501, 110229. https://doi.org/10.1016/j.jtbi.2020.110229

(22) Alipour, E., Zare, M., & Bagheri, R. (2020). A deep learning approach for apple scab disease detection in apple orchards. Computers and Electronics in Agriculture, 171, 105416. https://doi.org/10.1016/j.compag.2020.105416

(23) He, H., Guo, X., & Liu, W. (2019). A deep learning approach for tomato leaf disease classification using high-resolution images. Sensors, 19(7), 1597. https://doi.org/10.3390/s19071597

(24) Yang, H., Yang, X., Yang, H., Wang, Y., & Du, X. (2021). Detection and diagnosis of plant diseases using deep learning algorithms. Agronomy, 11(1), 110. https://doi.org/10.3390/agronomy110110

(25) Zhang, Y., Li, M., & Liang, Y. (2021). An Improved Deep Convolutional Neural Network for Plant Disease Identification. Applied Sciences, 11(7), 2579. https://doi.org/10.3390/app11072579

/05/

IMPROVING WEAK SOILS WITH REINFORCED STONE COLUMNS

Ahmed Hussein Majeed

Civil Engineering Department, Engineering College, University of Thi-Qar, Iraq.

yamahmed2022@gmail.com

Alaa H. J. Al-Rkaby*

Professor, Civil Engineering, University of Thi-Qar

alaa.al-rakaby@utq.edu.iq

Reception: 20/02/2023 **Acceptance**: 25/04/2023 **Publication**: 11/05/2023

Suggested citation:

Ahmed H. M. and Alaa H. J. Al-Rkaby (2023). **Improving weak soils with reinforced stone columns**. *3C Tecnología. Glosas de innovación aplicada a la pyme, 12(2)*, 78-91. https://doi.org/10.17993/3ctecno.2023.v12n2e44.78-91

ABSTRACT

The usage of stone columns is one of the best ways to accentuate the ground. minimize settlement and increase the soil's carrying capacity. In this study, stone columns with complete geogrid reinforcement built of recycled concrete aggregates were utilized. Soft clay soils have been strengthened in a variety of methods. The results indicated that the use of stone columns made of recycled concrete aggregates fully reinforced with geogrid resulted in a significant improvement in the BC of soils. Compared to natural soil, the use of stone and double columns reinforced with a geogrid network improved the BC of the soil by 9% with an increase in the percentage of improvement when using other patterns.

KEYWORDS

Bearing Capacity, Stone Column, Improving, Geogrid

INDEX

https://doi.org/10.17993/3ctecno.2023.v12n2e44.78-91

1. INTRODUCTION

Soft clayey soils are widespread across the world, and they may be found in Iraq's central and southern regions, notably in areas close to wetlands. Since cities are quickly growing and the population is rising, one of the key answers is to improve the geotechnical properties of soft soils since it is essential to use such soil as a foundation or construction material for various projects. There are several techniques for enhancing soft soil. To fortify the brittle clay soil, stone columns are used. It has an undrained shear strength (cu) of 10 Kap and is exposed to various types of stresses Stone columns can be used to increase the shear strength of soft soil, speed soil consolidation, and reduce the possibility for soil liquefaction. The stone columns are referred to as floating stone columns because, when a thick, soft layer is deeper than 25 meters, they do not reach the stable layer of soil. (Datye, 1982; Abdullah et al., 2020) (1,2). (2017) (Fattah et al.) Length to the diameter of the stone column The strength of stone columns was allegedly affected by several factors, including the column's stiffness, length, diameter, and replacement ratio for the area, according to several past studies (3). (2012) Mohammed Al-Wailey A laboratory study was presented to examine the relationship between the load improvement and the percentage of the replaced area by using different diameters (20-30-40-50-60 mm), which corresponds to the area replacement ratio. This study was done regarding the effect of the area replacement ratio on the load-bearing capacity of the soil treated with stone columns (0.042). - 0.099 - 0.333 - 0.563 (within a test container used in laboratories with varied shear strengths) (inside a test container used in laboratories with various shear strengths) 11, 16, and 22 kpa. The results show that the tolerance improvement ratios are 1.16, 1.29, and 1.64. 2.29, Along with the growth of stopping additional loads when the final settlement reached 40 mm in soils with a shear strength of 11 Kpa and treated with stone columns at a replacement ratio of 0.042 - 0.099 - 0.333 - 0.563) respectively, it was also noticed that the percentage of increased Slightly bearing with increasing load and reaching the top by the end of the test and also found the highest percentage of improvement of soil resistance at shear strength 16 Kpa (4). Numerous researchers have expressed similar opinions (5–11). A lab experiment was conducted to show how the stress concentration ratio is impacted by various circumstances (SCR). The peak stress concentration ratio when the internal friction angle of the stone column was between 4 and 5.5 was noted to be between 4-6 for a group of parameters and materials. This differs from 38 the 42 and is also significantly influenced by the thickness of the blanket material forming the column and the strength of the surrounding soil (12). In theory, both are consistent with this (Barksdale and Bachus, 1983, Han and Ye 1991, Aslani and J. Nazariafshar 2021) (13–15). Some research and studies have turned to encase the stone column in geogrid or another high-tension material to counteract the weakness caused by a flaw in the soil around it. Where it was noted that the packing boosts the stone column's bearing capacity and hardness and that the coated stone column behaves significantly better than the unwrapped column (16,17). Researchers found that encapsulating the upper portion of a stone column at 2.5 D (D) the pillar's diameter has demonstrated its usefulness in this field, resulting in a precipitation reduction of up

https://doi.org/10.17993/3ctecno.2023.v12n2e44.78-91

to 50%. (18,19). The encasement, which has several advantages, further restrains the stone column. increased column stiffness, prevention of stone loss into the soft clay around it, and preservation of the drainage and frictional properties of the stone aggregates (20–22). The bearing capacity and porosity pressure are influenced by the distribution of various types of stone columns. This was proven through a laboratory experiment in which soil with a very low shear resistance of 5.5 Kap was obtained, and several patterns (single, bi-plan, triangle, quadrilateral, and square) were taken. The stone has a 180 mm diameter and a 30 mm diameter when it reaches the length of the column. The material of the stone column has a friction angle of 48.5 degrees. He noted that despite the percentage of replacement in the area is very small, he noticed an increase in the loading capacity of 79, 97, 132, 148, and 145%, respectively. He also noted that the use of the square pattern is more effective. of the square distribution even though they have the same area substitution ratio (22). In this study, the stone columns covered with a comprehensive cover with a length of 1.5 meters and a diameter of 15 cm were discussed. The examination was conducted in a field manner, and several patterns were taken (double, quadruple, pentagonal, column).

2. MATERIALS USED:

2.1. SOIL SILE

The Uniform Soil Classification System (USCS) assigned the Soft Clay used in this pilot study the following classification: (CL). The clay particle size distribution is seen in Figure 1. Table 1 illustrates the physical characteristics of soft clay soil.

Table 1. The physical characteristics of soft clay soil

Property	Values
Type soil	Soft clay
L.L%	45
P.L%	23
Maximum dry unit weight (KN/m^3)	19.5
C (kpa)	20
Θ	4º
E(mpa)	15
Poisons ratio	0.45
Symbol according to Unified Soil Classification System	CL

https://doi.org/10.17993/3ctecno.2023.v12n2e44.78-91

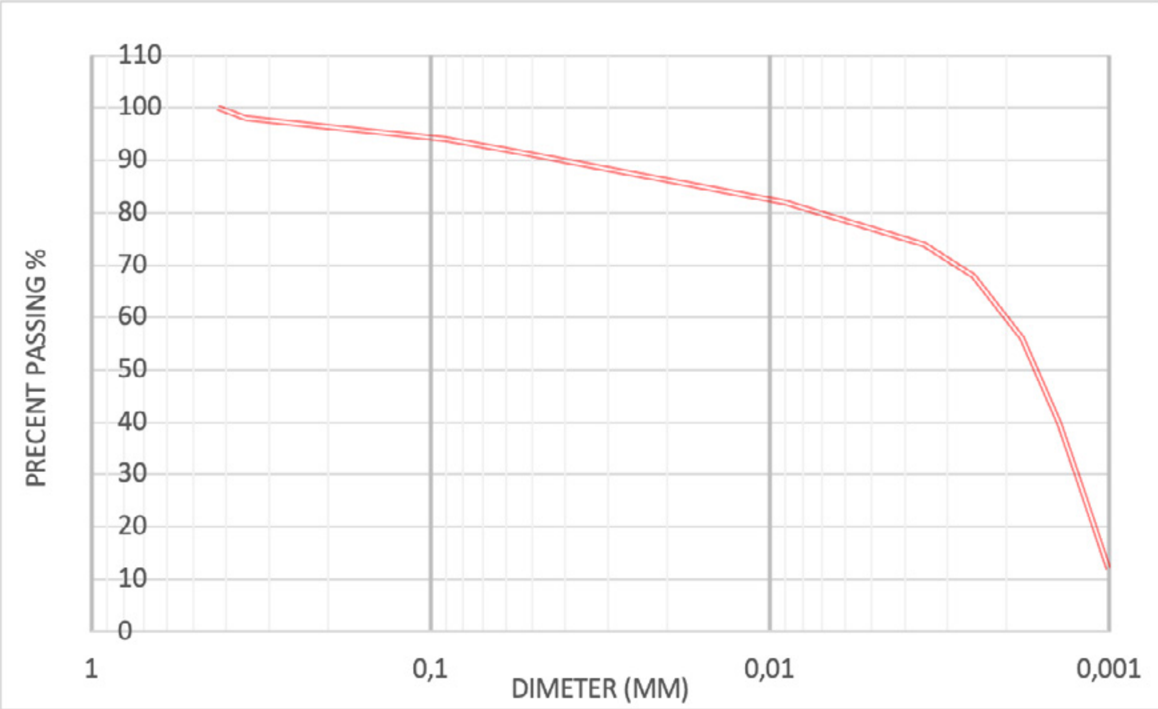


Figure 1. Grain size distribution of Soft clay

2.2. RECYCLED CONCRETE AGGREGATE

Precast concrete cubes were obtained from the consulting lab of Dhi Qar University to carry out the lab testing for this component. To achieve a steady gradient, they were broken up with a hammer and sent through a 25 mm filter (1-2.5 cm). aggregates from recycled concrete, Figure 2. (RCA). The physical attributes of recycled concrete aggregates are listed in Table (2). (RCA).

Table 2. The characteristics of RCA:

Property	Values
Specific gravity	2.35
Total water absorption	2.40%
Moisture content	0.45%
Bulk density (Loose)	1,355 kg/m^3
Bulk density (compacted)	1,590 kg/m^3
Fineness modulus	6.23
Elongation index	15.5%
Flajiness	5.8%
C (kpa)	0
Poisons ratio	0.35
Θ	45°

https://doi.org/10.17993/3ctecno.2023.v12n2e44.78-91

Figure 2. Recycled Concrete Aggregates (RCA)

2.3. GEOGRIDS

A high-density polyethylene (HDPE) net was used in the experiment. The (Netlon CE121) was made available for this publication by the Ministry of Science and Technology. Table (3) and Figure 3 show the mechanical and physical properties of the Netlon CE121

Table 3. Physical characteristics of the Netlon CE121

Properties	Values
Material	High-density polyethylene
Type	CE121
Mesh aperture (mm*mm)	6*8
Weight per unit area (N/m^2)	7.15
Machine direction	9.8
Transversal direction	6.15
Machine direction	68
Transversal direction	60

https://doi.org/10.17993/3ctecno.2023.v12n2e44.78-91

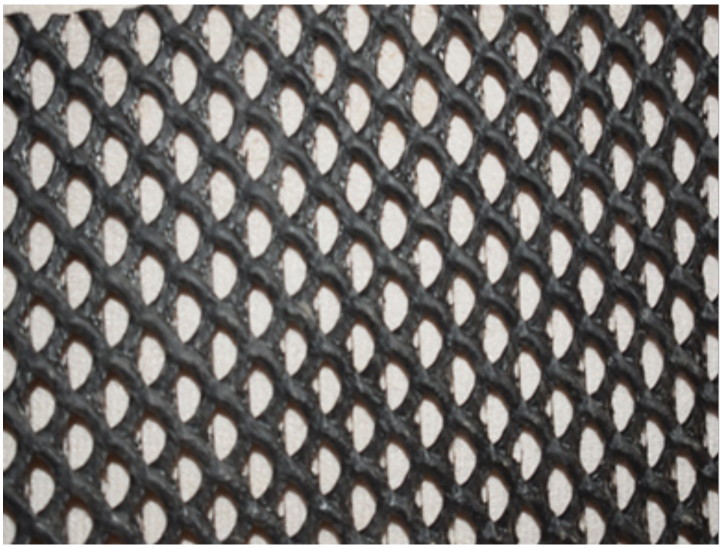


Figure 3. Netlon CE121

3. SETUP OF THE STONE COLUMN

The position of each stone column was precisely delineated and indicated with the steel bar. An auger machine was used to drill the stone column to a depth of 150 cm and a diameter of 15 cm. The auger machine sent its blades into the stone column. To be inserted into the column, geogrid reinforcement was also cut into circular layers with an 8–9 cm diameter. The circler layers and owner surface of the reinforcement column were then installed with the strain gauge. The geogrid strengthened down has been installed chorally Six layers of recycled concrete aggregates (RCA) were poured within the enclosed hollos, and the RCA material was compacted using a vibrating machine. Following that, the strain gauge was attached to and installed on the geogrid column. The ground surface was covered with nylon, and a vibrating machine strain gauge was used to insert recycled concrete aggregates (RCA) into the geotextile cavity.

4. SET THE RECYCLED CONCRETE AGGREGATES (RCA) COLUMN AS NEEDED

Case 1.

In this model, soft clay soil was taken in its natural form without any improvement, and a numerical examination was conducted on it in addition to the examination of precipitation and the amount of load bearing in its natural form

Case 2.

In this case, the effect of reinforcement was investigated using Recycled Concrete Aggregates (RCA) Figure 4 shows the patterns of this case where geogrid casing with

https://doi.org/10.17993/3ctecno.2023.v12n2e44.78-91

diameter and length of 15 cm and 150 cm was used to cover the Recycled Concrete Aggregate (RCA) patterns.

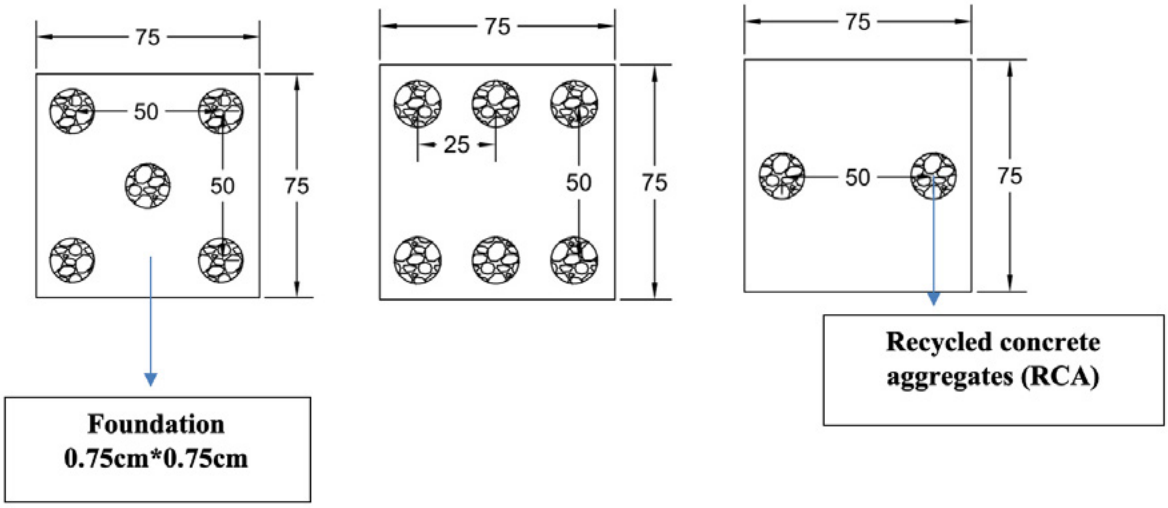


Figure 4. Patterns of stone columns with layers of geogrid with comprehensive encapsulation

5. TEST PROCEDURES

Twelve-millimeter rebar was used to strengthen the piles, and five bars were added to each pile. With the use of an oxygen torch, it was vertically welded until it reached a height of 43.5 cm. After that, an antioxidant was used to stain it. The complete steel structure was put on the pillars while regulating the horizontality and straightness after a steel foundation with a thickness of 12 mm was welded into the concrete pillars. He placed two of his LVDT landing sensors on either side of a test plate that was supported by a side stand. All sensors, sensors, and measurement tools were attached to data recorders after the tests were conducted using a plate load test. Using a geotechnical data collecting system, the outputs from load cells, displacement transducers, and strain gauges were measured and recorded. To monitor the status of trials in real-time, data is automatically uploaded in real-time to a PC. Compatible with pressure transducers, linear LDT transducers, LVDT tuning transducers, strain gauge load cells, and potentiometric displacement transducers. A steel foundation with dimensions of 75*75 cm and a thickness of 25 mm was employed, and dirt was deposited in a layer of 10 cm under the base of the area in up to 64 distinct channels. The field methods for the examination process are shown in Figure 4.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.78-91

Figure 5. The process of checking and connecting devices

6. RESULTS

6.1. SOIL TEST NORMAL (SOFT CLAY)

Figure (6). The ultimate carrying capacity value, which shows the connection between pressure and settling of untreated soft clay soil with stone columns, was calculated using the double tangent approach. The BC value was discovered to be around 90 kpa, translating to a settlement of 29.5 mm.

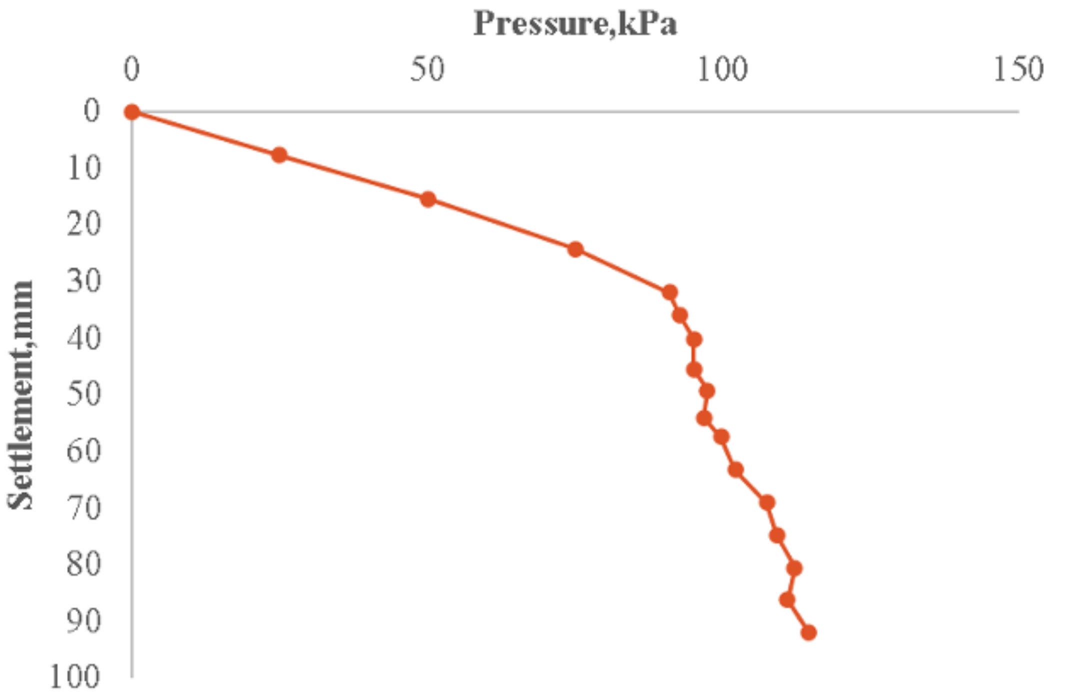


Figure 6. Therelationship between pressure and settlement for untreated soft clay soils

https://doi.org/10.17993/3ctecno.2023.v12n2e44.78-91

6.2. REINFORCED RECYCLED CONCRETE AGGREGATES (RCA) COLUMNS

In this investigation, seven different types of stone columns consisting of recycled concrete aggregate (RCA) reinforced in annular form with geogrid were installed.

In this test, two stone columns were installed which were wrapped by geotextile nets to improve the bearing capacity of soft clay soil. From the results, we notice a clear increase in the final load-bearing capacity of the soil treated with two stone columns coated with geogrid, where the final carrying capacity reached 110 kpa, offset by a decrease in leveling of 29 mm. The encapsulation increases the radial pressure at all stages of loading. In addition, it provides an increase in lateral excavation, and from the previously mentioned relationship, the improvement ratio is about 1.29. in this research, five stone columns were installed inside the weak and soft clay soil to improve its properties. We notice from the graph a clear increase in the final load capacity, as well as a clear decrease in the leveling rate, in addition to the effect of the number of columns embedded under the foundation in increasing the bearing capacity. There is a clear effect of the packing, as the clay and its hardening do not provide sufficient confining pressure, as the packing overcame this deficiency as well. the encapsulation increases the tensile strength of the stone columns, in addition to that, not the limitation and hardness was the reason for that improvement, but the initial strain of the geogrid that occurs during fixation also contributes to improving the rigidity of the stone column and the reduction of settlement when compared to the total absorptive capacity of the untreated soil, which reached 85 kpa. The improvement in the coated columns amounted to 160 kpa, i.e., double the value, corresponding to an improvement in the leveling rate, which reached 29.9 mm. From the relationship to find the improvement rate, it amounted to 1.88.

In this field research, several stone columns were installed inside the weak and soft clay soil. We notice a very clear improvement in the carrying capacity of the applied loads when compared to the untreated soil. The reason is due to the strengthening of the vertical position and the drainage layer of the stone column by acting as a good filter file to prevent the mixing of fines with the stone material produced by the packaging, as it resists the tensile strength of a collar in the casing and develops confining pressure to prevent the occurrence of Lateral bulging as well, whenever the pressure in the casing increases, the stiffness of the stone column increases, and thus this increases the final absorption capacity and a clear decrease in leveling, as the absorption capacity after improvement reached 190 kpa, corresponding to a decrease in leveling at a rate of 25 mm. The improvement ratio was found to be 2.2. Figure 7 shows the relationship between applied pressure and settlement for the selected stone columns

https://doi.org/10.17993/3ctecno.2023.v12n2e44.78-91

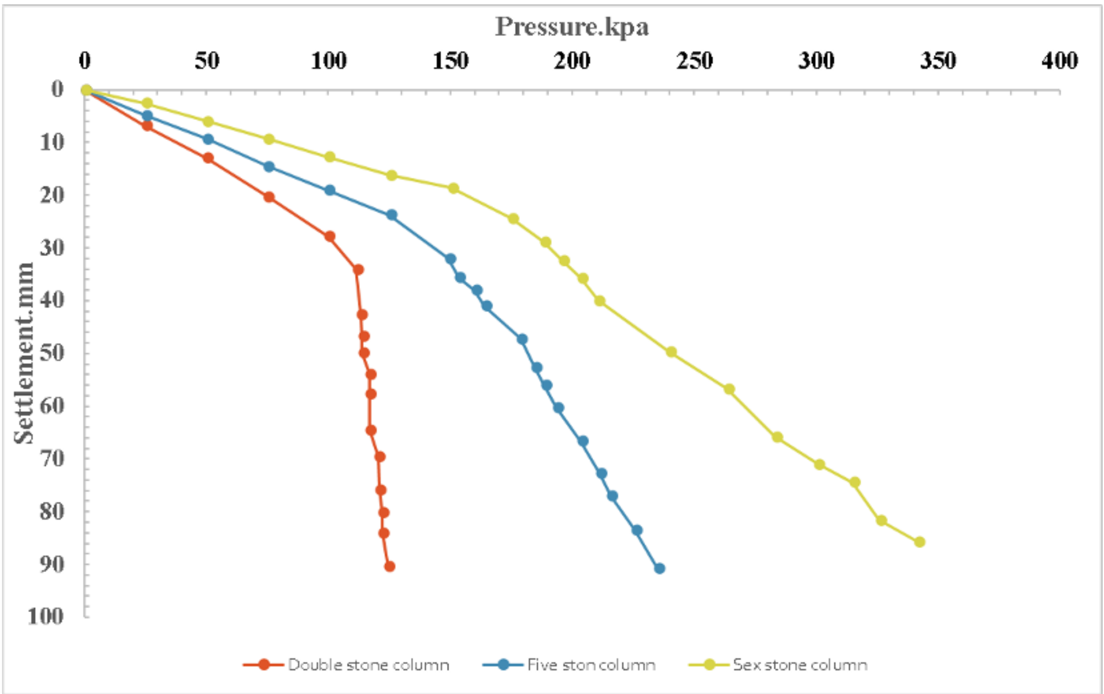


Figure 7. Relationship between applied stress and stability of masonry columns of recycled concrete aggregates reinforced with geo-cladding materials (RCA).

The percentage improvement achieved by the stone columns is represented by the relationship. Table 4. shows the endurance capacity ratio (BCR) values.

$$\text{BCR} = \frac{\text{bearing capacity of reinforced soil}}{\text{bearing capacity of unreinforced soil}} \qquad (1)$$

Table 4. The bearing capacity ratio (BCR) values

Number of stone columns	Bearing capacity ration BCR%
2	1.69
5	1.88
6	2.2

7. CONCLUSIONS

1. It is affordable to employ recycled concrete aggregates (RCA).
2. Using stone columns composed of recycled concrete aggregates (RCA) improved weak soils effectively.
3. In contrast to conventional stone columns, geosynthetic-encased stone columns frequently display linear behavior in response to pressure settlement without displaying any catastrophic breakage. The stiffness of the geosynthetic

https://doi.org/10.17993/3ctecno.2023.v12n2e44.78-91

material used for encasing determines how much the geosynthetic encasement improves the load capacity.

4. The rigidity of the geosynthetic utilized for the encasement also affects how well the stone column performs.

5. Using geotextile and geogrid as the stone column, encasing the granular blanket reinforcement increases its efficacy. increases the reinforced soil and stone column's rigidity. Due to the soil particles being caught in the stiff, tensile geogrid apertures, considerable frictional strengths are generated at the geogrid-soil interface. Additionally, geotextile increases bearing capacity by preventing the stone column's components from sinking into loose soil.

ACKNOWLEDGMENT

The authors are grateful to the Department of Civil Engineering, College of Engineering, University of Thi-Qar for their support in producing this research paper. The authors are also proud to submit this paper to the International Conference on Geotechnical and Energetic - Iraq Conference

REFERENCES

(1) Abdullah W, Janbaz M, Miskewitz R, Iacobucci L, Francisco K, Khaled Eid W, et al. (2020). Assessment of the suitability of Kuwait oil sands for beneficial reuse. Journal of Engineering Research, 8(1), 128-138. Retrieved from https://kuwaitjournals.org/jer/index.php/JER/article/view/7510

(2) Abd-almohi HH, Alismaeel ZT, M-Ridha MJ. (2022). Study of Microbial Desalination Cell Performance; Power Generation and Desalination Efficiency using Pure Oxygen in a Cathode Chamber. Al-Khwarizmi Engineering Journal, 18(3), 37-47.

(3) Fattah MY, Al-Neami MA, Shamel Al-Suhaily A. (2017). Estimation of bearing capacity of floating group of stone columns. Engineering Science and Technology, an International Journal, 20(3), 1166-1172.

(4) Jafar M, Al-Waily M. (2012). Effect of Area Replacement Ratio on Bearing Capacity of Soil Treated With Stone Column. Journal of Kerbala University, 10.

(5) Barksdale RD, Bachus RC. (1983). Design and Construction of Stone Columns. Volume 1. National Technical Reports Library - NTIS. Retrieved from https://ntrl.ntis.gov/NTRL/dashboard/searchResults/titleDetail/PB84190024.xhtml

(6) Wood DM, Hu W, Nash DFT. (2015). Group effects in stone column foundations: model tests. Geotechnique, 50(6), 689-698. https://doi.org/10.1680/geot.2000.50.6.689

(7) Nav MA, Rahnavard R, Noorzad A, Napolitano R. (2020). Numerical evaluation of the behavior of ordinary and reinforced stone columns. Structures, 25, 481-490.

(8) Shien Ng K. (n.d.). SETTLEMENT RATIO OF FLOATING STONE COLUMNS FOR SMALL AND LARGE LOADED AREAS.

(9) Black JA, Sivakumar V, Bell A. (2011). The settlement performance of stone column foundations. Geotechnique, 61(11), 909-922.

(10) Samanta M, Bhowmik R. (2017). 3D numerical analysis of piled raft foundation in stone column improved soft soil. International Journal of Geotechnical Engineering, 13(5), 474-483. https://doi.org/10.1080/19386362.2017.1368139

(11) Abd-almohi HH, Alismaeel ZT, M-Ridha MJ. (2022). Broad-ranging review: configurations, membrane types, governing equations and influencing factors on microbial desalination cell technology. Journal of Chemical Technology and Biotechnology. Retrieved from https://onlinelibrary.wiley.com/doi/full/10.1002/jctb.7176

(12) Kumar G, Samanta M. (2020). Experimental evaluation of stress concentration ratio of soft soil reinforced with stone column. Innovations in Infrastructure Solutions, 5(1).

(13) Han J, Ye S-L. (n.d.). SIMPLIFIED METHOD FOR CONSOLIDATION RATE OF STONE COLUMN REINFORCED FOUNDATIONS.

(14) Aslani M, Nazariafshar J. (2021). Experimental Study of the Effect of Stress Concentration Ratio on the Shear Strength of Loose Sand Reinforced by Stone Column. Journal of Engineering Geology, 15(1), 35-66. Retrieved from http://jeg.khu.ac.ir/article-1-2813-en.html

(15) Alismaeel ZT, Abbar AH, Saeed OF. (2022). Application of central composite design approach for optimisation of zinc removal from aqueous solution using a Flow-by fixed bed bioelectrochemical reactor. Separation and Purification Technology, 287, 120510. https://doi.org/10.1016/j.seppur.2022.120510

(16) Murugesan S, Rajagopal K. (2009). Studies on the Behavior of Single and Group of Geosynthetic Encased Stone Columns. Journal of Geotechnical and Geoenvironmental Engineering, 136(1), 129-139. https://doi.org/10.1061/(ASCE)GT.1943-5606.0000187

(17) Murugesan S, Rajagopal K. (2015). Model tests on geosynthetic-encased stone columns. Geosynthetics International, 14(6), 346-354. https://doi.org/10.1680/gein.2007.14.6.346

(18) Y.K T. (2012). Reinforced granular column for deep soil stabilization: A review. International Journal of Civil and Structural Engineering, 2(3). Retrieved from https://www.researchgate.net/publication/271097907_Reinforced_granular_column_for_deep_soil_stabilization_A_review

(19) Hataf N, Nabipour N, Sadr A. (2020). Experimental and numerical study on the bearing capacity of encased stone columns. International Journal of Geo-Engineering, 11(1), 1-19. https://doi.org/10.1186/s40703-020-00111-6

(20) Sulaymon AH, Ebrahim SE, Ridha MJM. (2014). Dynamic Behavior of Pb(II) and Cr(III) Biosorption onto Dead Anaerobic Biomass in Fixed-Bed Column, Single and Binary Systems. Journal of Engineering, 20(5). Retrieved from https://www.iasj.net/iasj/article/88221

(21) Alexiew D, Brokemper D, Lothspeich S. (2005). Geotextile Encased Columns (GEC): Load Capacity, Geotextile Selection and Pre-Design Graphs.

(22) Karkush M, Jabbar A. (2022). Effect of several patterns of floating stone columns on the bearing capacity and porewater pressure in saturated soft soil. Journal of Engineering Research, 10(2B), 84-97.

/06/

THE INNOVATIVE FIBER REINFORCED GEOPOLYMER FLY ASH-BASED GEOPOLYMER IN LOOSE SAND STABILIZATION

Ahmed Katea*

Civil Engineering Department, Engineering College, University of Thi-Qar

ahcieng1991@utq.edu.iq

Professor Alaa H. J. Al-Rkaby

Civil Engineering, University of Thi-Qar

alaa.al-rakaby@utq.edu.iq

Reception: 26/02/2023 **Acceptance**: 25/04/2023 **Publication**: 24/05/2023

Suggested citation:

Ahmed K. And Alaa H. J. Al-Rkaby. (2023). **The innovative Fiber reinforced geopolymer fly ash-based geopolymer in loose sand stabilization**. *3C Tecnología. Glosas de innovación aplicada a la pyme, 12(2)*, 93-105. https://doi.org/10.17993/3ctecno.2023.v12n2e44.93-105

ABSTRACT

Geopolymer (GP) has recently emerged as a new and environmentally friendly alternative to standard soil stabilization agents such as lime and Ordinary Portland Cement (OPC) to reduce environmental concerns. The addition of fibers to treated soil limits crack propagation, enhancing its strength even further. This study used high calcium class C fly ash (CFA) reacted with 10 M NaOH as a geopolymer (GP) binder to treat weak sand soil. Polypropylene (PP) fibers with a length of 4.5 mm were used as reinforcement in amounts ranging from 0.3 to 1.5%. Microstructure and unconfined compressive strength (UCS) testing were performed on the generated specimens. The study proved the benefits of fiber inclusion in improving the mechanical behavior of the treated weak soil. Superior strength characteristics were observed in GP-treated soil mixes with a binder content of 20% and an Activator/Binder (A/B) ratio of 0.4 reinforced with 1.5% PP fibers by weight, indicating that they can be used as a sustainable alternative to traditional binders in deep soil mixing applications.

KEYWORDS

Sustainable material, Fiber, Geotechnical application, geopolymer, soil stabilization, SEM

INDEX

https://doi.org/10.17993/3ctecno.2023.v12n2e44.93-105

1. INTRODUCTION

Weak soils are found in many parts of the world and are distinguished by high natural water content combined with poor shear strength, making them unsuitable for supporting civil engineering constructions. (Han, 2015). However, Because of the significant economic activity in such places, substantial infrastructure such as multi-story buildings will be developed atop such deposits. (Porbaha, 1998). Chemical treatment with conventional binders can improve several significant engineering properties of soils (e.g., lime and cement). The carbon footprint of such binders has raised considerable environmental concerns during the last decade. The production of ordinary Portland cement (OPC) is expected to produce 7% of artificial CO2. (Pacheco-Torgal et al., 2014). With this possibility of emissions and the other unavoidable environmental disadvantages of nonrenewable raw materials, there is a motivation to find more environmentally cost-effective and friendly alternative binders to replace OPC. As a result, recycling process materials derived from aluminosilicate industrial wastes and alkali-activated cement have been prioritized. (Davidovits, 2008). Geopolymers (GP) are cementitious binders made from amorphous (Si and Al) industrial wastes such as fly ash (FA) and metakaolin (MK) and alkaline activators such as potassium/sodium silicate or hydroxide. (Singhi et al., 2016). Geopolymerization is a four-step chemical reaction that begins with ion dissolution, then moves on to diffusion, gel formation by polymerizing Si and Al compounds with an activator, and gel hardening. (M. Zhang et al., 2013a). GP can have outstanding mechanical qualities such as high strength, low permeability, long durability, and insignificant volume variations depending on the synthesis circumstances. (van Deventer & Xu, 2002). However, it may be affected by the rate of the source material, the chemical qualities of the activator, the temperature, and the curing period. The mechanics of GP. The most difficult aspect is implementing the curing temperature in the field. (van Deventer & Xu, 2002; M. Zhang et al., 2013a). Because they are processed at 60-90°C, most GP can only be utilized in dry heat-cured or steamed concrete. (Gianoncelli et al., 2013). Because treating GPs at high temperatures is impractical, geotechnical engineering uses them at room temperature. Since geopolymerization is slower at low temperatures, GP-soil has lower impact strength and takes longer to impact than cement-treated soil. (Cristelo et al., 2012a). Thus, in comparison to cement, FA-based GP requires higher activator concentrations to be appropriate for soil stabilization. The bulk activator content, on the other hand, raises the cost of this stabilization approach. (Bernal & Provis, 2014). Formerly, class F fly ash (FFA) from bituminous coal combustion was used in the FA GP study. (Phair & van Deventer, 2002). This work used FA with a high Ca concentration to increase GP reactivity and decrease activator ratio (i.e., cost-effectiveness) while retaining satisfactory room temperature curing. The calcium content of FFA and class C fly ash differs the most (CFA). Both are composed of silica and alumina. CFA is made up of GGBFS and FFA. (Duxson & Provis, 2008). Because GGBFS and FFA combinations are chosen for GP manufacturing, CFA can produce them. Brittle failure was seen in the stabilized soil as the GGBS-based geopolymer dosage was raised. (Sargent, 2015). Furthermore, the shrinkage characteristics of slag-geopolymer stabilized soil are several orders of magnitude greater than those of cement. (Collins & Sanjayan, 2001), This may limit its ability to

https://doi.org/10.17993/3ctecno.2023.v12n2e44.93-105

deal with failure. As a result, reinforcing the treated soil with fibers enhances mechanical performance by minimizing crack development. (Aydın & Baradan, 2013; Syed et al., 2020). Many studies in the last decade demonstrated that introducing Polypropylene (PP) fibers into soil improves strength and ductility. (Freitag, 1986; Gaspard et al., 2003; Syed et al., 2020; L. Zhang et al., 2008; Ziegler et al., 1998) As a result, Reinforcing the CFA geopolymer with discrete PP fibers could be a feasible solution/alternative for increasing engineering properties like toughness and ductility. (Syed et al., 2020). Soil stabilization with CFA-based geopolymers and fiber addition has received minimal attention in the literature. As a result, a complete examination of the mechanical and durability performance of Fiber Reinforced Geopolymer (CFA-GP) with PP fibers in DSM technology is necessary, as disclosed in this work.

2. MATERIALS

Soil, fly ash class C, activator, and fiber were the primary ingredients in this investigation.

2.1. SOIL

The soil utilized in this study was locally available sand. Table 1 Its physical properties were summarized, including grain size distribution, Specific gravity, voids ratio, relative density (RD), maximum and minimum dry density, and angle of internal friction. The Unified Soil Classification System classifies this sand as (poorly graded) SP (USCS), as shown in Figure 1.

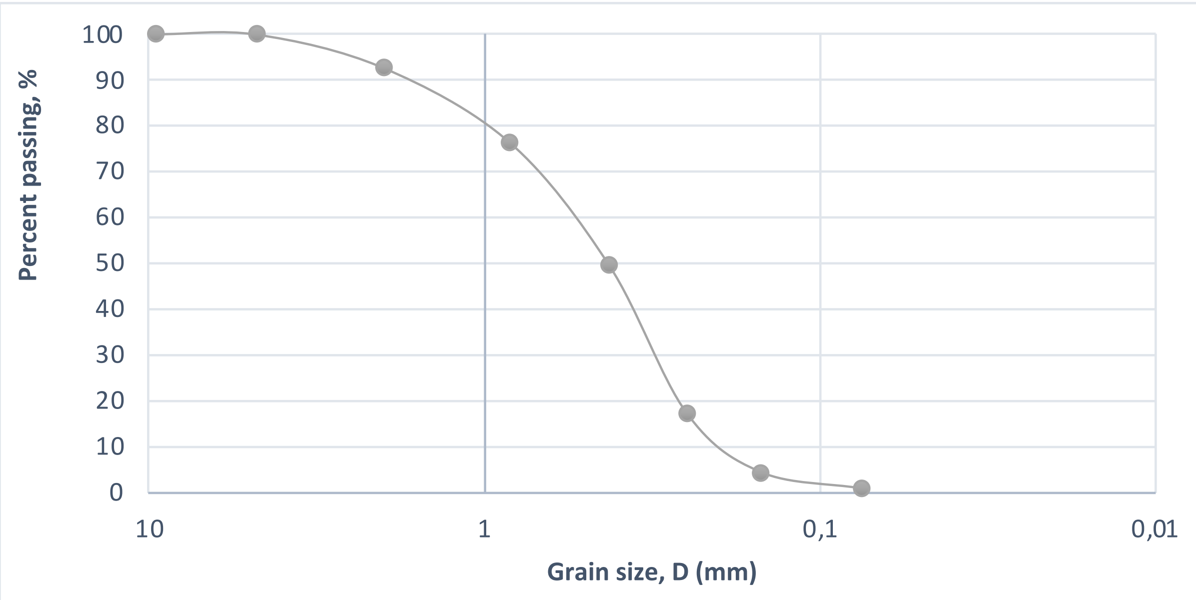


Figure 1. Grain size distribution of sand soil

https://doi.org/10.17993/3ctecno.2023.v12n2e44.93-105

Table 1. The physical properties of sand soil

Soil property	Standard	Value
Coefficient of uniformity (cu)	ASTM D 422	2.75
Coefficient of curvature (cc)		0.81
Mean effective diameter (D50)		443
Specific gravity (Gs)	ASTM D 854-00	2.65
Maximum dry density (gm/cm³)	ASTM D 4253	1.703
Minimum void ratio		558
Minimum dry density (gm/cm³)	ASTM D 4254	1.357
Maximum void ratio		0.84
Internal friction angle φ	ASTM D 3080	36
Relative density	---------------	50

2.2. FLY ASH

Local fly ash was used in this investigation, which was supplied by the Nasiriya power generating facility as a byproduct waste material generated during the generation of electricity. Figure 2 depicts a picture of fly ash and the particle distribution as determined by the hydrometer test

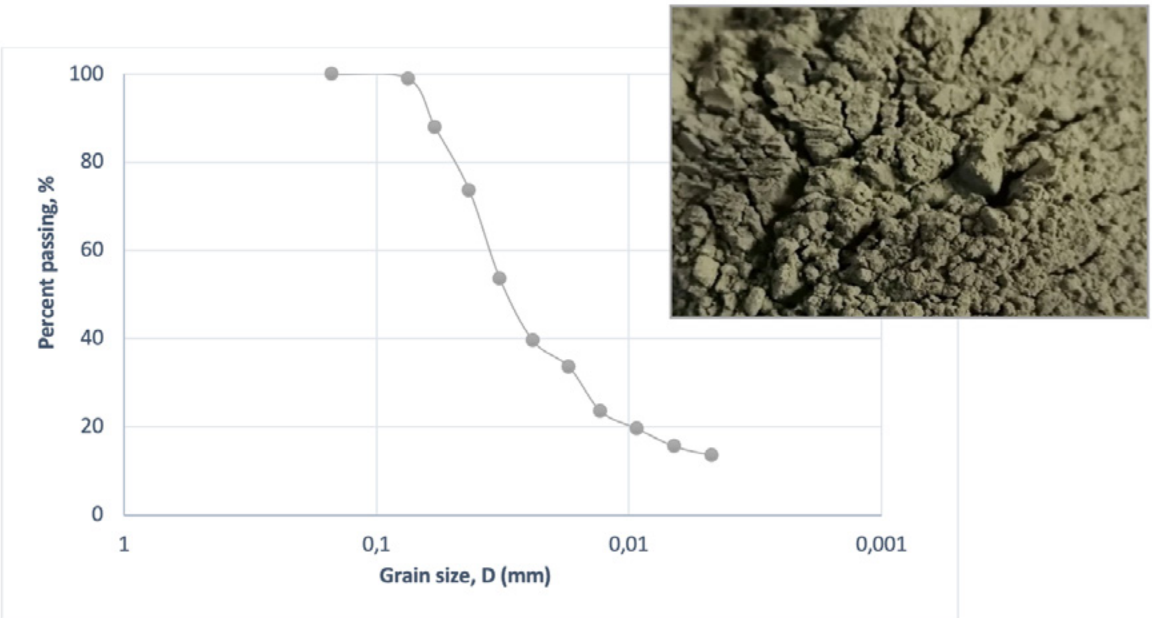


Figure 2. The particle size distribution curve of fly ash

https://doi.org/10.17993/3ctecno.2023.v12n2e44.93-105

2.3. ALKALI ACTIVATOR

In this work, sodium silicate and sodium hydroxide (NaOH) were employed to make the alkaline activator solution since they were less expensive and more readily accessible than a potassium-based solution. Moreover, NaOH has a high ability to release silicate and aluminate monomers. 98 percent pure sodium hydroxide pellets were acquired. Sodium silicate was bought in liquid form. A precise amount of sodium hydroxide pellets was dissolved in distilled water to make a NaOH solution. Throughout the investigation, the molarity of the NaOH solution was held constant at 10 M. The solution's molarity was obtained by dissolving 400 grams of NaOH pellets in one liter of distilled water. In this investigation, the weight ratio of sodium silicate to sodium hydroxide was 2.0.

2.4. FIBER

Commercially available fiberglass was used in this study, as shown in Figure 3.

Table 2 illustrates some of its properties.

Table 2. Fiberglass properties

Properties	Value
Length (mm)	4.5
Diameter (µm)	10
Strength (MPa)	650

Figure 3. Used Fiber

https://doi.org/10.17993/3ctecno.2023.v12n2e44.93-105

3. METHODOLOGY

3.1. COMPRESSIVE STRENGTH (UCS)

To study the compressive strength of geopolymer-treated soils, a series of unconfined compressive strength tests were performed on treated samples that had been cured for 28 days. The UCS test samples were manufactured from 50 mm diameter and 100 mm height (PVC) cylindrical split tubes with a height-to-diameter aspect ratio of 2:1. This sort of plastic mold has been recommended by several researchers because it is more resistant to the alkali mixture. A longitudinal incision was made to ease sample extraction. Before compaction, the mold was constrained by three stainless steel clamps to avoid volumetric expansion produced by compaction and movement.

A compressive strength test was performed on treated soil specimens using a uniaxial machine with a loading capacity of 50 kN by (ASTM D1633-00, 2007) as eq (1). The applied load and consequent displacements were determined using a load cell and a Linear Variable Displacement Transducer (LVDT). The displacement rate for all UCS tests was 0.1 mm per minute. Table 3 depicted the details of the samples.

$$UCS = \frac{P}{A} \tag{1}$$

where P = applied load (N) and A = cross sectional area of specimens (mm2).

3.2. FLEXURAL STRENGTH (FS)

Three-point bending tests were performed on specimens according to ASTM 1635/ D1635M-19, 2019, using an ARD-Auto flexural testing machine with a loading capacity of 50 kN to investigate the flexural strength of the geopolymer-treated soil. Samples with 35 x 35 x 130 mm dimensions were processed in rectangle molds. The resulting displacements were measured using an LVDT. The load and its corresponding displacement were recorded at a given time offset period. The flexural strength of samples was calculated using the equation below:

$$\mathrm{Fs_s} = \frac{3Pl}{2bh^2} \tag{2}$$

Where FS is flexural strength (MPa),

- P is the breaking load (N).
- l is the span of the simple supports (mm).
- b is the width of the specimen (mm).
- h is the thickness of the specimen (mm)

https://doi.org/10.17993/3ctecno.2023.v12n2e44.93-105

Table 3. Details of samples

Mixture No.	Mixture ID*	Fly ash (%)	Activator/Fly ash (A/FA)	Fiber (%)
1	M (f0.25)	20	0.4	0.25
2	M (f0.5)			0.5
3	M (f0.75)			0.75
4	M (f1.25)			1.25
5	M (f1.5)			1.5

*The combinations were identified using M(*f*). The letter M is a shortened version of the word "Mixture," followed by the ratio (fiber), denoted by brackets.

3.3. MICROSTRUCTURE ANALYSIS

Field Emission Scanning Electron Microscope (FESEM) with Energy-Dispersive Spectrometer was used to evaluate the microstructure samples (EDS). That test was carried out using small prepared samples collected from UCS samples.

4. RESULTS AND DISCUSSIONS

4.1. COMPRESSIVE STRENGTH

The key factor influencing the efficiency of a fly-ash-based geopolymer as a binder is temperature. The effects of fiber ratios on soil stabilization were investigated to identify a viable geopolymer mixture for soil stabilization and to evaluate the dependability of employing these new binders in weak soil stabilization. The unconfined compressive strength (UCS) test was chosen according to the methodology to investigate the degree of reactivity of different geopolymer content fiber components in treated soils.

To examine the influence of fiber inclusion on soil-geopolymer strength behavior, the UCS of treated fibers of the geopolymer-soil was tested using different fiber ratios (0,0.25, 0.5, 0.75, 1,1.25, and 1.5%). The UCS of geopolymer-treated fibers was determined for the above fiber ratios (1.85,2.15,2.3,2.55,2.62,2.75, and 2.81) MPa.

From Figure 4 the UCS of the specimens has improved with an increase in fiber content from 0% to 1.5%. The increased strength can be due to the uniform distribution of fibers throughout the treated soil matrix, which reduced the formation of micro-cracks under loading. This could be attributable to an increase in ductility of the treated samples as the fiber content increases. Among the various fiber contents tested, the treated specimens reinforced with 1.5% fiber content had the highest ductility. Figure 5 shows that at (0.25, 0.5, 0.75, 1, 1.25, 1.5%) fiber content, the treated fibers reinforced geopolymer-earth resulted in an approximate 116, 124,

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.93-105

137,141, 148, and 152% increase in UCS compared to untreated fibers. Although increasing the treated fiber ratios increased UCS, the rate of improvement became slower after (0.75) fiber ratio. As a result, it is approved for use in the soil remediation process.

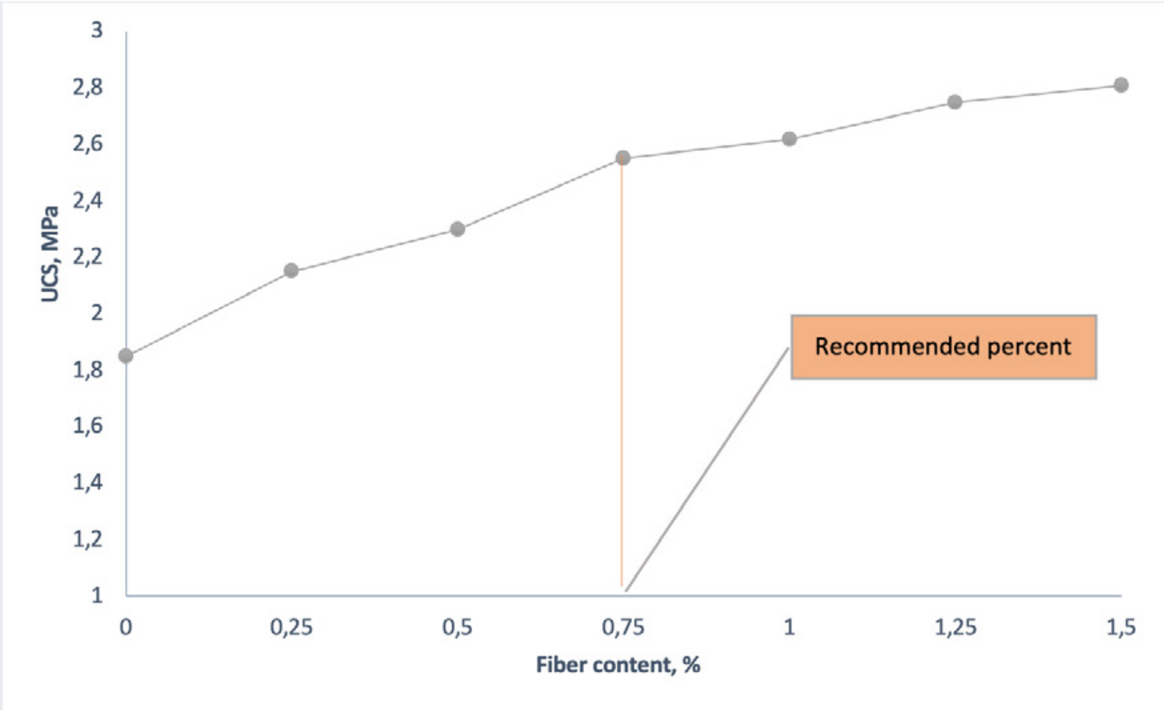


Figure 4. UCS values of fiber-reinforced specimens treated at geopolymer content (20%FA and 0.4 A/F)

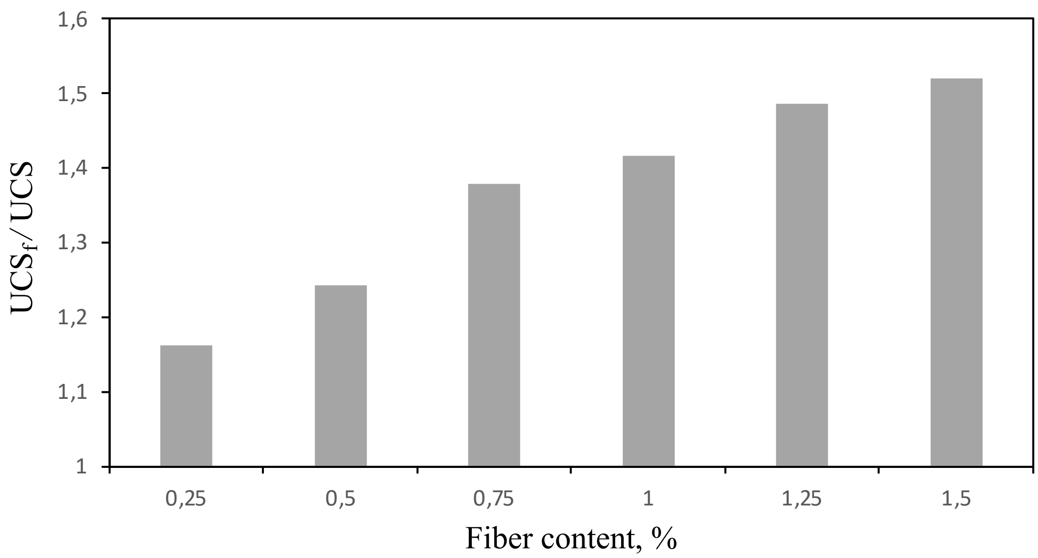


Figure 5. Variation UCS for treated and untreated fibers reinforced geopolymer- soil at the different fiber content

https://doi.org/10.17993/3ctecno.2023.v12n2e44.93-105

4.2. FLEXURAL STRENGTH

Beams of geopolymerized loose sand based on the selected ratio of fly ash 20% and A/F 0.4 were tested to investigate the flexural strength considering six different percentages of fiber content (0.25, 0.5, 0.75, 1, 1.25, and 1.5).

Figure 6 showed the variation between the flexural strength and the fiber content. Fiber content has an important role in increasing flexural strength. For example, with increasing fiber content from 0% to 0.25, 0.5, 0.75, 1, 1.25, and 1.5%, the flexural strength increased from 0.22 MPa for unreinforced sand to 0.27, 0.37, 0.56, 0.63, 0.67, and 0.72 MPa respectively. This means that the flexural strength increased by 122, 168, 254, 286, 304, and 327% respectively compared with the unreinforced geopolymerized sand. These observations are in line with the results reported by (Sakthivel et al., 2019; Sukontasukkul & Jamsawang, 2012).

When the untreated soil beam was exposed to flexural loading, just as concrete, there was a tendency for flexural stress to develop, leading to fracture when the soil carrying capacity was exceeded. The load developed approximately linearly with the deflection until fracture. Finally, failure occurred when a fracture developed at the bottom of the beam owing to stress. With the existence of fibers as reinforcements, the external load could be transferred to such fibers through the interfacial bonding between the fibers and the geopolymer soil matrix. Treated fibers were able to restrain the crack propagation and traverse across the cracks to transfer internal force, and the fibers and the geopolymer soil matrix sustain a higher load.

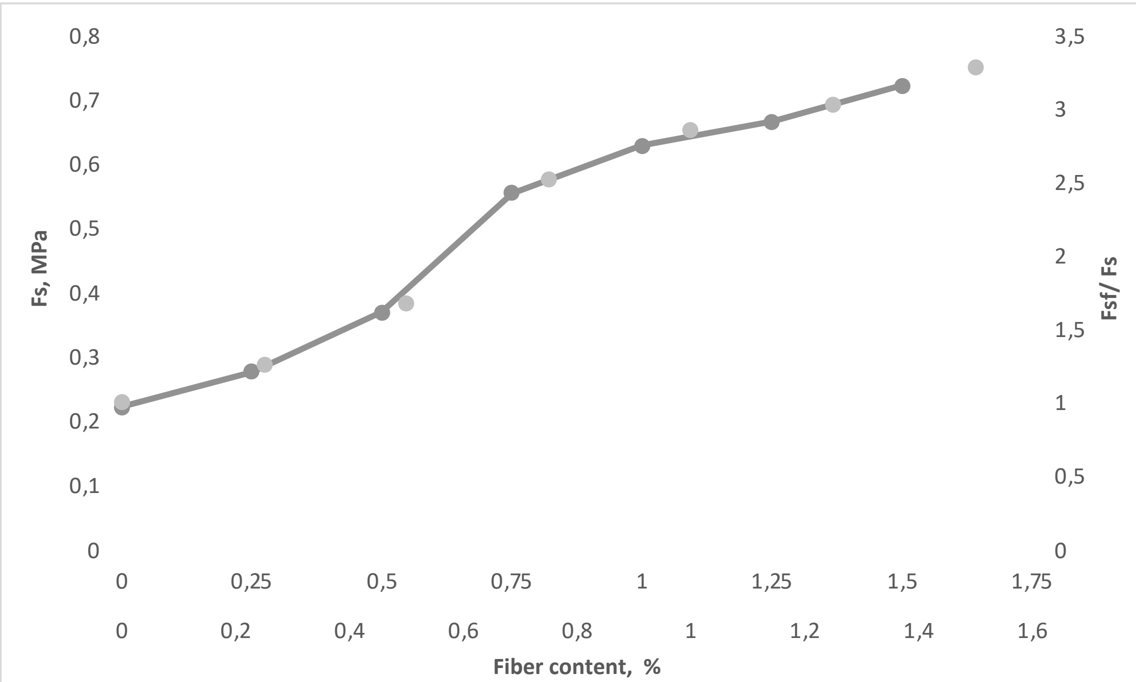


Figure 6. Flexural strength values for different fiber content samples

https://doi.org/10.17993/3ctecno.2023.v12n2e44.93-105

4.3. SEM OF GEOPOLYMER STABILIZED SOIL

The compact, stable structures of geopolymer-treated samples improved engineering properties. This primary reinforcement is caused by industrial soil bonding reinforcement materials. In geopolymer, an alkaline media dissolves silica and alumina oxides from fly-ash particles, creating Sodium Aluminum Silicate Hydrate (N-A-S-H), which hardens and cement soil particles. (Cristelo, Glendinning, Miranda, et al., 2012b; Phummiphan et al., 2016). Figure 7 shows an SEM analysis of a soil-geopolymer sample with 20% fly ash and a ratio of activator/fly ash (0.4). A higher fly ash ratio increases dissolution rate and binding activity, resulting in the most compact form. (Figure 7). Typically, fly ash gaps carved by silica and aluminum breakdown are filled by smaller particles and cementitious products, forming a thick matrix. This technique modifies the soil structure and strengthens the treated soil., similar to geosynthetic soil research (Abdullah et al., 2019; Cristelo et al., 2013; M. Zhang et al., 2013b).

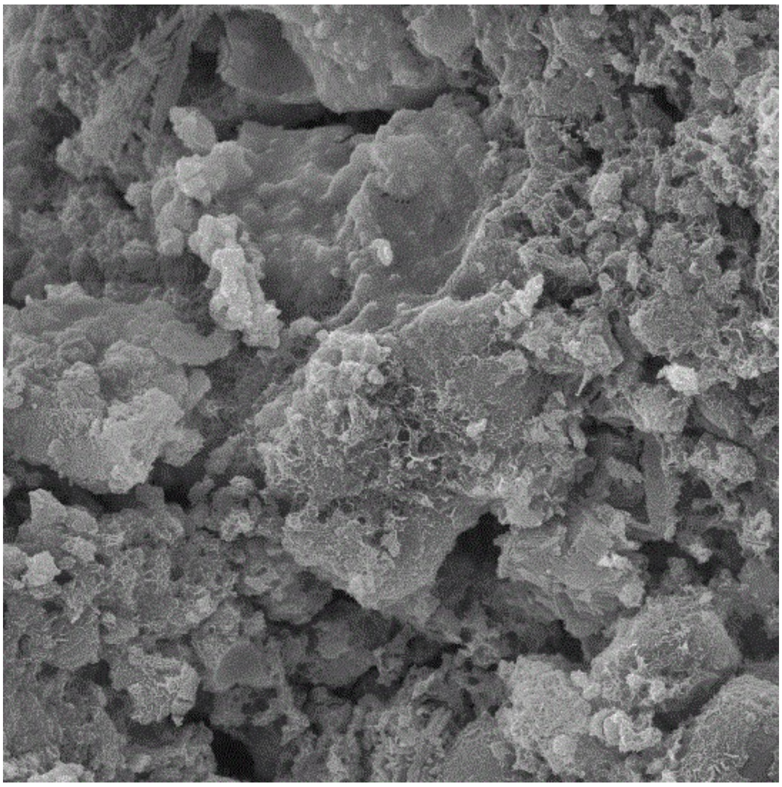


Figure 7. SEM images of geopolymer sample (20% fly ash, 0.4 activator)

5. CONCLUSIONS

1. In the first stage of this work, UCS tests on treated specimens were used to assess the strength and stiffness improvement of sand soil treated with various combinations of fly-ash, activator, and/or fiber. The effect of the fiber-to-fly ash ratio was the major variable explored here. The addition of fiber greatly

https://doi.org/10.17993/3ctecno.2023.v12n2e44.93-105

improved the strength and stiffness characteristics of soil treated with fly ash-based geopolymer. According to the findings of the studies, the ideal fiber ratio for sand soil was 1.5%.

2. The increase in flexural strength values follows the same pattern as the increase in compressive strength. When the fiber content was increased, the flexural strength increased. Flexural strength increases from 0.22 MPa to 0.72 MPa when fiber content increases from 0% to 1.5%.

3. The cementitious products on the fly ash surfaces are observed in FESEM analysis, indicating a geopolymerization response. The etched holes in fly ash surfaces created by silica and aluminum breakdown are generally filled with smaller particles, resulting in a thick matrix.

REFERENCES

(1) Abdullah, H. H., Shahin, M. A., & Sarker, P. (2019). Use of Fly-Ash Geopolymer Incorporating Ground Granulated Slag for Stabilisation of Kaolin Clay Cured at Ambient Temperature. Geotechnical and Geological Engineering, 37(2), 721–740. https://doi.org/10.1007/s10706-018-0644-2

(2) Aydın, S., & Baradan, B. (2013). The effect of fiber properties on high performance alkali-activated slag/silica fume mortars. Composites Part B: Engineering, 45(1), 63–69.

(3) Bernal, S. A., & Provis, J. L. (2014). Durability of alkali-activated materials: progress and perspectives. Journal of the American Ceramic Society, 97(4), 997–1008.

(4) Collins, F., & Sanjayan, J. G. (2001). Microcracking and strength development of alkali activated slag concrete. Cement and Concrete Composites, 23(4–5), 345–352.

(5) Cristelo, N., Glendinning, S., Fernandes, L., & Pinto, A. T. (2013). Effects of alkaline-activated fly ash and Portland cement on soft soil stabilisation. Acta Geotechnica, 8(4), 395–405. https://doi.org/10.1007/s11440-012-0200-9

(6) Cristelo, N., Glendinning, S., Miranda, T., Oliveira, D., & Silva, R. (2012a). Soil stabilisation using alkaline activation of fly ash for self compacting rammed earth construction. Construction and Building Materials, 36, 727–735.

(7) Cristelo, N., Glendinning, S., Miranda, T., Oliveira, D., & Silva, R. (2012b). Soil stabilisation using alkaline activation of fly ash for self compacting rammed earth construction. Construction and Building Materials, 36, 727–735.

(8) Davidovits, J. (2008). Geopolymer. Chemistry and Applications. Institute Geopolymere, Saint-Quentin, France.

(9) Duxson, P., & Provis, J. L. (2008). Designing precursors for geopolymer cements. Journal of the American Ceramic Society, 91(12), 3864–3869.

(10) Freitag, D. R. (1986). Soil randomly reinforced with fibers. Journal of Geotechnical Engineering, 112(8), 823–826.

(11) Gaspard, K. J., Mohammad, L., & Wu, Z. (2003). Laboratory mechanistic evaluation of soil-cement mixtures with fibrillated polypropylene fibers. Proceeding of the 82th Transportation Research Board Annual Meeting.

(12) Gianoncelli, A., Zacco, A., Struis, R. P. W. J., Borgese, L., Depero, L. E., & Bontempi, E. (2013). Fly ash pollutants, treatment and recycling. In Pollutant Diseases, Remediation and Recycling (pp. 103–213).

(13) Pacheco-Torgal, F., Labrincha, J., Leonelli, C., Palomo, A., & Chindaprasit, P. (2014). Handbook of alkali-activated cements, mortars and concretes. Elsevier.

(14) Phair, J. W., & van Deventer, J. S. J. (2002). Characterization of fly-ash-based geopolymeric binders activated with sodium aluminate. Industrial & Engineering Chemistry Research, 41(17), 4242–4251.

(15) Phummiphan, I., Horpibulsuk, S., Sukmak, P., Chinkulkijniwat, A., Arulrajah, A., & Shen, S.-L. (2016). Stabilisation of marginal lateritic soil using high calcium fly ash-based geopolymer. Road Materials and Pavement Design, 17(4), 877–891.

(16) Porbaha, A. (1998). State of the art in deep mixing technology: part I. Basic concepts and overview. Proceedings of the Institution of Civil Engineers-Ground Improvement, 2(2), 81–92.

(17) Sakthivel, P. B., Govindasami, S., & Suman, N. (2019). Flexural performance of hybrid polypropylene–polyolefin FRC composites. Asian Journal of Civil Engineering, 20(4), 515–526.

(18) Sargent, P. (2015). The development of alkali-activated mixtures for soil stabilisation. In Handbook of alkali-activated cements, mortars and concretes (pp. 555–604). Elsevier.

(19) Singhi, B., Laskar, A. I., & Ahmed, M. A. (2016). Investigation on soil–geopolymer with slag, fly ash and their blending. Arabian Journal for Science and Engineering, 41(2), 393–400.

(20) Sukontasukkul, P., & Jamsawang, P. (2012). Use of steel and polypropylene fibers to improve flexural performance of deep soil–cement column. Construction and Building Materials, 29, 201–205.

(21) Syed, M., GuhaRay, A., Agarwal, S., & Kar, A. (2020). Stabilization of expansive clays by combined effects of geopolymerization and fiber reinforcement. Journal of The Institution of Engineers (India): Series A, 101(1), 163–178.

(22) van Deventer, J. S. J., & Xu, H. (2002). Geopolymerisation of aluminosilicates: relevance to the minerals industry. AusIMM Bulletin, 20–27.

(23) Zhang, L., Wang, X. X., & Zheng, G. (2008). Effect of polypropylene fibers on the strength and elastic modulus of soil-cement. In Geosynthetics in Civil and Environmental Engineering (pp. 386–391). Springer.

(24) Zhang, M., Guo, H., El-Korchi, T., Zhang, G., & Tao, M. (2013a). Experimental feasibility study of geopolymer as the next-generation soil stabilizer. Construction and Building Materials, 47, 1468–1478.

(25) Zhang, M., Guo, H., El-Korchi, T., Zhang, G., & Tao, M. (2013b). Experimental feasibility study of geopolymer as the next-generation soil stabilizer. Construction and Building Materials, 47, 1468–1478.

(26) Ziegler, S., Leshchinsky, D., Ling, H. I., & Perry, E. B. (1998). Effect of short polymeric fibers on crack development in clays. Soils and Foundations, 38(1), 247–253.

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.93-105

/07/

BEARING CAPACITY OF ENCASED RECYCLED CONCRETE AGGREGATE (RCA) COLUMNS IN SOFT SOIL BASED ON EXPERIMENTAL AND NUMERICAL ANALYSIS

Ahmed Hussein
Civil Engineering Department, Engineering College, University of Thi-Qar
yamahmed2022@gmail.com

Professor Alaa H. J. Al-Rkaby*
Civil Engineering, University of Thi-Qar
alaa.al-rakaby@utq.edu.iq

Reception: 16/02/2023 **Acceptance**: 25/04/2023 **Publication**: 10/06/2023

Suggested citation:

Ahmed H. and Alaa H. J. Al-Rkaby. (2023). **Bearing Capacity of Encased Recycled Concrete Aggregate (RCA) Columns in Soft Soil Based on Experimental and Numerical Analysis**. *3C Tecnología. Glosas de innovación aplicada a la pyme, 12(2)*, 107-123.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.107-123

ABSTRACT

One of the finest techniques to highlight the terrain is to employ stone columns. decreasing soil stability while raising the soil's carrying capacity. In this study, recycled concrete aggregate-reinforced masonry columns were applied as the support structure. There are various techniques to fortify soft clay soils. According to the findings, soil BC significantly improved when stone columns made from recycled concrete aggregates and thoroughly reinforced with a geogrid net were used. The soil BC of the single, five, and nine columns was enhanced using stone and double columns supported by a geogrid in comparison to natural soils. The corresponding improvement rates were 5.5%, 23.3%, and 61.1%.

KEYWORDS

Bearing Capacity, Stone Column, Improving, Geogrid

INDEX

https://doi.org/10.17993/3ctecno.2023.v12n2e44.107-123

1. INTRODUCTION

From the perspective of geotechnical engineering, the unique properties of soft soil deposits are undoubtedly the most intriguing soil to work with. Soft soils are quite common around the planet, and some of them are found in significant cities. Excessive settlement and weak shear strength are the two primary issues that arise while executing civil engineering works in soft soil deposits. Stone columns are used to strengthen the ground because they have been proven to be an extremely successful approach for raising the shear strength and bearing capacity of ground soils as well as lowering total and differential settlements [1]. Related studies on theoretical, experimental, and field observations on the behavior of stone columns have been done by many researchers (Ambily and Gandhi 2007; Malarvizhi and Ilamparuthi 2007; Andreou et al. 2008; Lo et al. 2010; Awf A.Al-Kaisi, Hiba H. Ali 2013; Namir K.S. Al-Saoudi, et. al 2014). By altering variables like the distance between the columns, the shear strength of soft clay, and the loading situation, they presented a thorough experimental investigation of the behavior of a single column and a group of seven columns. To analyze and illustrate the behavior of a stone column with various parameters, a finite element analysis (FEA) using the PLAXIS software program was also carried out [2]. In the laboratory, Malarvizhi and Ilamparuthi (2007) investigated the load versus settlement response of a stone column and the impact of a reinforced stone column, specifically a geogrid-encased stone column. On a soft clay substrate stabilized with a single stone column and a reinforced stone column with varying slenderness ratios and utilizing various types of encasing material, load tests were conducted. They discovered that the stabilized bed with smaller diameter columns settles more readily than the stabilized bed with larger diameter columns and that the increased load capacity of the encased stone columns was caused by the hoop stress created in the geogrid [3]. According to Andreou et al (2008). research, the drainage conditions, the composition of the stone column, and the soil loading rate all have a significant role in how a soft foundation soil reinforced by granular columns responds to vertical loads. The study also showed that the reinforced soil loses strength as confining pressure rises [4]. Kirsch (2006) analyzed the changes in situ stress systems in soft clay formation due to the Installation of two sets of twenty-five stone columns. the difference in pore water pressure, effective horizontal stress, and soil Stiffness was analyzed to determine the post-fixation state stress in the soil. An increase in pore water pressure has been recorded in different locations immediately after installation [5]. An axisymmetric finite element analysis was used by Guetif, Bouassida, and Debats (2007) to predict the installation effects connected with stone columns (FEA). They created a stone column out of an elastic, low-stiffness "dummy material" by applying a cylindrical expansion to it. The initial radius of the "dummy substance" was increased from 250 mm, which corresponds to the normal poker radius, to a final column radius of 550 mm. The scientists carried out numerical analyses to determine how this approach affected the stiffness development of the surrounding soil and the expanding column's effect zone.[6]. (2012) Mohammad Al-Wailey A laboratory study was presented to examine the relationship between the load improvement and the percentage of the replaced area by using different diameters

https://doi.org/10.17993/3ctecno.2023.v12n2e44.107-123

(20-30-40-50-60 mm), which corresponds to the area replacement ratio. This study was done regarding the effect of the area replacement ratio on the load-bearing capacity of the soil treated with stone columns (0.042). 11 Kpa, 16 Kpa, and 22 Kpa (inside a test container used in laboratories with varying shear strengths of 0.099, 0.333, and 0.563). The findings reveal that the tolerance improvement ratios are 1.16, 1.29, and 1.64. 2.29, respectively, in soils treated with stone columns at a replacement ratio of 0.042 - 0.099 - 0.333 - 0.563 and has a shear strength of 11 Kpa. It was also noted that the proportion of increased stopping additional loads grew when the final settlement approached 40 mm, in addition to the rise of stopping additional loads. By the conclusion of the test, the soil resistance had improved by the largest percentage at shear strength of 16 Kpa and was only slightly bearing with increasing load.[7]. A laboratory investigation was done to demonstrate the impact of the factors that affect the stress concentration ratio (SCR). The peak stress concentration ratio when the internal friction angle of the stone column was between 4 and 5.5 was noted to be between 4-6 for a group of parameters and materials. This differs from 38 the 42 and is also significantly influenced by the thickness of the blanket material forming the column and the strength of the surrounding soil [8]. The vertical strength of the stone columns is influenced by the degree of confinement provided by the earth's surface. For the Stone column treatment to be effective, the soil may be too loose and not provide enough lateral support. The unaligned shear strength of the surrounding soil is often used as a criterion, with a minimum in the range of 5e15 kPa, to decide if a treatment is viable.[9]. In this field study, the behavior of reinforced and unreinforced stone columns with different patterns was studied, and the results were confirmed by using the finite element program Plaxis 3D.

2. MATERIALS USED

2.1. SOIL SILE.

The Soft Clay employed in this pilot research was classified as follows by the Universal Soil Classification System (USCS): (CL). The physical features of soft clay soil are shown in Table 1.

Table 1. The physical characteristics of soft clay soil

Property	Values
Type soil	Soft clay
L.L%	45
P.L%	23
Maximum dry unit weight (KN/m^3)	19.5
C (kpa)	20
Θ	4°
E (mpa)	15
Poisons ratio	0.45
Symbol according to Unified Soil Classification System	CL

https://doi.org/10.17993/3ctecno.2023.v12n2e44.107-123

2.2. RECYCLED CONCRETE AGGREGATE

To conduct the laboratory testing for this component, precast concrete cubes were procured from the consulting lab of Thi Qar University. They were smashed up with a hammer and put through a 25 mm filter to create a constant gradient (1-2.5 cm). recycled concrete's recycled aggregates, Figure 1. (RCA). The table provides a list of the physical characteristics of recycled concrete aggregates (2). (RCA).

Figure 1. Recycled Concrete Aggregates (RCA)

Table 2. The characteristics of (RCA)

Property	Values
Specific gravity	2.35
Total water absorption	2.40%
Moisture content	0.45%
Bulk density (Loose)	1,355 kg/m^3
Bulk density (compacted)	1,590 kg/m^3
Fineness modulus	6.23
Elongation Index	15.5%
Flakiness	5.8%
C (kpa)	0
Poisons ratio	0.35
Θ	45º

https://doi.org/10.17993/3ctecno.2023.v12n2e44.107-123

2.3. GEOGRIDS

In the experiment, a high-density polyethylene (HDPE) net was utilized. For this publication, the Ministry of Science and Technology made the (Netlon CE121) accessible. The mechanical and physical characteristics of the Netlon CE121 are shown in Table (3) and Figure 2.

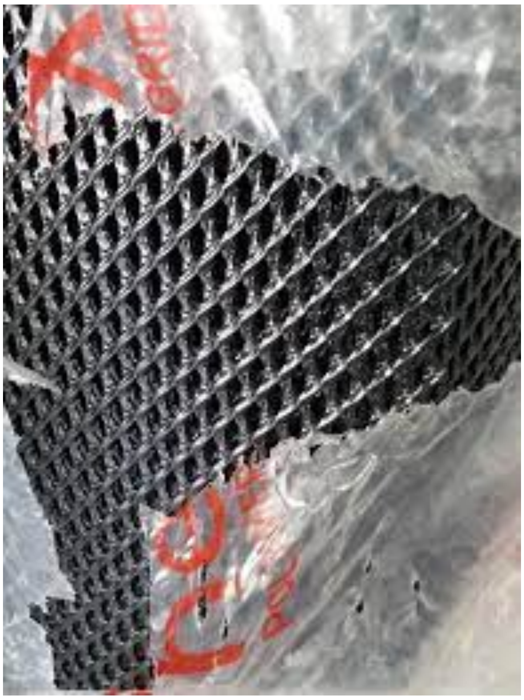


Figure 2. Netlon CE121

Table 3. Physical characteristics of the Netlon CE121

Property	Values
Material	High-density polyethylene
Type	CE121
Mesh aperture (mm*mm)	6*8
Weight per unit area (N/m^2)	7.15
Machiner direction	9.8
Transversal direction	6.15
Machine direction	68
Transversal direction	60

3. SETUP OF THE STONE COLUMN

The steel bar was used to accurately outline and designate the location of each stone column. The stone column was drilled using an auger machine to a 150 cm depth and 15 cm diameter. The auger machine rammed the stone column with its blades. Geogrid reinforcement was also divided into layers with a diameter of 8–9 cm

https://doi.org/10.17993/3ctecno.2023.v12n2e44.107-123

so that it could be put into the column. Afterward, the strain gauge was mounted on the circler layers and owner surface of the reinforcing column. Installed chorally is the geogrid that has been reinforced down. Inside the enclosed hollos, recycled concrete aggregates (RCA) were poured into six layers and crushed with a vibrating machine. The strain gauge was then put on the geogrid column and linked to it. Nylon was utilized to cover the ground and recycled concrete aggregates (RCA) were added into the geotextile cavity using a vibrating machine strain gauge.

4. SET THE RECYCLED CONCRETE AGGREGATES (RCA) COLUMN

Case 1.

In this model, soft clay soil was obtained in its natural state without any improvement, and in addition to examining precipitation and the amount of load bearing in its natural state, a numerical examination was done on it.

Case 2.

In this instance, a recycled concrete aggregates (RCA) column was utilized to simulate soft clay. The column's length in this instance was 150 cm, and its average diameter was 15 cm. according to figure 3

Case 3.

Like Case 2, in this instance, the effect of the reinforcement was examined using encased recycled concrete aggregates (RCA). Figure 3 depicts the patterns of this case, in which a casing of geogrid with a respectable diameter and length of 15 cm and 150 cm was used to cover the patterns of RCA.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.107-123

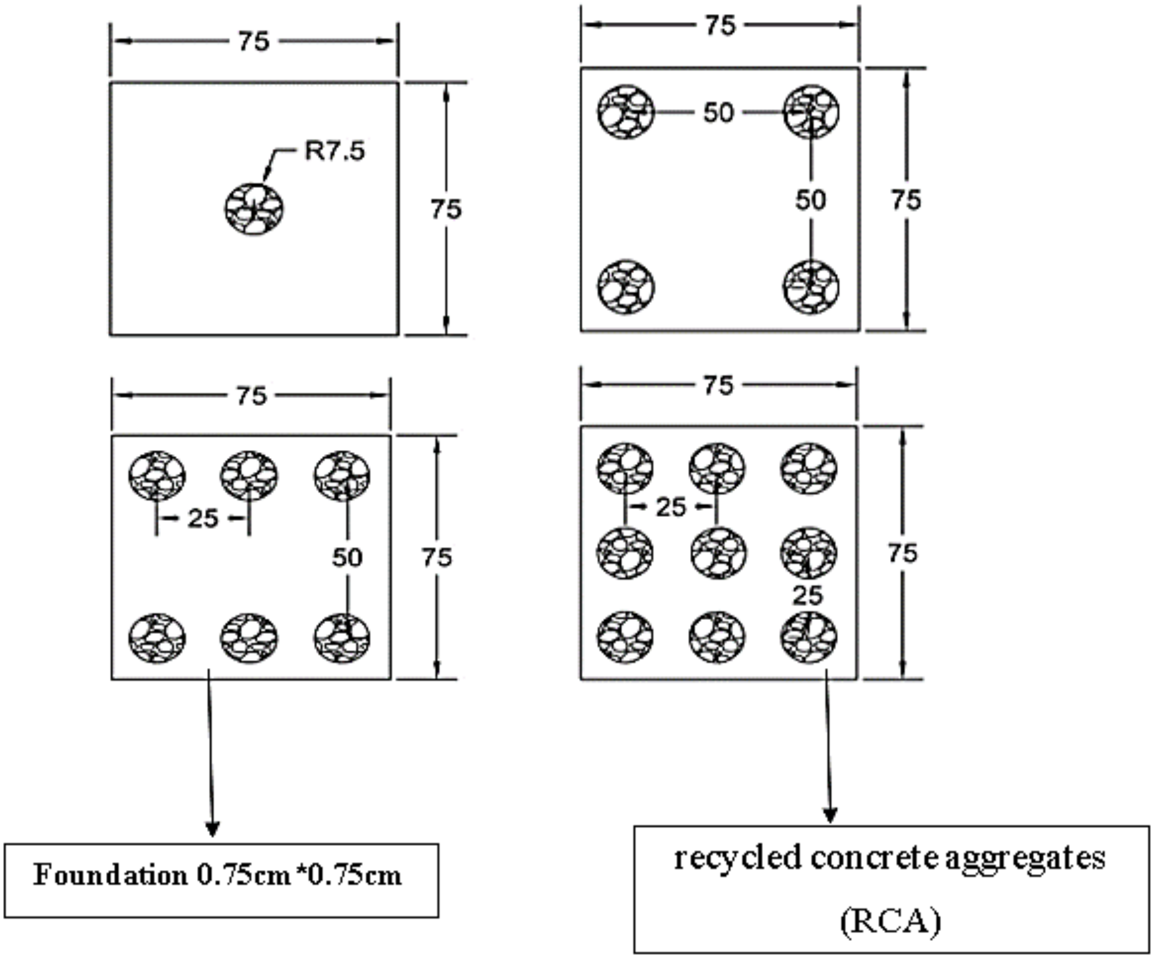


Figure 3. The seven patterns of the stone column

5. TEST PROCEDURES

Five rebars, each measuring 12 millimeters, were placed in each pile to reinforce them. It was vertically welded using an oxygen torch until it measured 43.5 cm in height. Then it was stained with an antioxidant. A steel foundation with a thickness of 12 mm was welded into the concrete pillars, and the entire steel structure was then placed on top of them while controlling the horizontality and straightness. On either side of a test plate that was supported by a side stand, he set up two of his LVDT landing sensors. When the tests were carried out using a plate load test, all sensors, sensors, and measurement instruments were connected to data recorders. The outputs from load cells, displacement transducers, and strain gauges were measured and recorded using a geotechnical data collection system. Data is instantly transferred in real-time to a computer so that trials may be tracked in real-time. Compatible with strain gauge load cells, potentiometric displacement transducers, linear LDT transducers, LVDT tuning transducers, and pressure transducers. A steel foundation with dimensions of 75*75 cm and a thickness of 25 mm was used, and up to 64 different channels were used to dump dirt in a layer 10 cm deep under the area's base. Figure 4 depicts the field procedures for the examination procedure.

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.107-123

Figure 4. The process of checking and connecting devices

https://doi.org/10.17993/3ctecno.2023.v12n2e44.107-123

6. RESULTS

6.1. FIELD MODEL RESULTS

6.1.1. SOIL TEST NORMAL (SOFT CLAY)

Figure 5 The ultimate carrying capacity value, which shows the connection between pressure and settling of untreated soft clay soil with stone columns, was calculated using the double tangent approach. The BC value was discovered to be around 90 kpa, translating to a settlement of 29.5 mm.

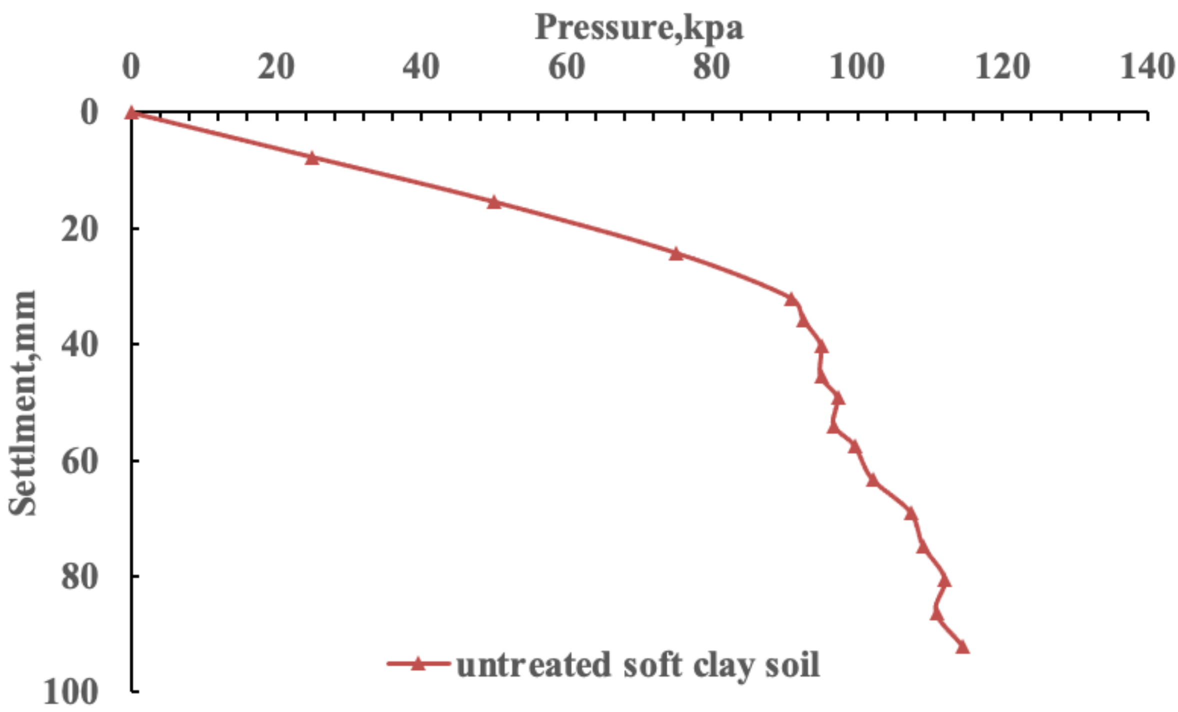


Figure 5. The relationship between pressure and settlement for untreated soft clay soils

6.1.2. UNREINFORCED RECYCLED CONCRETE AGGREGATES (RCA) COLUMNS

In this investigation, the results of stone columns made of recycled concrete aggregates (RCA) without geotextile coating are presented. This field study was conducted on a single stone column without packaging that was installed inside a bed of soft clay, and it was examined after 24 hours of the preparation process. From Figure 6. which shows the relationship between the pressure applied and settlement, we notice an increase in the total carrying capacity due to the greater efficiency of the soil treated with a stone column One, an increase in the applied load is observed. This behavior is due to the correct use of the stone shaft to improve weak soils as well as

https://doi.org/10.17993/3ctecno.2023.v12n2e44.107-123

the replacement area ratio and the increase in friction thanks to the stone used for the high friction angle and the double tangent method to extract the final bearing capacity. The soil treated with one stone column reached (95 kPa), with a decrease in the stability value of about (29 mm (. Where the percentage of soil improvement with one stone column was (1.14). Compared to natural soil, we note that the improvement rate was 5.5%.

In this pattern, stone columns were installed in the form of a 2 * 2 grid in a square shape, with center-to-center dimensions of 50 cm. The pressure-bearing was calculated using the double tangent method, where we notice a noticeable increase in the increase in pressure tolerance and the maximum bearing value reached 111 kpa, corresponding to a settlement of 37 mm and a noticeable increase for untreated soil. The explanation for this is due to the increase in the number of columns under the square foundation and an increase in the stress distribution area on the columns and reduce the camel on the weak soil, where the percentage of improvement was found to be 1.37. Compared to natural soil, we note that the improvement rate was 23.3%.

In this field investigation, six stone pillars were installed within the weak and soft clay soil. Through the results, we note an excellent resistance to the pressure applied to the enhanced soil, and this is due to the availability of the soil from lateral confinement and the high lateral pressure of the columns installed inside the soil. In addition, the group of stone columns is exposed to the vertical pressure of the load as a foundation, and therefore it that can enhance confinement against swelling from the double shadow method to extract the absorptive capacity of the stone-enhanced soil and the columns reached 123 kPa, and we notice a decrease in the settlement rate, which reached 32 mm. From that resistance, we notice an increase in the rate of improvement, which reached 1.78, which is a good rate. Compared to natural soil, we note that the improvement rate was 36.6%. In this examination, 9 stone columns were installed inside the soft clay bed. The increase in the carrying capacity was 220 kPa, compared to a decrease in settlement of 28 mm and an increase in the improvement ratio of 2.58. Compared to natural soil, we note that the improvement rate was 77.7%.

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.107-123

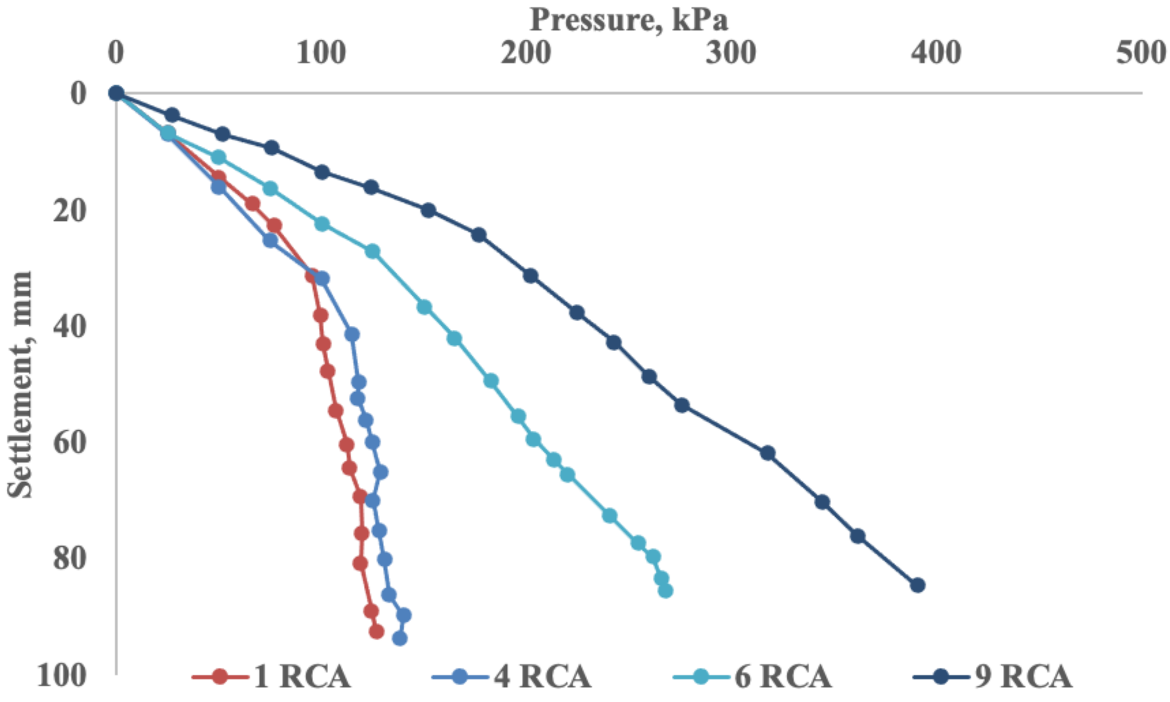


Figure 6. The relationship between applied stress and settlement of stone columns of unreinforced recycled concrete aggregates (RCA).

6.1.3- Reinforced Recycled Concrete Aggregates (RCA) Columns

In this investigation, a stone column covered with geogrids packed with recycled concrete aggregates (RCA) was installed to study the effect of the reinforced column on soft clay soil behavior. (Figure 7) represents the relationship between applied pressure and settlement of the reinforced stone columns, we note an increase in the absorptive capacity of the soil, which was improved by one stone column covered with a layer of geogrid, where the ab-sportive capacity reached 97 kPa compared to untreated soil, which amounted to 90 kPa because the packaging provides sufficient lateral confinement to resist The loads applied as well as the casing has a major role in increasing the stiffness that results. Increasing the carrying capacity and decreasing the leveling, as the improvement rate reached 1.15. Compared to natural soil, we note that the improvement rate was 7.77%.

In this style, laminated stone columns are installed in the form of a 2*2 square grid, with center-to-center dimensions of 50cm. We notice from the results that the casing works to improve the transfer of the load to the depths of the deep soil. The casing also works to prevent contamination of the stones that make up the column, and this will lead to a better performance of the stone pillar in the long run because the frictional properties of the recycled aggregate remain unchanged. Moreover, the casing reduces significantly due to the confinement provided by the geogrid cover, therefore, improving the performance of the stone column by reducing stability and preventing failure in the stone column. All these reasons are sufficient to increase the absorptive capacity of the soil improved by the coated stone columns, as it reached 125 kpa, corresponding to a drop in settlement, which reached 27.5 mm, where we notice a noticeable improvement When compared with the untreated soil, in addition

https://doi.org/10.17993/3ctecno.2023.v12n2e44.107-123

to that, the improvement rate was found to be 1.47 Compared to natural soil, we note that the improvement rate was 38.8%. In this field research, several stone columns were installed inside the weak and soft clay soil. We notice a very clear improvement in the carrying capacity of the applied loads when compared to the untreated soil. The reason is due to the strengthening of the vertical position and the drainage layer of the stone column by acting as a good filter file to prevent the mixing of fines with the stone material produced by the packaging, as it resists the tensile strength of a collar in the casing and develops confining pressure to prevent the occurrence of Lateral bulging as well, whenever the pressure in the casing increases, the stiffness of the stone column increases, and thus this increases the final absorption capacity and a clear decrease in leveling, as the absorption capacity after improvement reached 166kpa, corresponding to a decrease in leveling at a rate of 25 mm. The improvement ratio was found to be 2.2. Compared to natural soil, we note that the improvement rate was 84.4%. This is also what we can see from the schematic diagram of the stone pillars fixed in the form of a 3 * 3 grid. Figure 7 shows the relationship between the pressure applied between the untreated soil and the soil which was supported by a grid of 3 * 3 stone pillars covered with a geogrid. The increase in carrying capacity was 235 kPa, corresponding to a decrease in settlement of 15.5 mm, and an increase in the rate of improvement of 2.88. This improvement is the reason for the cladding, as it reduces lateral swelling as well as provides perfect confinement to the stone columns. As the maximum tensile capacity of the package increases, so does the maximum carrying capacity- Compared to natural soil, we note that the improvement rate was 161.1%.

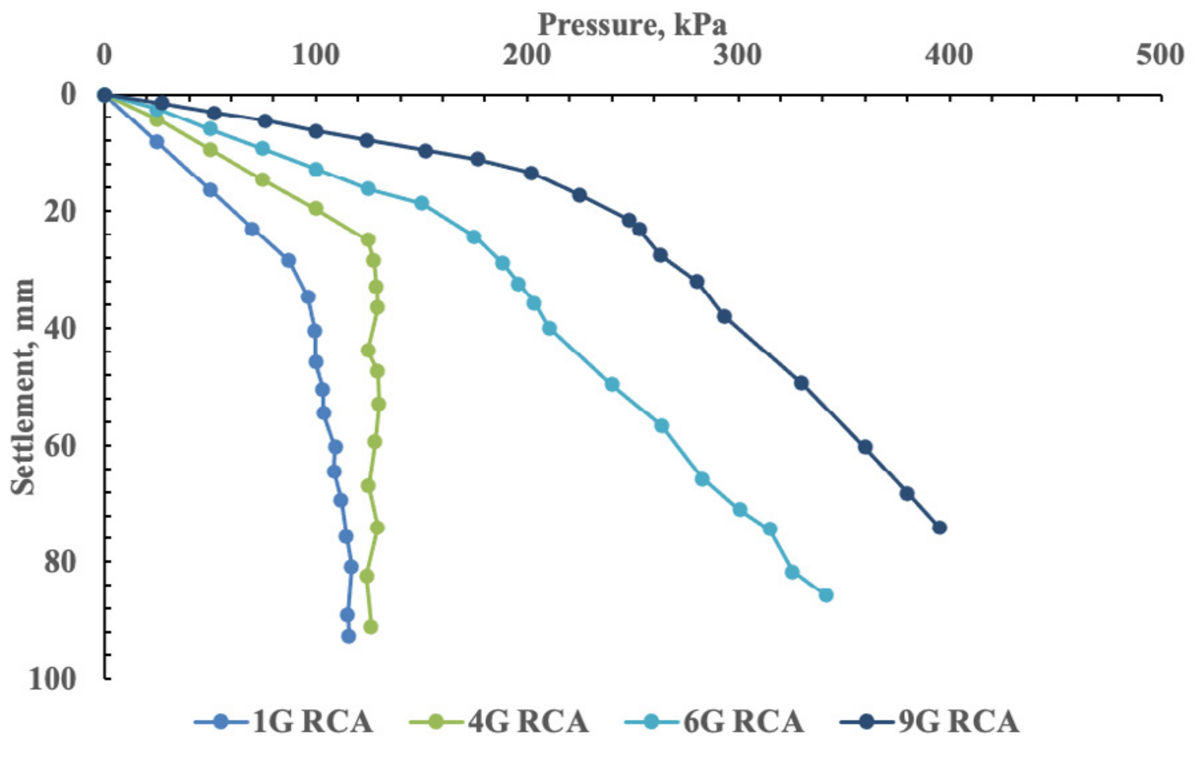


Figure 7. Relationship between applied stress and stability of masonry columns of recycled concrete aggregates reinforced with geo-cladding materials (RCA).

https://doi.org/10.17993/3ctecno.2023.v12n2e44.107-123

6.2. RESULTS NUMERICAL MODEL

6.2.1. SOIL TEST NORMAL (SOFT CLAY)

The initial bearing capacity of the soil recorded in several unimproved soils was analyzed with a solid base resting on the soil to be analyzed. The load leveling relationship is a direct method to obtain the final bearing capacity. Figure 8 shows the relationship curve between load and settlement that was analyzed using PLAXIS 3D It was found that the value of the maximum bearing capacity of the unimproved soil from the leveling curves of the double tangent method is 90kPa.

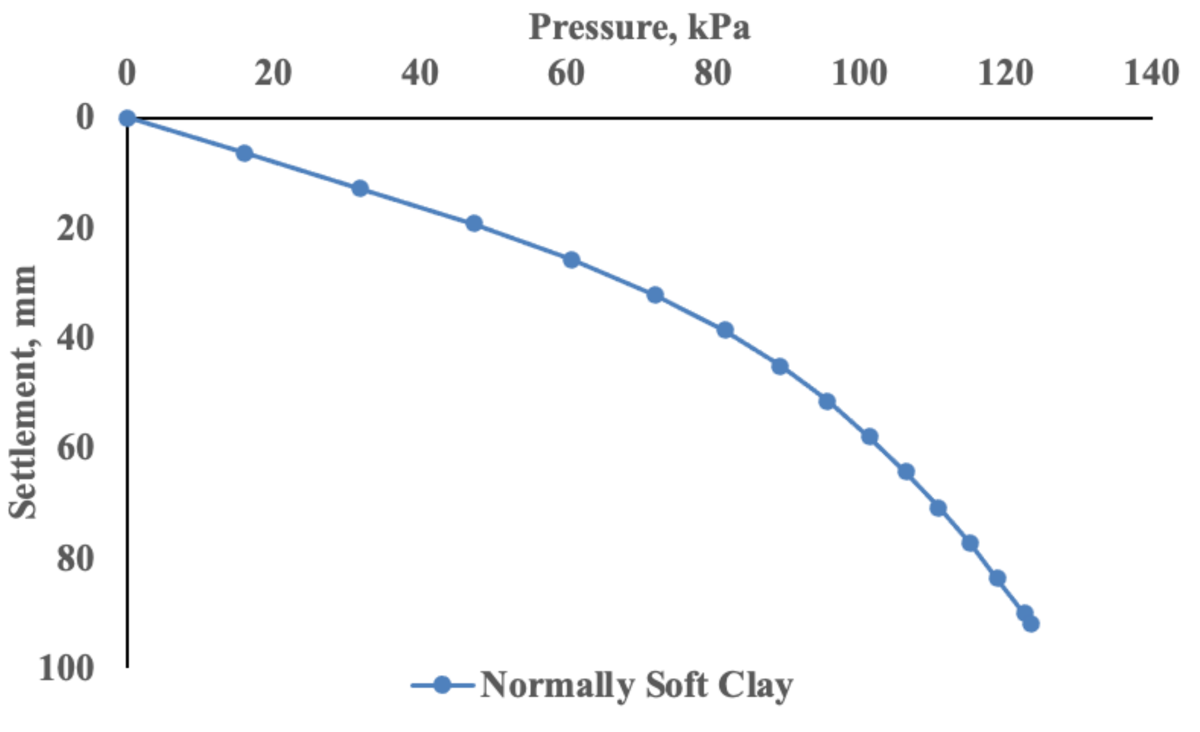


Figure 8. Curve load and settlement that was analyzed using PLAXIS 3D

6.2.2. UNREINFORCED RECYCLED CONCRETE AGGREGATES (RCA) COLUMNS

Figure 9 shows the pressure leveling curves for stone columns consisting only of stones after representing them within the finite element program Plaxis and installing them inside the soft clay bed, where we note the final bearing capacity of the single column amounted to 93 kPa, which is slightly higher than the natural soil, due to the increase in the area replacement ratio. From the diagram, we notice that there is a slight difference between the installation of the two columns and the four columns, as the final bearing capacity reached 105 kPa. The improvement jumps with an increase with the installation of six columns, where we notice an excellent improvement of the pressure applied to the improved soil. The reason for this is due to the increased concentration of stress on the annular collar of the stone columns and thus increasing

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.107-123

the consolidation process, as the final load capacity reached 160 kPa. With the increase of the stone columns inside the supposed foundation, we notice an increase in the bearing capacity also with a noticeable increase. Therefore, when installing nine stone columns inside the soft clay, the total capacity of the load reached 205 kPa. It is very important in improving the performance of the stone columns, as it amounted to more than 25% of the total soil percentage, as well as increasing the condensation area around the stone column. Also, the presence of columns reduces the liquefaction force.

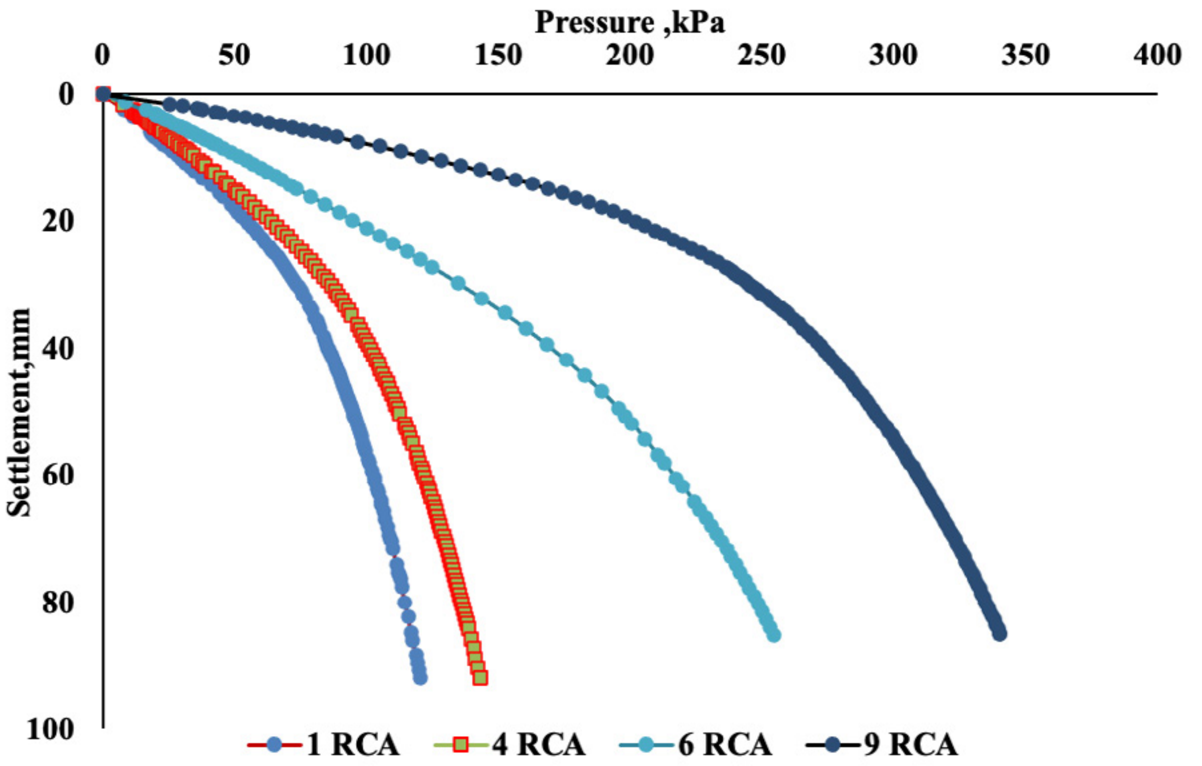


Figure 9. Settlement and load curves for stone columns included in the 3D Plaxis analysis.

6.2.3. REINFORCED RECYCLED CONCRETE AGGREGATES (RCA) COLUMNS

The addition of geographic networks leads to a change in the mechanical properties of the stone columns in this section. The results of the analysis were presented from the finite element method using the Plaxis 3D program. The design was made by placing the geogrid in a complete annular shape on the stone column. Figure 10 shows the relationship between applied stress and settlement of stone columns reinforced with geogrid, which were analyzed by the Plaxis 3D program. When reinforcing a single stone column, we notice a significant increase in the bearing capacity, and the reason is due to the presence of geogrid, which increases the lateral confinement force to provide a better loading capacity. The increase in the carrying capacity continues successively when increasing the number of columns with geogrid reinforcement, as it reached a succession of (single, fourth, pentagonal, and hexagonal columns, and a 9 column). as the final bearing capacity, respectively,

https://doi.org/10.17993/3ctecno.2023.v12n2e44.107-123

reached (110, 150, ,240 and 255). The reason for these increases is due to the availability of geotextiles of high lateral confinement, as it prevents the occurrence of early failure of the stone columns. The synthetic geosphere also greatly increases the bearing and increases in turn by confining the pressure on the column, in turn, increases the stiffness of the column, and this in turn improves the bearing capacity and the flexibility factor and the non-flexibility of the geogrid has a role in This process and with the formation of pre-stress in the casing with the development of the initial tensile strength in the casing, which increases the bearing capacity. Also, the concentration of stress on the columns reduces the lateral pressure. The geogrid acts as a good filter to prevent soil particles from mixing with the column materials. This leads to better performance over time. The percentage of improvement, when compared with natural soil for stone columns, was 6.66%,38.8%,94.4%, and 183.3%.

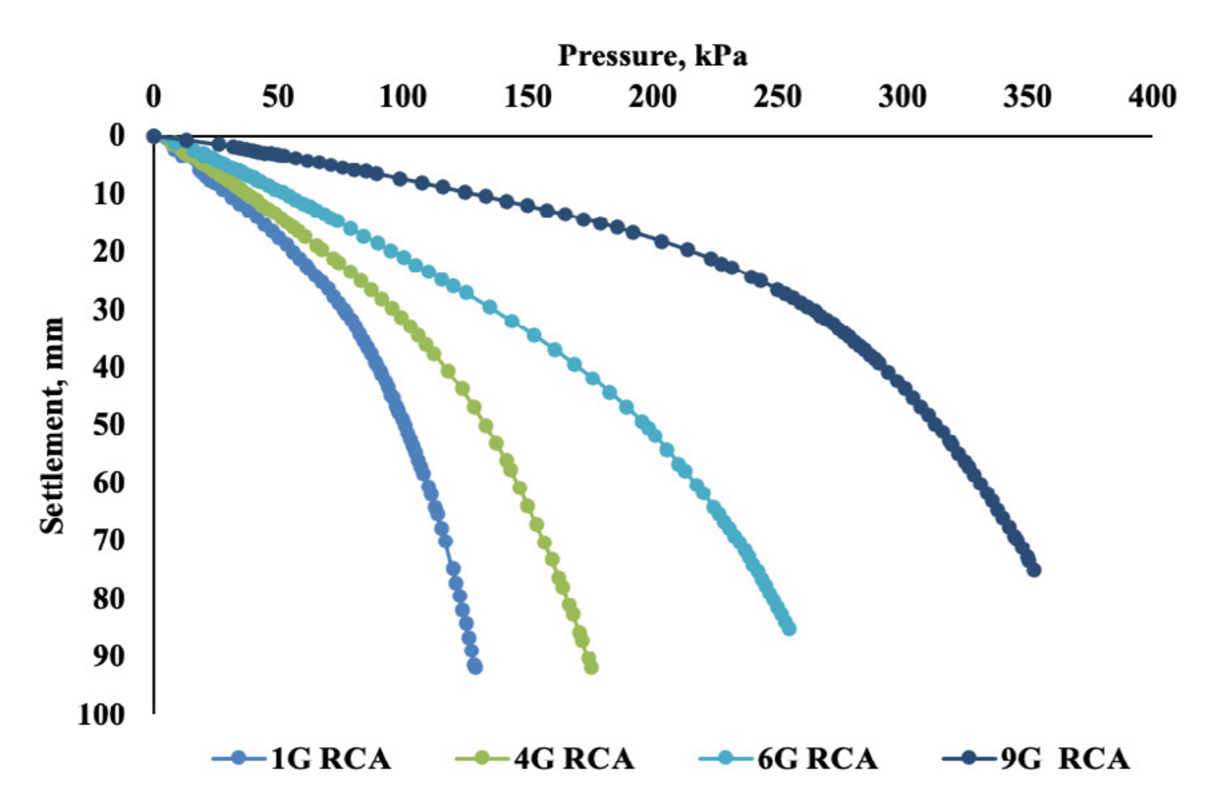


Figure 10. The relationship between pressure and settlement of stone columns reinforced with geogrid.

7. CONCLUSIONS

1. It is affordable to employ recycled concrete aggregates (RCA).

2. Using stone columns composed of recycled concrete aggregates (RCA) improved weak soils effectively.

3. In contrast to conventional stone columns, geosynthetic-encased stone columns frequently display linear behavior in response to pressure settlement without displaying any catastrophic breakage. The stiffness of the geosynthetic

https://doi.org/10.17993/3ctecno.2023.v12n2e44.107-123

material used for encasing determines how much the geosynthetic encasement improves the load capacity.

4. The rigidity of the geosynthetic utilized for the encasement also affects how well the stone column performs.

5. Using geotextile and geogrid as the stone column, encasing the granular blanket reinforcement increases its efficacy. increases the reinforced soil and stone column's rigidity. Due to the soil particles being caught in the stiff, tensile geogrid apertures, considerable frictional strengths are generated at the geogrid-soil interface. Additionally, geotextile increases bearing capacity by preventing the stone column's components from sinking into loose soil.

REFERENCES

(1) Ambily, A. P., & Gandhi, S. R. (2007). The behavior of Stone Columns Based on Experimental and FEM Analysis. Journal of Geotechnical and Geoenvironmental Engineering (ASCE), 133(4), 1090-1099. doi:10.1061/(ASCE)1090-0241(2007)133:4(1090)

(2) Lo, S. R., Zhang, R., & Mak, J. (2010). Geosynthetic-encased stone columns in soft clay: A numerical study. Geotextiles and Geomembranes, 28(3), 292-300.

(3) Malarvizhi & Ilamparuthi. (2007). Comparative study on the behavior of encased stone columns and conventional stone columns. Soils and Foundations, 47(5), 873-885.

(4) Andreou, P., Frikha, W., Canou, J., Papadopoulos, V., & Dupla, J. C. (2008). Experimental Study on Sand and Gravel columns in Clay. Proceedings of the ICE - Ground Improvement, 161(GI2), 189-198.

(5) Kirsch, F. (2006). Vibro Stone Column Installation and Its Effect on Ground Improvement. Numerical Modelling of Construction Processes in Geotechnical Engineering for Urban Environment - Triantafyllidis (Ed).

(6) Guetif, Z., Bouassida, M., & Debats, J. M. (2007). Improved Soft Clay Characteristics due to Stone Column Installation. Computers and Geotechnics, 34, 104-111.

(7) Al-Wailey, M. J. M. (2012). Effect of Area Replacement Ratio on Bearing Capacity of Soil Treated with Stone Column. Journal of Kerbala University, 10(4), 280-290.

(8) Kumar, G., & Samanta, M. (2021). Experimental evaluation of stress concentration ratio of soft soil reinforced with the stone column. Innovative Infrastructure Solutions, 5(1), 1-10.

(9) Wehr, J. (2006). The undrained cohesion of the soil is a criterion for the column installation with a depth vibrator. Proceedings of the International Symposium on Vibratory Pile Driving and Deep Soil Vibratory Compaction. TRANSVIB, Paris, 157-162.

/08/

A COMPARATIVE STUDY OF USING ADAPTIVE NEURAL FUZZY INFERENCE SYSTEM (ANFIS), GAUSSIAN PROCESS REGRESSION (GPR), AND SMRGT MODELS IN FLOW COEFFICIENT ESTIMATION.

Ruya mehdi*

Gaziantep University, Civil Engineering Department, Yeditepe st., no 85088, sahinbey dist., Gaziantep, Turkey.

ruya.mehdi1991@gmail.com

Ayse Yeter GUNAL

2Gaziantep University, Civil Engineering Department, Osmangazi district, University Street, 27410 Sehitkamil / Gaziantep, Turkey .

agunal@gantep.edu.tr

Reception: 04/03/2023 **Acceptance**: 25/04/2023 **Publication**: 23/05/2023

Suggested citation:

Ruya M. And Ayse Yeter G. (2023). **A Comparative Study of Using Adaptive Neural Fuzzy Inference System (ANFIS), Gaussian Process Regression (GPR), and SMRGT Models in Flow Coefficient Estimation.** *3C Tecnología. Glosas de innovación aplicada a la pyme, 12(2)*, 125-146. https://doi.org/10.17993/3ctecno.2023.v12n2e44.125-146

ABSTRACT

Estimating the flow coefficient is a crucial hydrologic process that plays a significant role in flood forecasting, water resource planning, and flood control. Accurate prediction of the flow coefficient is essential to prevent flood-related losses, manage flood warning systems, and control water flow. This study aimed to predict the flow coefficient for a period of 19 years (2000-2019) in the Aksu River Sub-Basin in Turkey, using historical climatic data, including precipitation, temperature, and humidity, provided by The Turkish State of Meteorological Service (TSMS). The study utilized three different approaches, namely, the Adaptive Neural Fuzzy Inference System (ANFIS), Simple Membership function and fuzzy Rules Generation Technique (SMRGT), and Gaussian Process Regression (GPR), to predict the flow coefficient. The models were evaluated using several statistical tests, such as Root Mean Square Error (RMSE), Coefficient of Determination (R2), Mean Absolute Error (MAE), and Mean Square Error (MSE), to determine their accuracy. Based on the evaluation criteria, it is concluded that the Simple Membership Functions and Fuzzy Rules Generation Technique (SMRGT) model has superior flow coefficient estimation performance than the other models.

KEYWORDS

ANFIS, SMRGT, Flow coefficient, Prediction, Gaussian process regression.

INDEX

https://doi.org/10.17993/3ctecno.2023.v12n2e44.125-146

1. INTRODUCTION

Hydrology is the study of the entire water cycle, with the most critical aspect being the section where rainfall causes water to flow. The flow is crucial in designing flood protection measures for urban and agricultural areas, as well as determining the amount of water that can be extracted from a river for irrigation or water supply. Turkey is located in a region that is prone to natural disasters, such as floods and earthquakes, and the amount of rainfall, particularly during the rainy season, is a significant factor in climate change. The rainy season is when floods and landslides are most likely to occur, and several factors, such as the condition of the catchment area [1], rain duration and intensity [2], land cover [3], topographic conditions [4], and drainage network capacity [5], can contribute to floods. However, climate change is the fundamental cause of these disasters. Urban floods, including flash floods, are considered the most distressing types of floods. Flood forecasts for Turkey indicate that 51% of flood events occur in late spring and early summer, with a significant portion observed during winter and a small portion in autumn. The Black Sea, Mediterranean, and Marmara Regions have the highest frequency of flood occurrence in that order.

In flood forecasting, the flow coefficient is the most important factor to consider. Flow coefficient is the ratio of the volume of water that drains superficially throughout rainfall to the total volume of precipitation over a specified period [6,7]. The flow coefficient, an essential tool in hydrologic processes of countless urban and rural engineering projects, etc. [8], can indicate the quantity of water flowing from specific precipitation and reflect the influence of natural geomorphological elements on the flow. Flow coefficients are also useful when contrasting watersheds to determine how various landscapes convert precipitation into rainfall events. [9,10] Precipitation is one of the most crucial variables when assessing and determining the flow coefficient [7, 11]. Precipitation may refer to a single rainfall event or an interval in which multiple rainfall events occur. Initial losses and infiltration capacity are attained when precipitation intensifies—consequently, flow increases, leading to a greater flow coefficient. In addition to precipitation properties such as intensity, duration, and distribution, specific physical aspects of watersheds, such as soil type, vegetation, slope, and climate, influence the occurrence and volume of the flow. The flow coefficient can be estimated by employing tables in which the flow is related to the surface type. According to [12], the effective study of the coefficient is a highly complex operation due to many influencing variables. This implies that the flow coefficients reported in the literature transmit less information than is required [9] and that their values, when tabulated as if they were constant, may not reflect reality.

Since the accurate estimation of the flow coefficient is crucial to our existence, improving models incorporating meteorological, hydrologic, and geological variables is necessary. Thus, effective water management and operation of water structures will be possible. Several models are used to model such a process. These models are separated into experimental models, conceptual black box models, or grey box models, and physically-based distributional models, or white box models.

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.125-146

Experimental models (black box model) do not explicitly account for the physical laws of the processes and only connect the input and output via the conversion function. The second group consists of conceptual models, which are based on limited studies of the existing processes in the basin hydrology system, as opposed to the distributional physically-based models; their development has not been based on the total number of physical processes but rather on the designer's comprehension of the system's behavior. The third group consists of distributional physically-based models; these models attempt to account for all the processes within the desired hydrological system by applying physical definitions. In contrast, physically based models provide a more realistic approach by mathematically representing the real phenomenon. Even though physically-based models appear to be more suitable for modeling purposes, they lack acceptability because of their fundamental uncertainty and high computational cost.

Reports indicate that machine learning techniques such as ANN and FIS effectively model such complexities (flow coefficient). Their simplicity and capacity for dealing with nonlinearity without understanding the entire system distinguish them from others. Numerous examples in the literature demonstrate that fuzzy logic (FL)-based systems excelled at modeling different hydrological events such as precipitation, runoff, streamflow, etc. Due to the presence of uncertainty and vagueness in these domains, FL-based systems are well-suited for modeling.

This study proposes one of the pertinent machine learning algorithms, the Adaptive Neuro-Fuzzy Inference System (ANFIS), for estimating the flow coefficient. The ANFIS model employs Tagaki-Sugeno-Kang (TSK) first order [13,14]. As a flow coefficient prediction, the hybrid learning algorithm is selected from various algorithms for supervised learning. The widespread use of hybrid learning algorithms justifies their selection. An advantage of ANFIS is that it is a combination of ANN and fuzzy systems employing ANN learning capabilities to acquire fuzzy if-then rules with suitable membership functions, which can learn something from the inaccurate data that has been input and leads to the inference. Another benefit is that it can effectively utilize neural networks' self-learning and memory capabilities, resulting in a more sustainable training process [15].

These methods (ANFIS and other fuzzy systems) lack a definitive method for determining the number of fuzzy rules and membership functions (MF) required for each rule [13]. In addition, they have no learning algorithm for refining MF that can minimize output error. Therefore, Toprak in 2009 [16] proposed a new method known as the Simple Membership functions and fuzzy Rules Generation Technique (SMRGT). This new technique takes into account the physical cause-and-effect relationship and is designed to assist those who struggle to select the number, form, and logic of membership functions (MFs) and fuzzy rules (FRs) in any fuzzy set.

Gaussian Process Regression (GPR) is a statistical learning theory and Bayesian theory-based machine learning technique. It is well-suited for handling complicated regression tasks, such as high dimensions, a small number of samples, and

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.125-146

nonlinearity, and it has a substantial potential for generalization. Gaussian process regression has many favorable circumstances over neural networks, including simple implementation, self-adaptive acquisition of hyper-parameters, flexible inference of non-parameters, and probabilistic significance of its outcome. Results are less affected by bias and easier to read thanks to the GPR's seamless integration of hyperparameter estimates, model training, and security assessments. Processes with a Gaussian (GP) distribution take it for granted that the overall distribution of the model's probabilities is Gaussian.

The objectives of this study are to (1) compare the predictive power of the ANFIS, SMRGT, and GPR models and (2) select the model and algorithm with the highest degree of accuracy and the lowest error rate. This is the first attempt to compare the abovementioned models to determine the flow coefficient.

2. MATERIALS AND METHODS

2.1. AREA OF STUDY AND DATASET

The Aksu River basin is located in the Antalya Basin, southwest of Turkey. The total length of the Aksu River is approximately 145 km, with headwaters Akdag situated within Isparta Province and discharges to the Mediterranean from the Antalya-Aksu border. The southern part of the basin is narrower than the north. Two different climatic types, Mediterranean and continental climates, are observed in the Aksu River basin. The north part has low precipitation throughout the year, and the northwest and northeast mountain areas are the highest areas and have lower temperatures, intense precipitation, and snow, whereas the south plain areas are generally warmer with intense rainfall and evaporation. Several measurement data are collected to support the study. The primary data are obtained from TSMS (Turkish State of Meteorological Service). The data processed for this study are precipitation, temperature, and humidity.

2.2. CLIMATE PROPERTIES OF THE STUDY AREA

2.2.1. PRECIPITATION

The most severe effect of climate change is a rise in the frequency and intensity of extreme weather events in some parts of the world; the most obvious manifestation of this is the recent rise in the frequency and intensity of extreme precipitation in various parts of the world, which is causing infrastructure systems to become completely inadequate. Precipitation ranks among the most crucial elements of climatic parameters and atmospheric circulation, as well as the element that provides water to the land and is the primary flow source. In this work, the precipitation stations' data and locations are obtained from TSMS (Turkish State of Meteorological Service). 57

https://doi.org/10.17993/3ctecno.2023.v12n2e44.125-146

precipitation observation stations (POSs) with (1793) records of monthly precipitation data for 20 years are used. The precipitation increased in (Oct., Nov., Dec., Jan., and Feb.) and the minimum precipitation recordings showed in (June, July, August. and Sep.). The maximum monthly precipitation (907.2 mm) was recorded in (Nov. 2001). In comparison, the minimum record for most of the years was (0.1 mm), especially in August. The annual average rainfall was 963.60 mm based on 19 years of Aksu meteorological station measurements (see Fig.1). The maximum annual rainfall was 1891.8mm in 2001.

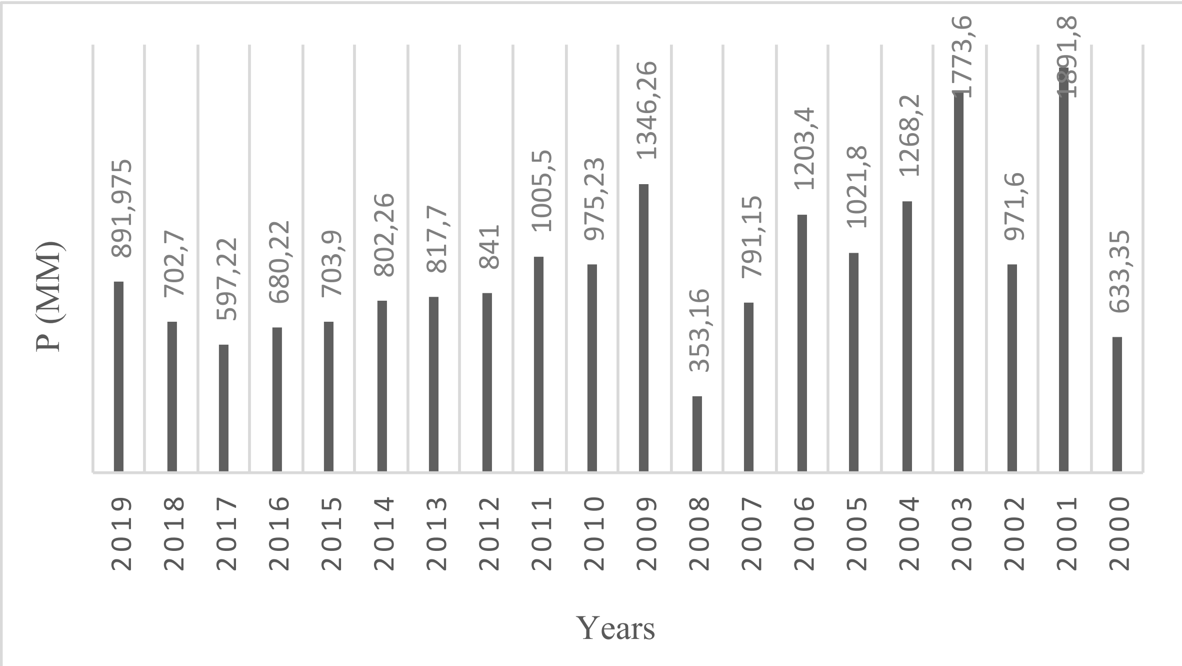


Figure 1. Average annual precipitation values for 19 years.

2.2.2. TEMPERATURE

The region is influenced by both moist tropical (MT) and warm and dry tropical air (CT) from the African and Arabian regions during the summer. (6996) Monthly temperature data have been studied in Aksu meteorological stations; the temperature showed an increase in (July, and Aug.), while the minimum temperature recordings showed in (Dec., and Jan.). The maximum monthly temperature was (31.4 °C) recorded in Aug. 2012, and the minimum record (- 5 °C) was shown in (Dec., and Jan.) 2016 and 2017. The annual average temperature was 16.03 °C based on 19 years of Aksu meteorological station measurements (see Fig.2). The maximum annual temperature was 16.92 °C in 2010.

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.125-146

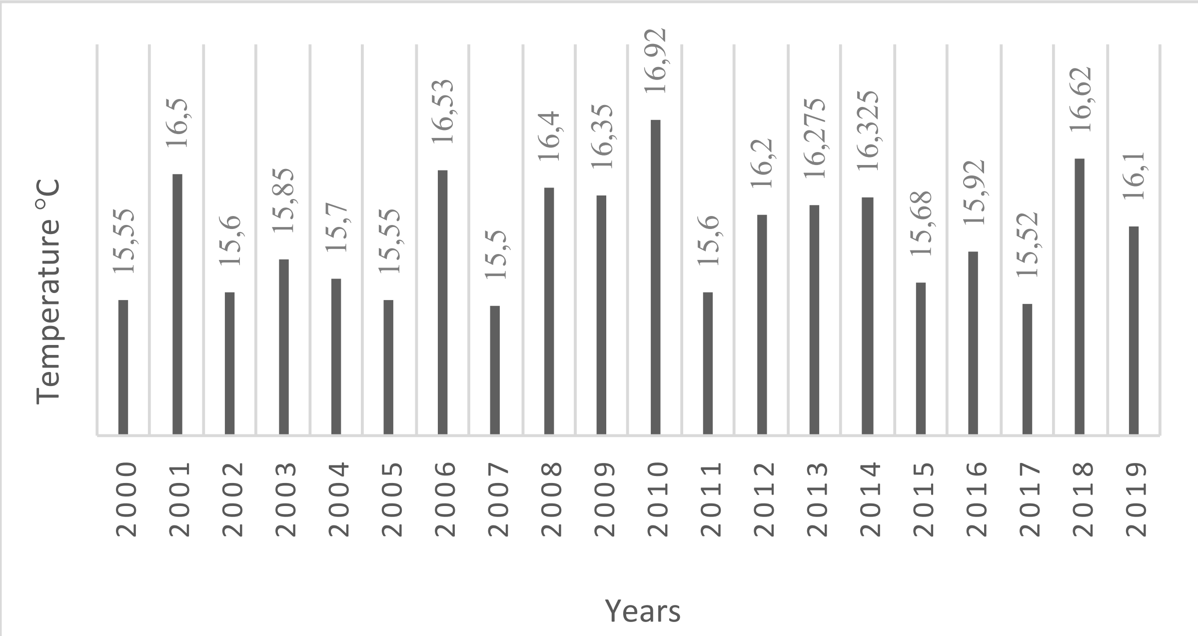


Figure 2. Average annual temperature values.

2.2.3. RELATIVE HUMIDITY

(6680) of monthly relative humidity data have been considered from the Aksu meteorological stations; it is recognized that the humidity increased in (Jan., and Dec.), while the minimum humidity recordings showed in (July and Aug.). The maximum monthly humidity was (97.7%) recorded in Jan. 2017, and the minimum record was (2.4%) in Dec. 2017. the annual average humidity was 63.3% (see Fig.3). The maximum annual humidity was 67.4 % in 2002, and the minimum was 58.85 % in 2013.

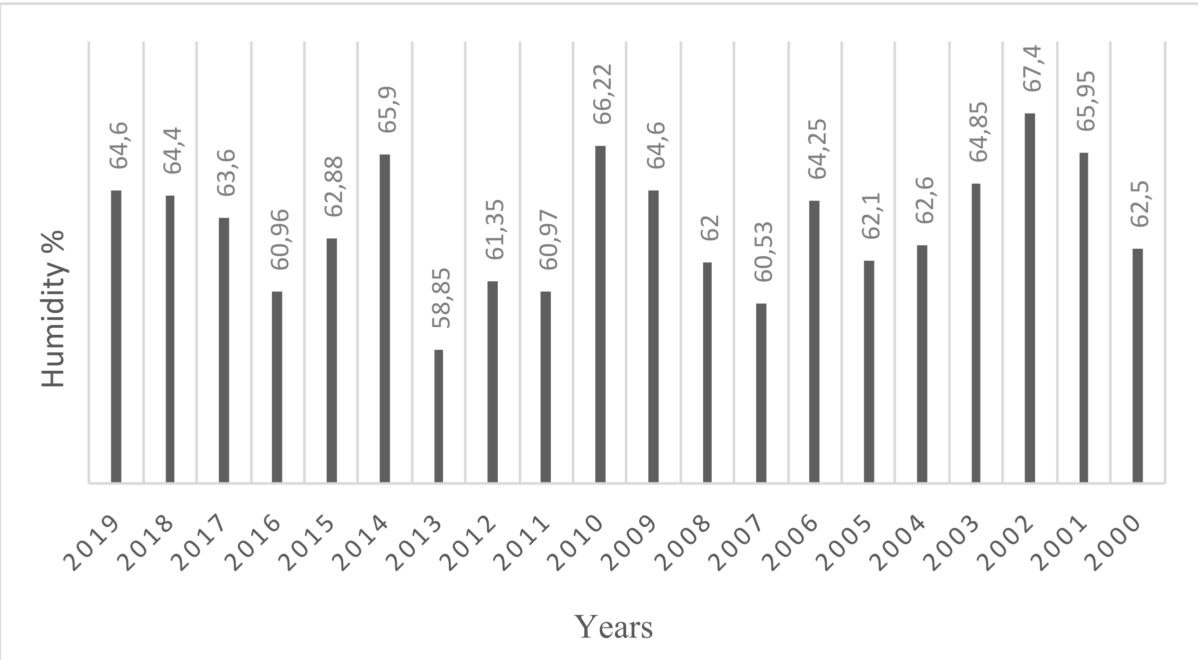


Figure 3. average annual relative humidity rates.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.125-146

2.3. METHODS

2.3.1. ANFIS MODEL DEVELOPMENT

The Adaptive Neuro-Fuzzy Inference System (ANFIS) is a hybrid approach combining the advantages of two intelligent methods, neural networks, and fuzzy logic, to ensure qualitative and quantitative rationality. This new network can be effectively trained to interpret linguistic variables by utilizing neural networks and fuzzy logic. ANFIS implements a Sugeno-style first-order fuzzy system; it applies TSK Takagi Sugeno and Kang rules in its architecture [17] and effectively handles nonlinear real-time problems. ANFIS has been utilized extensively in disaster risk management, rock engineering [18,19], health services, finance, and other real-time areas [20–22]. It addresses regression and classification issues.

In first-order Sugeno's system, a typical set of IF/THEN rules for three inputs and one output can be expressed as follows:

Rule 1: If x is A1 and y is B1, then f1 = p1 x + q1 y + r1 (1)

Rule 2: If x is A2 and y is B2, then f2 = p2 x + q2 y + r2 (2)

Rule 3: If x is A3 and y is B3, then f3 = p3 x + q3 y + r3 (3)

Generally, ANFIS is composed of five layers:

Input Layer:

Nodes in the input layer stand in for the system's input variables. Each input node is associated with a membership function connecting an input value to a fuzzy set. If there are n input variables, the input layer can be denoted as:

$$y_1 = x_1, y_2 = x_2 \cdots y_n = x_n \tag{4}$$

Where Input variables are denoted by $x_1, x_2, \cdots, x_n$ and their corresponding nodes in the input layer are denoted by $y_1, y_2, \cdots, y_n$.

Fuzzification Layer:

The multiplicators and transmitters of this layer are their nodes. This product signifies the firing strength of a rule. Let $A_{ij}(x)$ be the membership function of node (i) for input (j) with parameters (p_{ij}). The output of the fuzzification layer can be denoted as:

$$u_{ij} = A_{ij}(x_j),\ for\ i = 1\ to\ m\ and\ j = 1\ to\ n \tag{5}$$

Where (m) is the number of membership functions per input variable and (u_{ij}) is the degree of membership of the j^{th} input variable in the i^{th} fuzzy set.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.125-146

Rule Layer:

The nodes in this layer calculate the i^{th} rule's firing strength relative to the total firing strength of all rules.

$$\bar{W} = \frac{W1 + W2 + W3}{W1} \tag{6}$$

Defuzzification Layer:

This layer's nodes are adaptive with node functions.

$$\bar{W}if = \bar{W} \cdot (pix + qiy + ri) \tag{7}$$

Where is the output of Layer 3 and $\{pi, qi, ri\}$ are the parameter set? Parameters of this layer are referred to as consequent parameters.

Output Layer:

All inputs are combined at a single fixed node to produce the final output. We can model the output layer as:

$$f = \sum_{i=1}^{n} \bar{W}ifi \tag{8}$$

In this model, 7-year data is used, where the training data were Precipitation, temperature, and humidity (input variables) data from January 2013 to December 2017 (5 years). On the other hand, the testing data from January 2018 to December 2019 (2 years), in this case, by trial and error, is 70%:30%. Training is conducted using a membership function such as the Gaussian membership function (gaussmf). In this step, a fuzzy inference system (FIS) is generated and evaluated, which can produce MSE and MARE.

To reduce computations that are too large in the pre-processing, the data is normalized into the range (0-1) using the following equation:

$$\bar{x} = \frac{x - m}{n - m} \tag{9}$$

Where $\bar{x}$ the normalized data x is the original data, and n, m are the maximum and minimum values of the original data, respectively.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.125-146

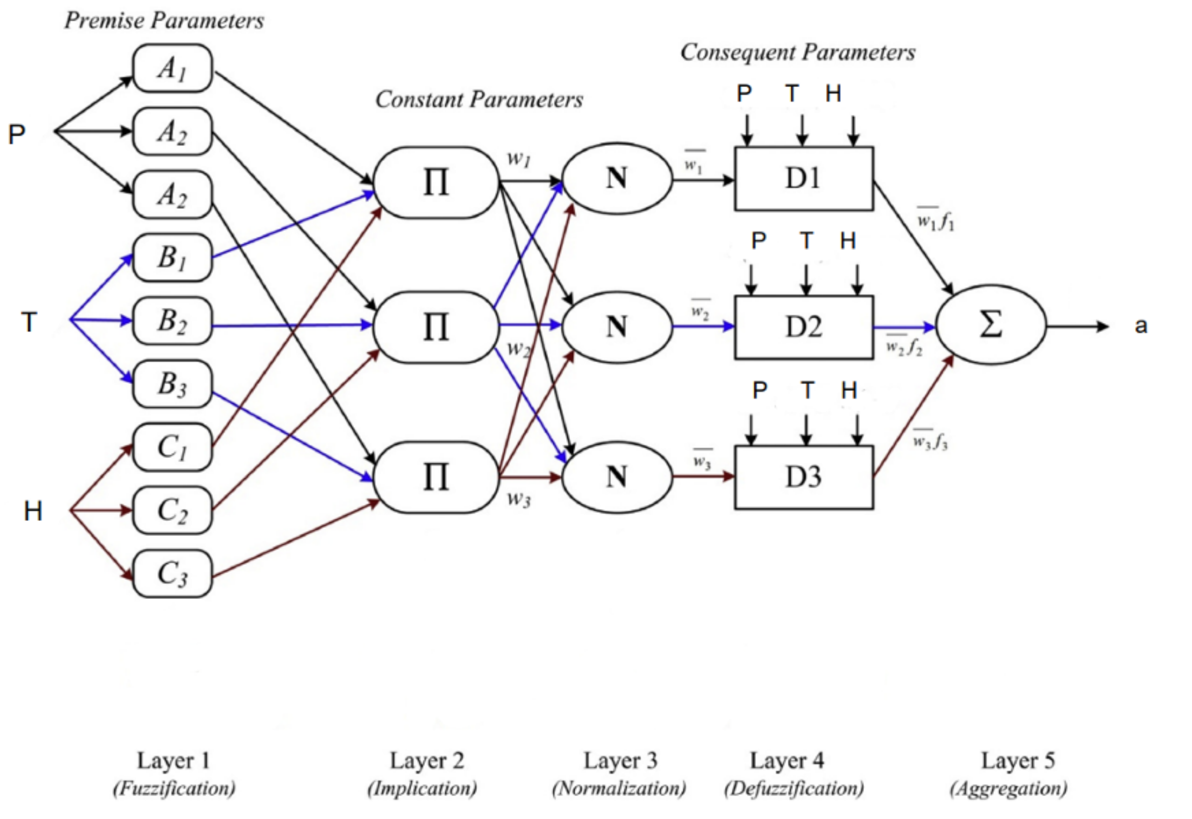


Figure 5. A framework of the ANFIS model.

2.3.2. SIMPLE MEMBERSHIP FUNCTIONS AND FUZZY RULES GENERATION TECHNIQUE (SMRGT)

The fuzzy-Mamdani method is used to construct the SMRGT model. A combination of expert judgment and data-driven experimentation determines both the fuzzy subset and the variable ranges in this model. This method streamlines incorporating the event's physics into a fuzzy model. The steps involved in the SMRGT procedure are as follows:

1. Define input and output variables: The first step is to define the input and output variables of the fuzzy logic system. This work used three inputs (Precipitation, temperature, and humidity) with one output (flow coefficient).

2. Determine membership functions: Membership functions (MFs) map input values to fuzzy sets. Five MFs were used and labeled as; Very low, Low, Medium, High, and Very high. Also, this step involves selecting the shape of the membership function, a triangular shape was selected.

3. Determine the key values: in this step, the unit width (UW), core value (C_i), the number of right-angled triangles (nu), the expanded base width (EUW), and key values (K_i) of the fuzzy sets were determined. Equations [10–18] were used to calculate the key values. Table 1 shows the obtained key values. These key values are the inputs of the model.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.125-146

$$Vr = (P,T,H)\max - (P,T,H)\min \tag{10}$$

$$Ci = K3 = \frac{Vr}{2} - (P,T,H)\min \tag{11}$$

$$UW = \frac{Vr}{nu} \tag{12}$$

$$O = \frac{UW}{2} \tag{13}$$

$$EUW = UW + 0 \tag{14}$$

$$K4 = Ki = C_i + 1 = \left(\frac{Ci - (P,T,H)\min}{2}\right) + (P,T,H)\min \tag{15}$$

$$K2 = C_i - 1 = (P,T,H)\max - \left((P,T,H)\max - \frac{Ki}{2}\right) \tag{16}$$

$$K1 = (P,T,H)\min + \left(\frac{EUW}{3}\right) \tag{17}$$

$$K_5 = (P,T,H)_{\max} - \frac{EUW}{3} \tag{18}$$

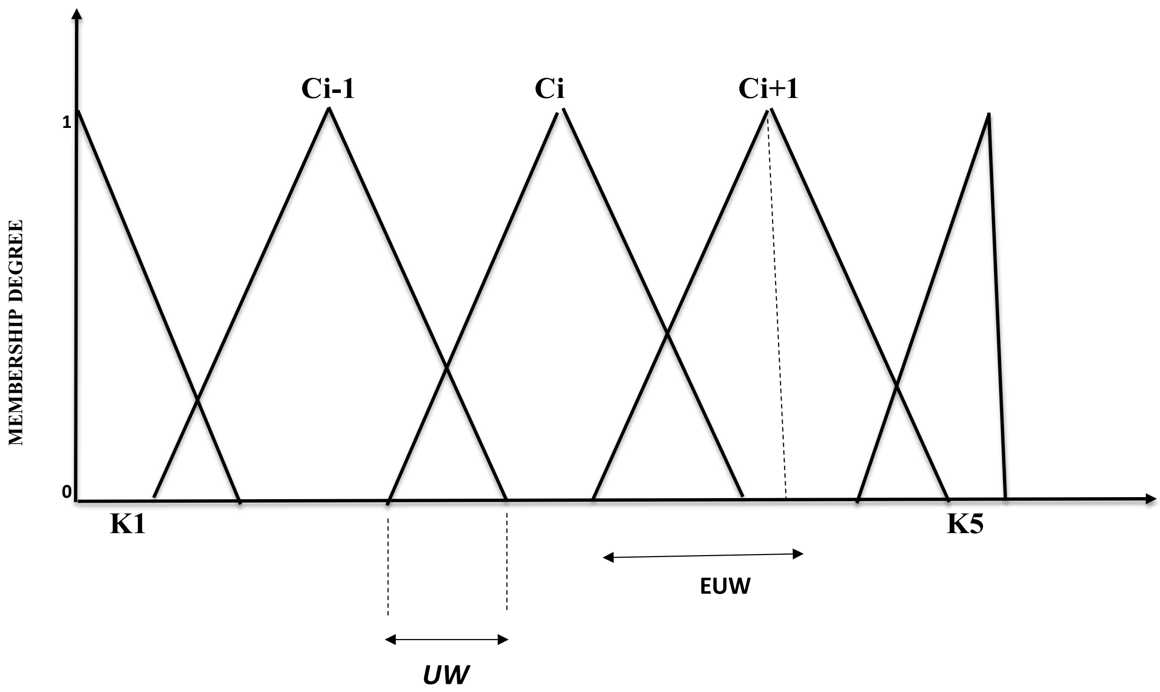


Figure 5. The parameters of the triangular MF.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.125-146

Table 1. key values of the SMRGT model.

	Ci-1 (K2)	Ci (K3)	Ci+1 (K4)	K1	K5
Precipitation	650	1100	1550	312.5	1887.5
Temperature	12.5	25	37.5	3.125	46.88
Humidity	25	50	75	6.25	93.75

4. Generate fuzzy rules: Fuzzy rules map input values to output values. Each rule consists of an antecedent (input) and a consequent (output). In this step, 125 rules were set in pertinent physical conditions such as "IF", "AND", and "THEN."

5. Run the model: MATLAB software was selected. As an operator, the Mamdani algorithm is implemented. The centroid method was selected for the defuzzification procedure. Input and output files prepared and added to the program with (.dat) extension. Then the program with the (.fis) extension is loaded. The (.m) extension file is prepared for running the prepared program. Model results can be obtained by running this file with the (.m) extension. Preparing the program with this procedure will reduce the trial and error process. Then the table of the fuzzy set was created.

2.3.3. GAUSSIAN PROCESS REGRESSION (GPR)

Numerous disciplines employ a potent instrument that can be considered a generalized regression model. This paper uses a Gaussian Process Regression (GPR) model to predict the flow coefficient values. Before explaining the Gaussian Process Regression, it is required to describe a regression model. In regression, i^{th} observation's (y_i) output is considered to be a function of the variables (x_i) input, plus some noise (ε_i).

$$y_i = f(x_i) + \varepsilon_i \tag{19}$$

The fundamental regression function is forecasted based on the input parameters and the given outputs. Once the regression model has been developed, a new value for the output variable can be determined for a given input variable. This is why regression models are widely used [23-25]. For GPR, it is assumed that the regression function (x) is derived from a Gaussian Process (GP) with a zero mean function and the covariance/kernel function (x, x').

$$f(x) \sim GP\left(0{,}k\,(x, x')\right) \tag{20}$$

https://doi.org/10.17993/3ctecno.2023.v12n2e44.125-146

It is also assumed that the noise ε_i has a Gaussian distribution. The function (x, x') is known as a kernel function. This function represents the covariance between the x and x' values in a regression model given x and x' as inputs.

GPR offers numerous advantages over alternative regression models. For instance, it offers an indication of the uncertainty of the predictions, which is crucial for various practical applications. It can also model nonlinear relationships between input and output variables and accommodate missing data.

The procedure of the Gaussian Process Regression (GPR) in MATLAB can be summarised as follows:

i. Load the data of three inputs and one output (The training data was average monthly precipitation, temperature, and humidity records for 15 years) into MATLAB. The input data should be a size N x D matrix, where N is the number of data points and D is the number of input variables. The output data should be a column vector of size N x 1.

ii. Define the kernel function: the kernel function was defined using the 'make kernel' function.

iii. Specify the prior distribution: the prior distribution over the Gaussian process is specified using MATLAB's 'fitrgp' function. We can specify a mean function, a kernel function, and hyperparameters for the kernel function.

iv. Train the model: the GPR model is trained using the 'fitrgp' function. This function estimates the hyperparameters of the kernel function from the training data.

v. Make predictions: the trained GPR model uses the' predict' function to predict new input values. The 'predict' function returns a predicted mean and a variance for each input value.

vi. Load test data: 5 years of measurements of the abovementioned parameters were selected and loaded. Then the prediction was made. Cross-validation (v=5) was selected for GPR to protect the models against overfitting.

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.125-146

```
% Load the input and output data
X = load('input_data.mat');
y = load('output_data.mat');

% Define the kernel function
kernel = fitrgp(X, y, 'KernelFunction', 'squaredexponential');

% Train the model
gprMdl = fitrgp(X, y, 'KernelFunction', 'squaredexponential');

% Make predictions
X_new = [1 2 3]; % example new input values
[y_pred, y_sd] = predict(gprMdl, X_new);

% Evaluate the model
mse = immse(y_pred, y_true);

% Load the trained GPR model
load('gpr_model.mat'); % the trained GPR model is stored in a .mat file

% Load the test data
X_test = load('test_input.mat'); % N x D matrix of new input data

% Make predictions
[y_pred, y_sd] = predict(gprMdl, X_test);

% Evaluate the predictions
y_true = load('test_output.mat'); % N x 1 vector of true output values
mse = immse(y_pred, y_true);
```

Figure 6. The generated code for the GPR model in MATLAB.

2.4. MODELS EVALUATION

Four parameters were used to evaluate the model's performance: Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), the coefficient of determination (R^2), and Mean Square Error (MSE). They were given in Eq. (5-7). MAE, MSE, and RMSE are two measures of error. Thus ideal models would have MAE and RMSE values equal to zero. The coefficient of determination is the proportion of variability the

https://doi.org/10.17993/3ctecno.2023.v12n2e44.125-146

regression line indicates to the variability of data for linear regression. A regression line that is the mean value of data would have $R^2=0$, while an ideal model would have $R^2=1$.

$$MAE = \frac{1}{n}\sum_{1}^{n} |\, \text{Ci, measured} - \text{Ci, estimated} \,| \tag{21}$$

$$MSE = \frac{1}{n}\sum_{1}^{n} (\text{Ci, measured} - \text{Ci, estimated})^2 \tag{22}$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{1}^{n} (Ci, \text{ measured} - \text{Ci, estimated})\hat{}2} \tag{23}$$

3. RESULTS AND DISCUSSION

In this study, the flow coefficient in the Aksu river basin was estimated by using Adaptive Neural Fuzzy Inference System (ANFIS), Simple membership functions and fuzzy Rules Generation Technique (SMRGT), and Gaussian Process Regression (GPR) models. The results were compared with each other. The dataset belonging to the years 2000–2019 was used in modeling the SMRGT and GPR. For ANFIS, seven year's data from 2013-2019 were used; 70% was used for training and 30% for testing. Monthly Precipitation (P), Temperature (T), and Relative Humidity (H) were used as the input variables. To determine the success of the models used to estimate the flow coefficient value, RMSE (root mean square error), MAE (mean absolute error), MSE (mean square error), and R (correlation coefficient) were calculated, as explained in the previous section. The performance of the model results is shown in Table 2. When Table 2 was examined, all models gave similar results. According to the RMSE, MAE, MSE, and R criteria, the best results were obtained in the SMRGT, and the worst was in the GPR.

Table 2. The RMSE, MAE, MSE, and R^2 statistics of all models.

Models	Period	RMSE	MSE	MAE	R^2
ANFIS	Training	1.92	37	1.01	993
	Testing	15.67	2.45	12.15	561
	All data	8.53	728	4.19	863
SMRGT	All data	9.6	0.93	8.07	963
GPR	Training	26.9	7.24	20.26	0.61
	Testing	20.1	4.05	15.79	0.55

In ANFIS analysis, Gaussian parabolic 5 × 5 × 5 Membership Functions (MFs) and Grid partition section were analyzed with 100 iterations, assuming the output as linear.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.125-146

Variation and scatter graphs for the ANFIS method are shown in Fig.7. The correlation coefficient of all data is seen as R: 0.863. As realized in the figure, ANFIS results were close to the observed values.

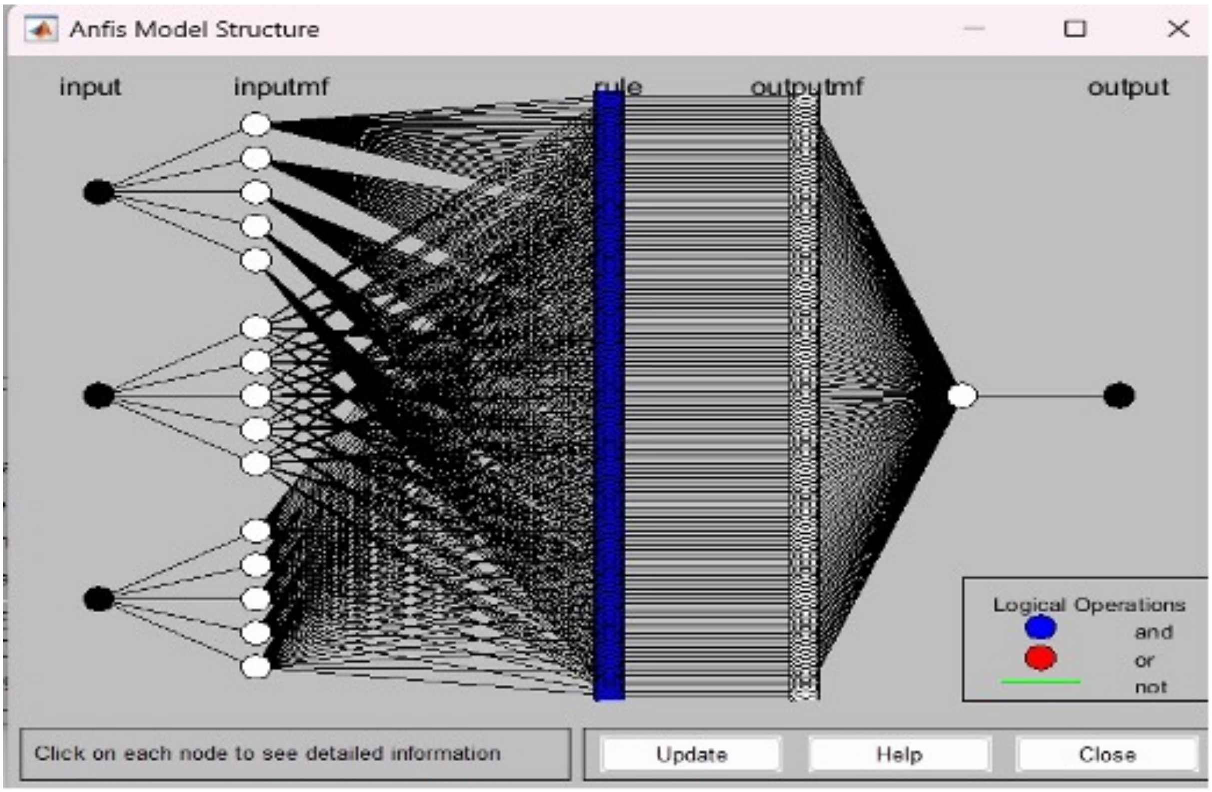


Figure 7. ANFIS structure uses three inputs and 5 MFs for each input with a type of Gaussmf.

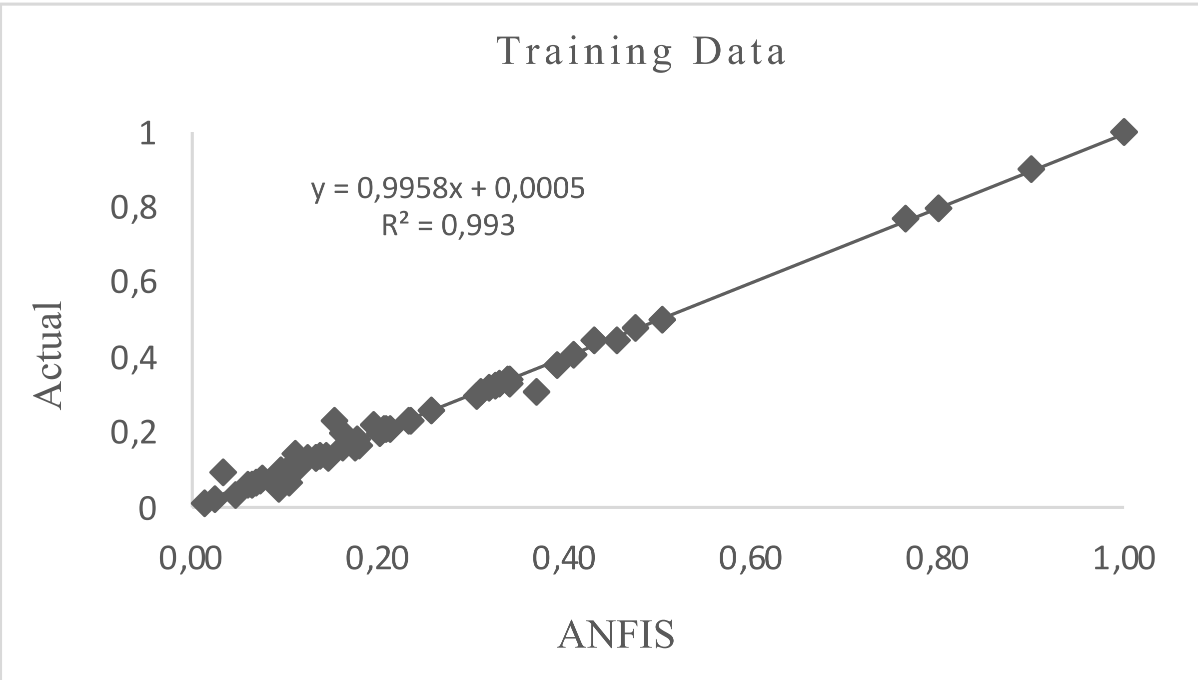


Figure 8. Scatter diagram of the trained data results.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.125-146

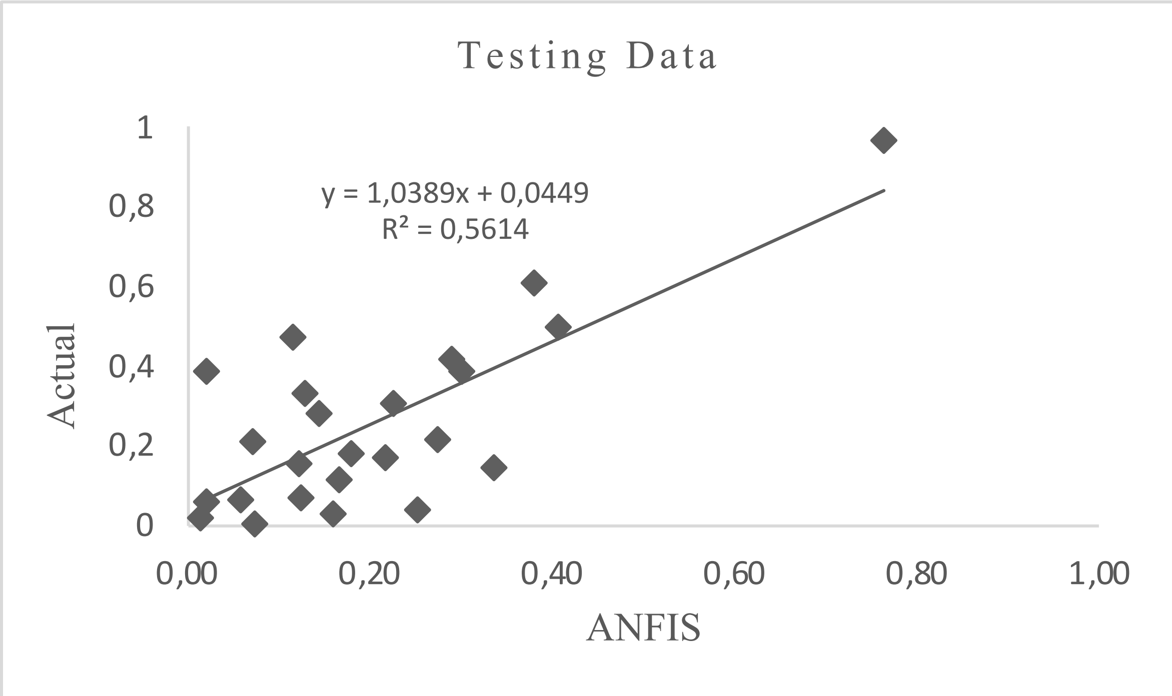


Figure 9. Scatter diagram of the tested data results.

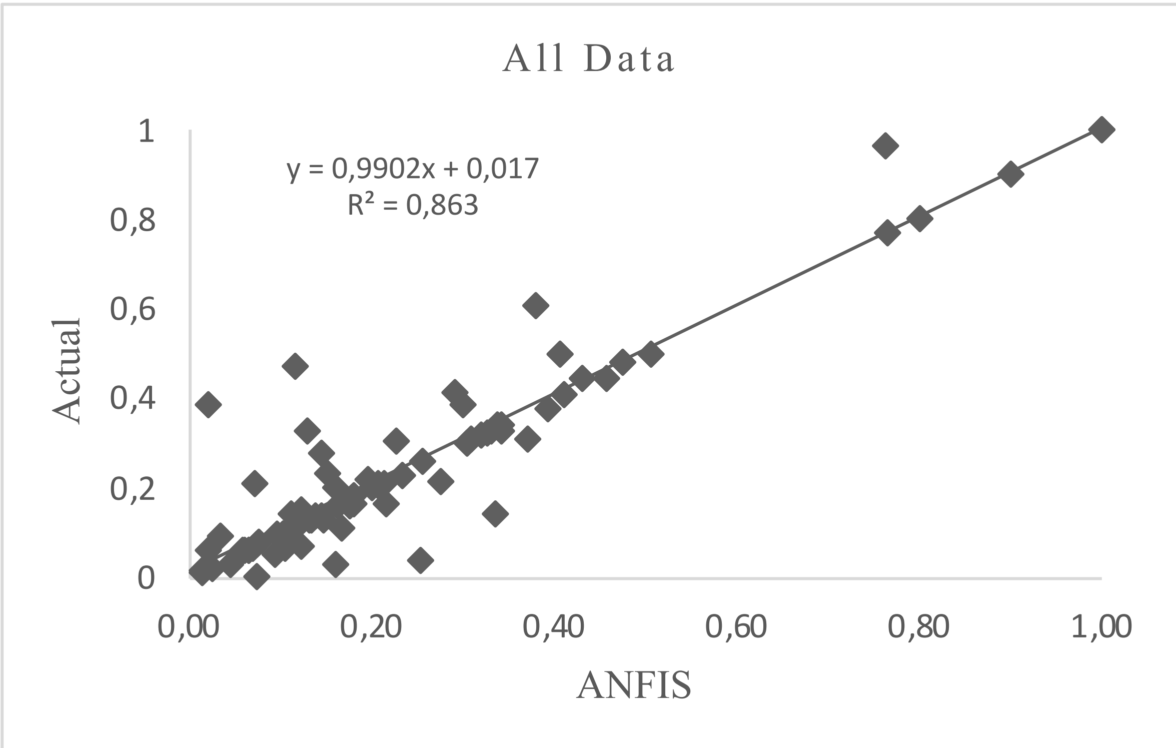


Figure 10. Scatter plot for all data results.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.125-146

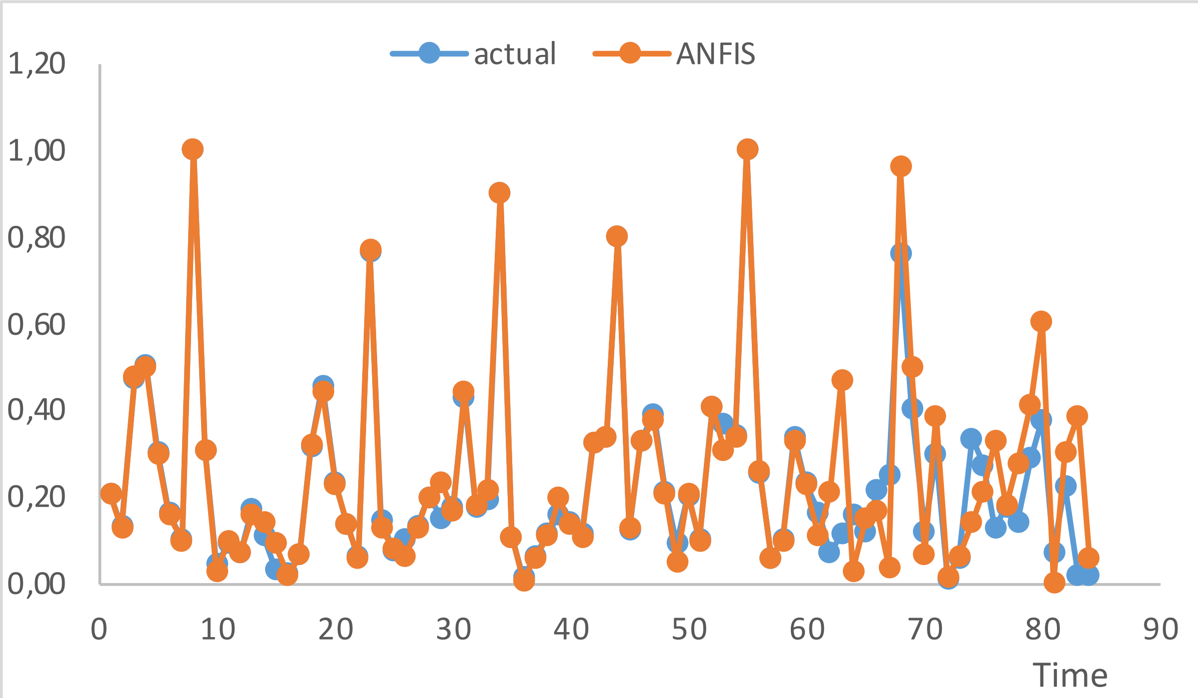


Figure 11. Variation graph of ANFIS model outcomes.

Simple Membership Functions and Fuzzy Rules Generation Technique (SMRGT) model results are given in Figure 12. When the scatter graph was examined, it was seen that the output values of the SMRGT model gave closer results to the actual values; also, the correlation coefficient was 0.96. In Table 2, it was found that the SMRGT model showed the best performance among all models. Compared to all models, it can be seen from Table 2 that SMRGT model results had the low error rates (RMSE: 9.6; MSE: 0.93; MAE: 8.07) and the highest correlation (R: 0.963). The figures show that the SMRGT approach shows almost the same trend as the actual values.

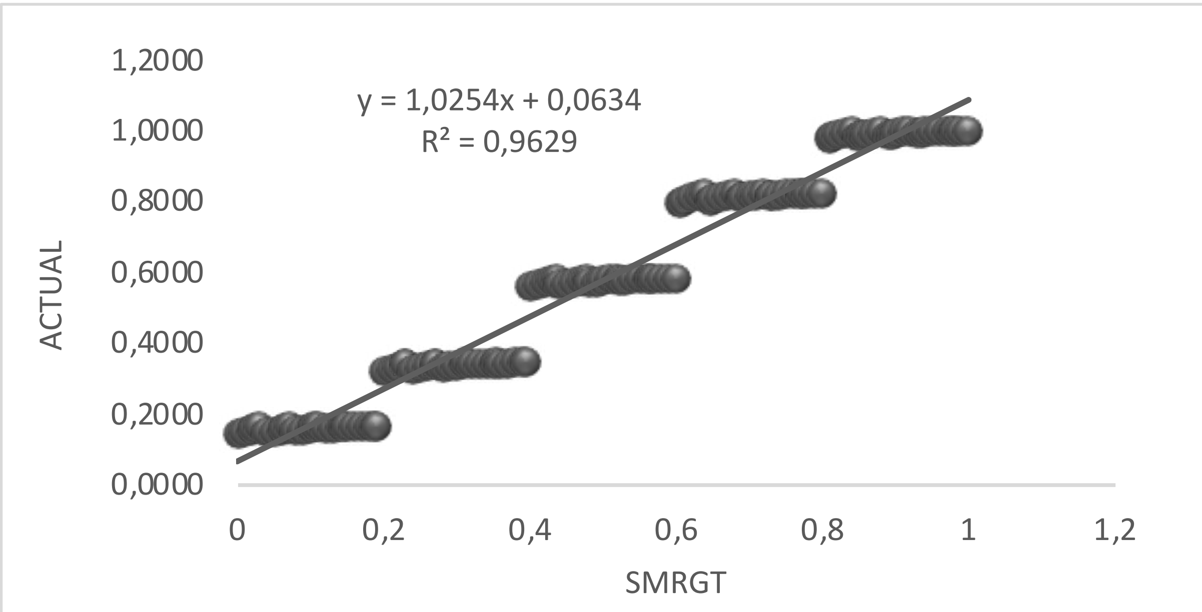


Figure 12. scatter diagram of SMRGT model.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.125-146

The forecasting result of the Gaussian Process Regression (GPR) model for training and testing data are given in Fig.13, 14. It can be seen clearly that some of the data fall along the regression line, while the rest were distributed far to the line. Moreover, the statistic error rate is higher than SMRGT and ANFIS models with a lower correlation coefficient (R^2:61 training; R^2:55 testing). In other words, the predicted data values are not highly fitted with the actual date values as in SMRGT and ANFIS.

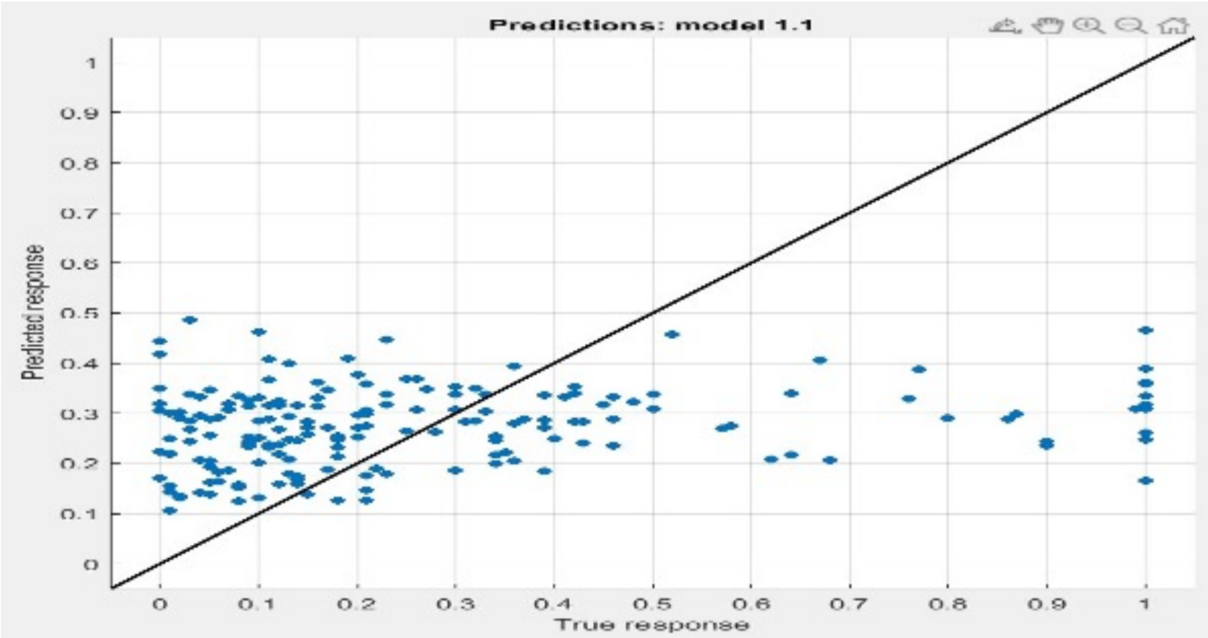


Figure 13. the prediction result of the training set for the GPR model.

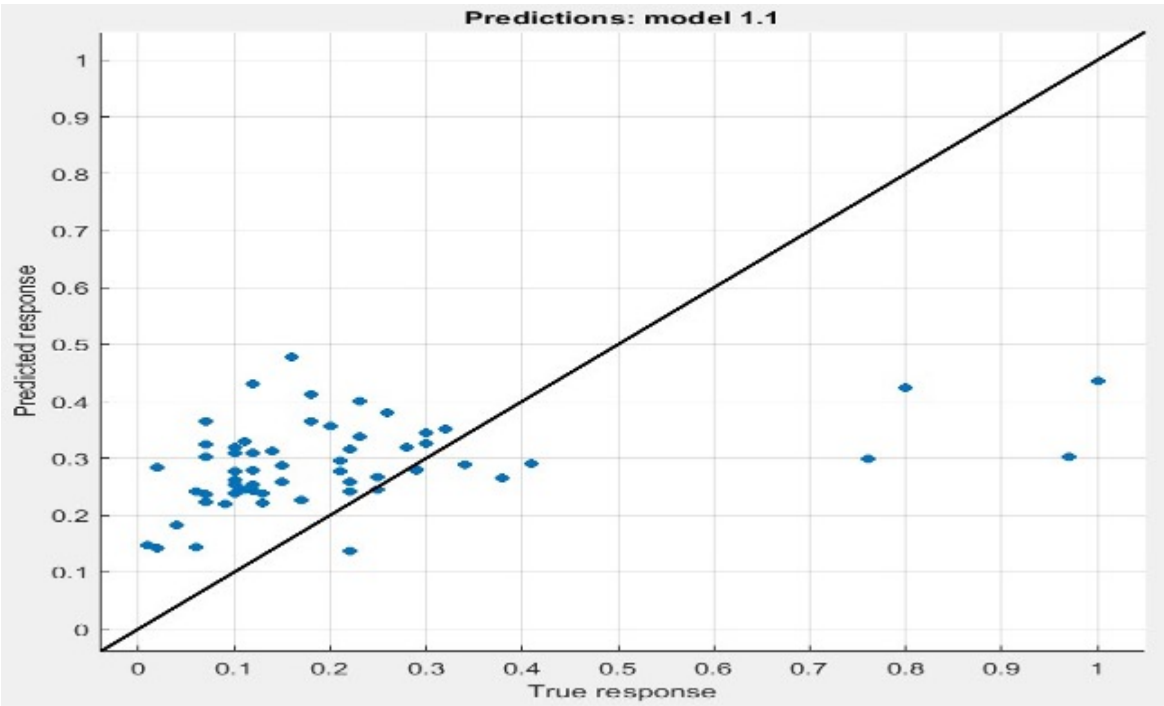


Figure 14. the prediction result of the training set for the GPR model.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.125-146

4. CONCLUSION

Determining river flows and variations is important to use water resources efficiently, construct water structures, and prevent flood disasters. However, accurate flow prediction is related to a good understanding of the hydrological and meteorological characteristics of the river basin. Artificial intelligence has taken a large portion of climate and water science research. The nonlinearity of meteorological variables and their dependency on many other properties and variables render machine-learning models beneficial and efficient in this field. This study used monthly average temperature, precipitation, and relative humidity values for flow coefficient prediction. The dataset belonging to the year range of 2000–2019 in the Aksu River Basin was examined. The flow coefficient was estimated by using Adaptive Neuro-Fuzzy Inference System (ANFIS), Simple Membership Functions and Fuzzy Rules Generation Technique (SMRGT), and Gaussian Process Regression (GPR) models.

The best models were found by applying statistical indicators such as RMSE, MAE, MSE, and R. The SMRGT model performed well with a low error rate and high correlation coefficient.

ANFIS model showed good performance with a lower error rate, but the correlation coefficient was lower than the SMRGT model.

The GPR model performed worse than other models; the error rate was higher, and the correlation coefficient was very low. The reason might be in using an inappropriate kernel function or overfitting or underfitting the data; when the model is too complex or has too many hyperparameters, it may fit the noise in the data rather than the true relationship between the input and output variables. It is important to examine the data and the statistical model carefully is used to identify the reasons for higher statistical errors and lower correlation coefficients. Appropriate statistical techniques and data-cleaning methods can address these issues and improve the accuracy of the results.

For future works, Scientists can improve the predictability of the flow coefficient by looking into the relationships between other variables and precipitation. These variables include wind speed, permeability, and land use information. Understanding what causes flash floods is essential in urban areas where rapid housing development or the conversion of marginal areas into housing is of interest. The overall study demonstrated the predictive ability of fuzzy logic models (SMRGT and ANFIS). Even though the available data size is relatively small, the prediction of the flow coefficient yields very good results and high performance. If more data becomes available, successful models can be used to estimate more accurately. The similarity between statistical parameters for the SMRGT model suggests that it can be relied upon to calculate the flow coefficient. The implementation of the algorithm demonstrates that model calibration does not require additional data. To begin using SMRGT, the modeler's knowledge is required.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.125-146

REFERENCES

(1) Alexander, G. N. (1972). Effect of catchment area on flood magnitude. Journal of Hydrology, 16, 225-240.

(2) Ghazavi, R., Rabori, A. M., & Reveshty, M. A. (2016). Modelling and assessment of urban flood hazards based on rainfall intensity-duration-frequency curves reformation. Natural Hazards and Earth System Sciences Discussions. Advance online publication. https://doi.org/10.5194/nhess-2016-304

(3) Mousavi, S. M., Roostaei, S., & Rostamzadeh, H. (2019). Estimation of flood land use/land cover mapping by regional modelling of flood hazard at sub-basin level case study: Marand basin. Geomatics, Natural Hazards and Risk, 10, 1155-1175.

(4) Masoudian, M., & Theobald, S. (2011). Influence of land surface topography on flood hydrograph. Journal of American Science, 7, 354-361.

(5) Ngamalieu-Nengoue, U. A., Martinez-Solano, F. J., Iglesias-Rey, P. L., & Mora-Melia, D. (2019). Multi-objective optimisation for urban drainage or sewer networks rehabilitation through pipes substitution and storage tanks installation. Water, 11, 935. https://doi.org/10.3390/w11050935

(6) Bedient, P. B., Huber, W. C., & Vieux, B. E. (2008). Hydrology and Floodplain Analysis. Upper Saddle River, NJ: Prentice Hall.

(7) Junior, A. R. B. (2022). Elementos de Hidrologia aplicada. Editora Blucher.

(8) Sen, Z., & Altunkaynak, A. (2005). A comparative fuzzy logic approach to runoff coefficient and runoff estimation. Journal of Hydrology, 312, 1-14.

(9) Blume, T., Zehe, E., & Bronstert, A. (2007). Rainfall-runoff response, event-based runoff coefficients and hydrograph separation. Hydrological Sciences Journal, 52, 843-862. https://doi.org/10.1623/hysj.52.5.843

(10) Che, D., Liang, A., Li, X., & Ma, B. (2018). Remote sensing assessment of safety risk of iron tailings pond based on runoff coefficient. Sensors, 18, 4373. https://doi.org/10.3390/s18124373

(11) Campos, M. De R., & Machado, R. E. (n.d.). Time distribution of intense rainfalls at Campinas, Brazil. International Journal of Advanced Engineering Research and Science (IJAERS), 5(11).

(12) Lallam, F., Megnounif, A., & Ghenim, A. N. (2018). Estimating the runoff coefficient using the analytic hierarchy process. Journal of Water and Land Development, 38, 67-74. https://doi.org/10.2478/jwld-2018-0043

(13) Jang, J. S. R. (1993). ANFIS: adaptive network-based fuzzy inference systems. IEEE Transactions on Systems, Man, and Cybernetics, 23, 665-685.

(14) Jang, J. S., & Sun, C. T. (1995). Neuro-fuzzy modeling and control. Proceedings of the IEEE, 83(3), 378-406.

(15) Huang, M., Zhang, T., Ruan, J., & Chen, X. (2017). A new efficient hybrid intelligent model for biodegradation process of DMP with fuzzy wavelet neural networks. Scientific Reports, 7, 41239. https://doi.org/10.1038/srep41239

(16) Toprak, Z. F. (2009). Flow Discharge Modeling in Open Canals Using a New Fuzzy Modeling Technique (SMRGT). CLEN – Soil, Air, Water, September. https://doi.org/10.1002/clen.200900146

(17) Takagi, T., & Sugeno, M. (1985). Fuzzy identification of systems and its applications to modeling and control. IEEE Transactions on Systems, Man, and Cybernetics, 15(1), 116-132. https://doi.org/10.1109/TSMC.1985.6313399

(18) Jalalifar, H., et al. (2011). Application of the adaptive neuro-fuzzy inference system for prediction of a rock engineering classification system. Computers and Geotechnics, 38(7), 783-790.

(19) Rajesh, S., et al. (2012). Estimation of elastic constant of rocks using an ANFIS approach. Applied Soft Computing, 12(1), 40-45.

(20) Rai, A. A., et al. (2015). Prediction models for performance and emissions of a dual fuel CI engine using ANFIS. Sadhana, 40(2), 515-535.

(21) Sankar, S. G., et al. (2018). Prediction of PM 2.5 using an ensemble of artificial neural networks and regression models. Journal of Ambient Intelligence and Humanized Computing, 9, 1-11.

(22) Xianghong, W., & Baozhen, W. (2019). Research on prediction of environmental aerosol and PM2.5 based on artificial neural network. Neural Computing and Applications, 31(12), 8217-8227.

(23) Raposo, F., Borja, R., & Ibelli-Bianco, C. (2020). Predictive regression models for biochemical methane potential tests of biomass samples: Pitfalls and challenges of laboratory measurements. Renewable and Sustainable Energy Reviews, 127, 109890.

(24) Liu, K., Hu, X., Wei, Z., Li, Y., & Jiang, Y. (2019). Modified Gaussian process regression models for cyclic capacity prediction of lithium-ion batteries. IEEE Transactions on Transportation Electrification, 5(4), 1225-1236.

(25) Chen, X., Huang, J., & Yi, M. (2020). Cost estimation for general aviation aircrafts using regression models and variable importance in projection analysis. Journal of Cleaner Production, 256, 120648.

/09/

SIGNED GRAPHS FROM PROPER COLORING OF GRAPHS

Divya Antoney*

Department of Mathematics CHRIST (Deemed to be University) Bengaluru, India.

divya.antoney@res.christuniversity.in

Tabitha Agnes Mangam

Department of Mathematics CHRIST (Deemed to be University) Bengaluru, India.

tabitha.rajashekar@christuniversity.in

Mukti Acharya

Department of Mathematics CHRIST (Deemed to be University) Bengaluru, India.

mukti1948@gmail.com

Reception: 29/03/2023 **Acceptance**: 22/05/2023 **Publication**: 12/06/2023

Suggested citation:

Antoney, D., Mangam, T. A. and Acharya, M. (2023). **Signed graphs from proper coloring of graphs**. *3C Tecnología. Glosas de innovación aplicada a la pyme, 12(2)*, 148-161. https://doi.org/10.17993/3ctecno.2023.v12n2e44.148-161

ABSTRACT

Let $\chi(G)$ denote the chromatic number of a graph G. Under the proper coloring of a graph G with $\chi(G)$ colors, we define a signed graph from it. The obtained signed graph is defined as parity colored signed graph and denoted as S_c. The signs of edges of G are defined from the colors of the vertices as $+(-)$ if the colors on the adjacent vertices are of the same (opposite) parity. In this paper, we initiate a study on S_c. We further investigate the chromatic rna number of some classes of graphs concerning proper coloring.

KEYWORDS

Signed graph, parity colored signed graph of a graph, chromatic rna number.

INDEX

https://doi.org/10.17993/3ctecno.2023.v12n2e44.148-161

1. INTRODUCTION

In this paper, we consider simple connected graphs. The smallest positive integer k such that $f : V(G) \to \{1,2,\ldots,k\}$ such that $f(a) \neq f(b)$ whenever ab is an edge in G is called the chromatic number of G and it is denoted by $\chi(G)$.

In [7], the concept of a signed graph has been introduced. Let $S = (G,\sigma)$ be a signed graph with $\sigma : E(G) \to \{+,-\}$ the signature of G, where G is the underlying graph of S. The edges of G receiving $+(-)$ sign are called the positive (negative) edges of S. A signed graph is all positive (negative) if all the edges of S are positive (negative). A homogeneous signed graph is a signed graph in which either all the edges are positive or all negative and heterogeneous, otherwise. $E^-(S)\big(E^+(S)\big)$ denotes the negative (positive) edge set of the signed graph and $E(S) = E^-(S) \cup E^+(S)$ is the edge set. In [2], by the negation, we mean a signed graph $\eta(S)$ obtained S by reversing the sign of every edge S. By $d^-(v)\big(d^+(v)\big)$ we mean the number of negative (positive) edges incident to v and $d(v) = d^-(v) + d^+(v)$. The positive (negative) edges in S are represented by solid (dashed) line segments as shown in Figure 1. The negative section of a signed S is the maximal connected edge-induced subgraph in S consisting of only the negative edges S as defined in [2].

Motivated by the definition of rna number $\sigma^-(G)$[3], we initiate the concept of chromatic rna of G. For a detailed study of the rna number, we refer to [4,9–11]. The signed graphs $S = (G,\sigma)$ and $S' = (H,\sigma')$ are isomorphic if there exists a one-to-one correspondence between the vertex sets which preserves adjacency and signs on it.

A triangular Snake graph $TS(L)$ is obtained from a path on $L+1$ vertices in which every edge is replaced by a triangle. The sign of a cycle (path) in a signed graph is the product of the signs of its edges. A cycle is said to be positive if the product of the signs of the edges is positive or the cycle has an even number of negative edges. A signed graph S is said to be balanced if all the cycles in S are positive [7]. Therefore, acyclic signed graphs are always balanced. Two vertices u and v of S_c are of the same parity if their colors $c(u)$ and $c(v)$ are both odd or both even and of opposite parity otherwise [4].

Motivated by the concept of set coloring in signed graphs [1] and induced signed graphs [5], we initiate a study on S_c of a graph. We refer to [6,8,12,13] for our study. Throughout the paper, by S_c we mean parity colored signed graph of a graph.

1.1. PRELIMINARIES

Definition 1.1. Let $A = \{1,2,\ldots,\chi(G)\}$ be a set of colors and $c : V(G) \to A$ be an onto function. Then parity colored signed graph of a graph G (S_c, in short) is defined by taking the signature function for every edge uv in G as:

https://doi.org/10.17993/3ctecno.2023.v12n2e44.148-161

$$\sigma_c(uv) = \begin{cases} + \text{, } c(u) \text{ and } c(v) \text{ are both odd or both even} \\ - \text{, Otherwise.} \end{cases}$$

Example 1. In Figure 1(a) we show a proper coloring of a graph and in Figure 1(b) its S_c.

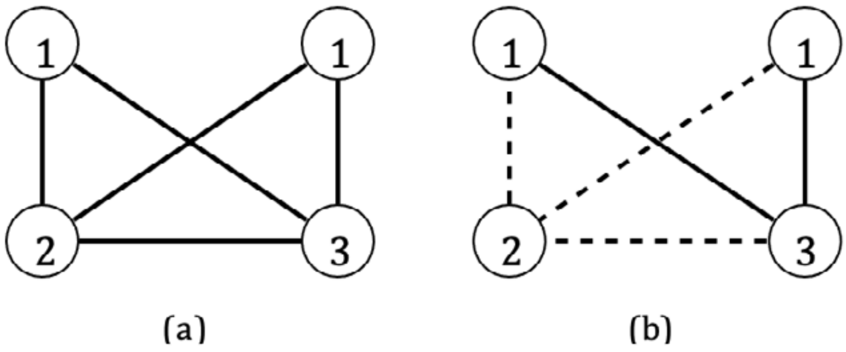


Figure 1. A graph with its Sc

Definition 1.2. The chromatic rna number of a graph G, denoted by $\sigma_c^-(G)$, is the smallest number of negative edges in S_c with respect to any proper coloring of G.

2. RESULTS ON Sc

Now we investigate some properties of S_c.

Observation 2.1. *S_c is positive homogeneous if $\forall v_i \in V\left(S_c\right), c\left(v_i\right) \equiv 1(mod 2)$ $\left(c\left(v_i\right) \equiv 0(\bmod 2)\right)$.*

From the definition of S_c, we can see that it is not unique. Does there exist a graph whose Sc is unique? The answer is yes as shown below.

Proposition 2.2. *S_c on a complete graph is unique up to isomorphism.*

Proof. The chromatic number of K_n is n with $c : V\left(K_n\right) \rightarrow \{1,2,\ldots,n\}$ as the vertex coloring. Since K_n is uniquely colored under c, there is exactly one S_c on K_n up to isomorphism.

Theorem 2.3. *Every non-trivial S_c of order n will have at least one negative edge.*

Proof. Let G be a non-trivial graph with $\chi(G) = k \leq n$ and $|V(G)| \geq 2$. Therefore, $\chi(G) = k \geq 2$. If $\chi(G) = 2$, then there exist at least two vertices colored with 1 and 2. Therefore, S_c will have a negative edge between these two vertices. So let $\chi(G) = k > 2$. Under the proper coloring of the graph, there exists a vertex v_i colored with m which is adjacent to vertices colored with $\{1,2,\ldots m-1,m+1,\ldots k\}$. If the vertex v_i is colored with an odd (even) number, then the edge between v_i and the vertex colored with $2(1)$ is a negative edge in S_c. Hence the result follows.

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.148-161

The following theorem gives the balanced nature of S_c.

Theorem 2.4. *S_c of graph G is balanced.*

Proof. Consider S_c of G and let $o_i(e_i)$ represent the colors with odd (even) positive numbers. If G is acyclic, then obviously S_c is balanced. Assume that S_c contains at least one cycle. Consider an arbitrary cycle C_k in G. Without loss of generality, let C_k be the cycle on the vertices $v_1v_2\ldots v_kv_1$. Consider a path P_k on the vertices $v_1v_2\ldots v_k$ of the cycle C_k. Then, there are two cases:

Case 1: Under the function c, if the end vertices of P_k are colored with numbers of the same parity, then S_c of P_k will have an even number of negative edges, and the edge between v_1 and v_k will receive a positive sign. We can observe that when vertices of opposite colors are adjacent in a cycle, it will always induce two negative edges as seen in Figure 2. Therefore the cycle has an even number of negative edges.

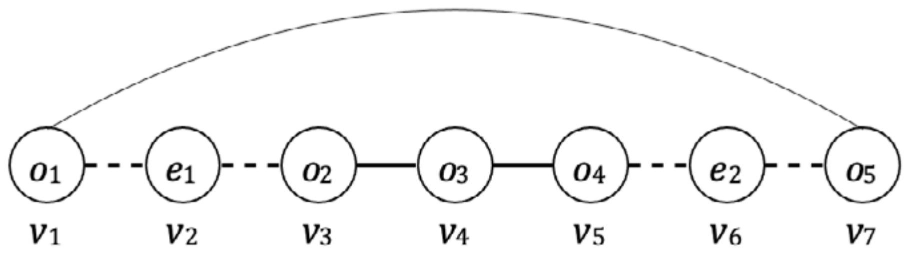


Figure 2. S_c on C_7

Case 2: Under the function c, if the end vertices of P_k are colored with numbers of opposite parity, then S_c of P_k will have an odd number of negative edges and the edge between v_1 and v_k will receive a negative sign as seen in Figure 3.

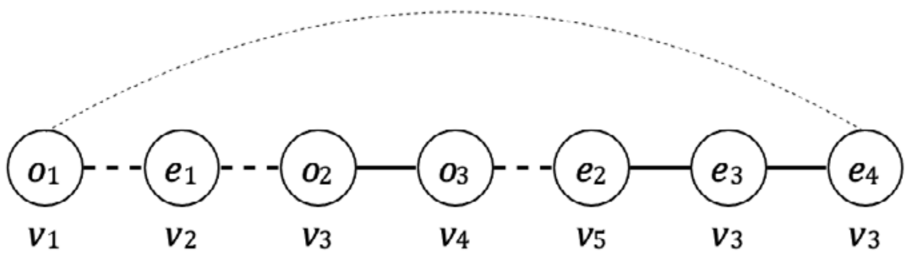


Figure 3. S_c on C_7

In both cases, any cycle in S_c has an even number of negative edges. Therefore, S_c is always balanced.

The converse need not be true as we know that positive homogeneous signed graphs are always balanced. However, S_c can never be a positive homogeneous signed graph. This observation leads to the next result.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.148-161

Theorem 2.5. *The negation of S_c is balanced if and only if the underlying graph of S_c is bipartite.*

Proof. Let S_c and $\eta(S_c)$ be the parity-colored signed graph and its negation respectively. Assume that $\eta(S_c)$ is balanced. Therefore, every cycle in $\eta(S_c)$ contains an even number of negative edges. This implies S_c contains an even number of positive edges. From Theorem 2.4, every cycle in S_c contains an even number of negative edges. Now, every cycle of S_c has an even number of negative and positive edges. Therefore, the underlying graph of S_c is bipartite.

Assume G is a bipartite graph. Therefore, every cycle in G is of even length. From Theorem 2.4, every cycle in S_c contains an even number of negative edges. Hence $\eta(S_c)$ is balanced.

Remark 1. *A subsigned graph of S_c need not be S_c.*

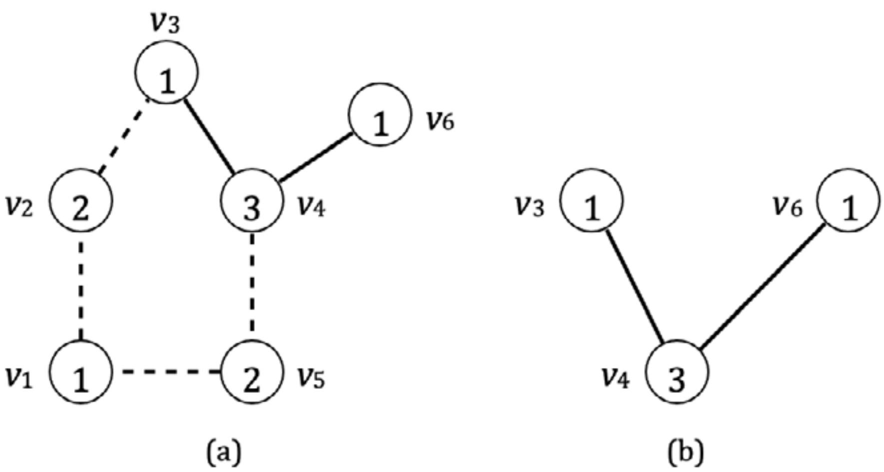


Figure 4

The underlying graph of the signed graph in Figure 4(a) has chromatic number 3. Therefore, the S_c in Figure 4(a) has at least one positive edge. Furthermore, the underlying graph of the signed graph in Figure 4(b) has chromatic number 2. Therefore, the S_c of Figure 4(b) is negative homogeneous. In Figure 4(a), the edges v_3v_4 and v_4v_6 will receive a positive sign. However, the subsigned graph with the same vertices will receive negative signs only since its chromatic number is 2. Therefore, the subsigned graph of S_c need not be S_c.

Remark 2. *The parity-colored signed graphs of graph G need not be isomorphic.*

The parity-colored signed graphs of Figure 5(a) are shown in Figure 5(b) and Figure 5(c). We can observe that they are not isomorphic to each other.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.148-161

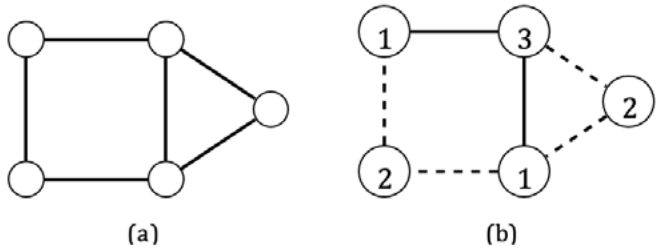


Figure 5

3. CHARACTERIZATION OF S_c

In this section, we will characterize S_c of some classes of graphs like bipartite graphs, cycles, and wheels. We also explore the 'chromatic rna' number of some classes of graphs concerning proper coloring.

We have already noted that there exists at least one negative edge in S_c. Therefore, it is impossible to have a positive homogeneous S_c. So we aim at finding a negative homogeneous S_c.

Theorem 3.1. *S_c is negatively homogeneous if and only if its underlying graph is bipartite.*

Proof. Assume that S_c is negatively homogeneous. From the balanced nature of S_c, its vertices can be partitioned into two subsets such that the edges between them are negative. Therefore, the vertices can be colored with two colors. This implies that the underlying graph of S_c is bipartite.

The converse is easy to see as G is bipartite and we need only two colors to color its vertices and get a negative homogeneous signed graph. Hence the result.

Corollary 3.2. *S_c of $G_1 \circ G_2$ is negative homogeneous if and only if G_2 is $\overline{K_n}$ and G_1 being $\overline{K_m}$ or bipartite graph.*

Corollary 3.3. *S_c of $G_1 + G_2$ is negative homogenous if and only if G_1 is $\overline{K_n}$ and G_2 being $\overline{K_m}$.*

We have seen that S_c is balanced. Next, we discuss the nature of a negative section in S_c of a cycle.

Proposition 3.4. *The negative section in S_c of a cycle C_k is always of even length or a whole cycle of even length.*

Proof. We know that $\chi\left(C_k\right) = 2(3)$, when k is even (odd). Therefore, there exists at least one vertex colored with 2 in C_k. In the proper coloring of C_k, the vertex colored with 2 is adjacent to the vertex colored with 1 or 3. This will give negative edges between the vertices colored with 1 and 2 or 2 and 3. Therefore, the negative

https://doi.org/10.17993/3ctecno.2023.v12n2e44.148-161

section of C_k is of even length and when k is even the cycle will have all negative edges.

The next theorem gives the characterization of the signed cycle which is the S_c of its underlying graph.

Theorem 3.5. *A signed cycle C_k on k vertices is S_c if and only if C_k satisfies any one of the following:*

(i) C_k is negatively homogeneous for even k.

(ii) C_k is heterogeneous for odd k with length of each negative section even.

Proof. In C_k, the number of negative sections is equal to the number of positive sections. Let $l_{ni}\left(l_{pi}\right), 1 \leq i \leq \left\lfloor \frac{k}{2} \right\rfloor$, be the negative (positive) sections in a signed cycle.

Case 1: For even k, C_k is a bipartite graph. From Theorem 3.1, S_c of C_k is negative homogeneous. Hence (i) follows.

Case 2: For odd k, C_k is heterogeneous. From Proposition 3.4, the length of each negative section is even. Hence (ii) follows.

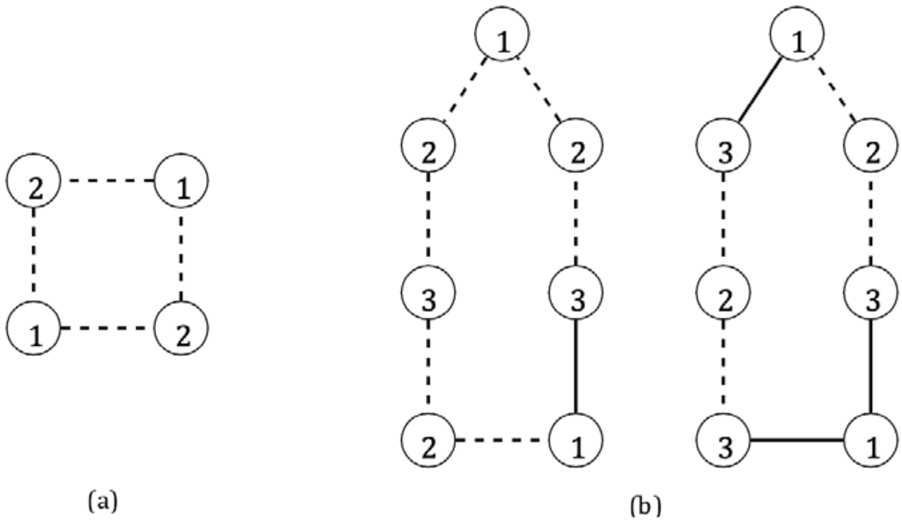


Figure 6. S_c of C_4 and C_7

Sufficiency is easy to see in Figure 6.

The next theorem gives the characterization of S_c on a wheel having an odd number of vertices.

Theorem 3.6. *A signed wheel $W_n = C_{n-1} + K_1$ for an odd integer n is S_c if and only if W_n satisfies any one of the following:*

https://doi.org/10.17993/3ctecno.2023.v12n2e44.148-161

(i) C_n *is positive homogeneous and* $\left|E^-\left(W_n\right)\right| = \left|E^+\left(W_n\right)\right|$.

(ii) C_{n-1} *is negative homogeneous,* $\left\| E^-\left(W_n\right) | - | E^+\left(W_n\right) \right\| = n-1$ *and the distance between the vertices which are the end vertices of the positive edge lying on the* C_{n-1} *is two.*

Proof. We know that $\chi\left(W_n\right) = 3$ (n is odd). The vertices of C_{n-1} can be colored in two ways such that the edges of C_{n-1} are either positive (negative) homogeneous. If the vertices on the cycle are colored with 1 and 3 (1 and 2 or 2 and 3), then C_{n-1} is positive (negative) homogeneous respectively.

Case 1: If C_{n-1} is positive homogeneous, the vertex of K_1 will be colored with 2 only and the edges joining K_1 to all the vertices of C_{n-1} are negative.

Therefore, $\left|E^-\left(W_n\right)\right| = \left|E^+\left(W_n\right)\right|$. Thus (i) holds.

Case 2: If C_{n-1} is negative homogeneous, then the vertex of K_1 can be colored with 1 or 3. Then the edges joining K_1 to all the vertices of C_{n-1} are negative (positive) depending upon the colors on the C_{n-1} and it is easy to see that the distance between any two vertices lying on C_{n-1} which have a positive edge incident on them is two. We can observe that $\left|E^-\left(W_n\right)\right| = n-1+\frac{n-1}{2}$ and $\left|E^+\left(W_n\right)\right| = \frac{n-1}{2}$.

Therefore, $\left\| E^-\left(W_n\right) | - | E^+\left(W_n\right) \right\| = n-1$. Thus (ii) holds.

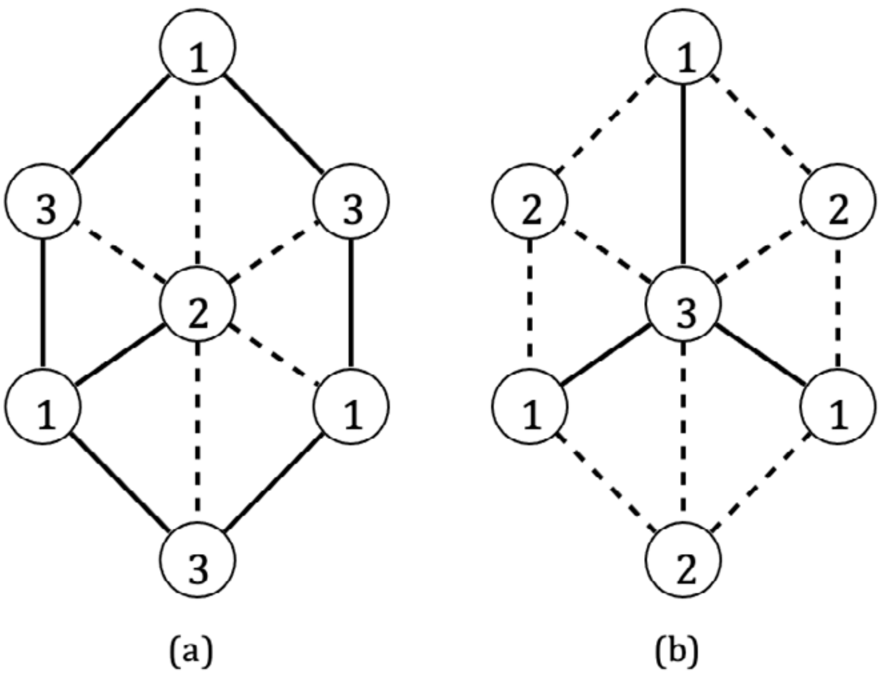


Figure 7. S_c of W_7

Sufficiency part is easy to see in Figure 7.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.148-161

Theorem 3.7. *A signed graph on $TS(L)$ is S_c if and only if the following conditions hold:*

(i) Every cycle in $TS(L)$ has exactly two negative edges and

(ii) For a vertex $v \in V(TS(L))$ whose $d(v) = 4$, its $d^-(v)$ is either 4 or 2, and $d(v) = 2$ is due to two negative edges incident at v lying in two adjacent triangles.

Proof. Assume that $TS(L)$ is S_c. We know that $\chi(TS(L)) = 3$. From the definition of S_c, each triangle of $TS(L)$ will have 2 negative edges. Hence (i) follows.

Now we prove (ii), let vertex $v \in V(TS(L))$ whose $d(v) = 4$ has $d^+(v) = 4$. That is, there is an edge in a triangle whose end vertices receive same color. This is a contradiction. Similarly we can show that $d^+(v) \neq 3$ and $d^+(v) \neq 1$. Therefore, $d^+(v)$ can be 2 or 0. In other words, $d^-(v) = 2$ or 4. If $d^-(v) = 2$ and two negative edges lie in the same triangle then the adjacent triangle will have exactly one negative edge, which is not possible. Thus $d^-(v) = 2$ is due to the negative edges lying in two adjacent triangles. When $d^-(v) = 4$, the proof is easy to see. Thus (ii) follows.

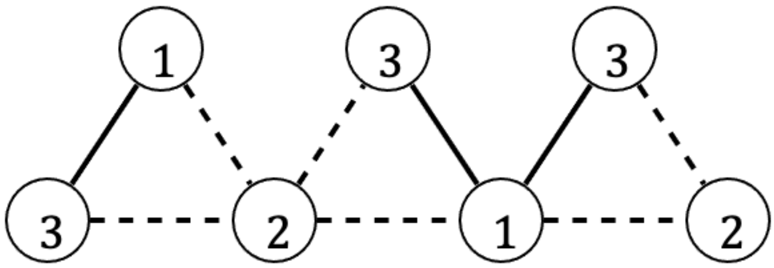


Figure 8. S_c of $TS(3)$

Further sufficiency is easy to see. S_c of $TS(3)$ is shown in Figure 8. Hence the proof.

4. CHROMATIC RNA NUMBER

Definition 4.1. The chromatic rna number of a graph G, denoted by $\sigma_c^-(G)$, is the smallest number of negative edges in S_c with respect to any proper coloring of G.

We investigate the 'chromatic rna' number of bipartite graphs, complete graphs, multipartite graphs, and cycle-related graphs.

Proposition 4.2. *For any bipartite graph B, $\sigma_c^-(B) = |E(B)|$.*

Proof. From Theorem 3.1, S_c of a bipartite graph is negative homogeneous. Therefore, $\sigma_c^-(B) = |E(B)|$.

Proposition 4.3. *For any complete graph Kn,*

https://doi.org/10.17993/3ctecno.2023.v12n2e44.148-161

$$\sigma_c^-(K_n) = \begin{cases} \frac{n^2}{4}, n \text{ is even.} \\ \frac{n^2-1}{4}, n \text{ is odd} \end{cases}$$

Proof. From Proposition 2.2, the S_c of a complete graph, K_n is unique up to isomorphism. We know that $\chi(K_n) = n$. Let $X(Y)$ be the set of vertices colored with even (odd) positive integers from the set $\{1,2,\ldots,n\}$. The edges of K_n that occur across the set $X(Y)$ receive a negative sign. That is, the total number of negative edges is $|X||Y|$.

Case 1: When n is even, $|X| = |Y| = \frac{n}{2}$. Hence, $|X||Y| = \frac{n^2}{4}$.

Therefore, $\sigma_c^-(K_n) = \frac{n^2}{4}$.

Case 2: When n is odd, $|X| = \frac{n-1}{2}, |Y| = \frac{n+1}{2}$. Hence, $|X||Y| = \frac{n^2-1}{4}$.

Therefore, $\sigma_c^-(K_n) = \frac{n^2-1}{4}$. Hence de proof

Proposition 4.4. *For any complete r-partite graph* $K_{n,n,\ldots,n}$,

$$\sigma_c^-(K_{n,n,\ldots n}) = \begin{cases} \frac{r^2}{4}n^2, r \text{ is even} \\ \frac{r^2-1}{4}n^2, r \text{ is odd} \end{cases}$$

Proof. From Proposition 2.2, the Sc of a complete r-partite graph, $K_{n,n,\ldots,n}$ is unique up to isomorphism and its chromatic number is r. Let $X(Y)$ be the set of vertices colored with even (odd) positive integers from the set $\{1,2,\ldots,r\}$. The edges of $K_{n,n,\ldots,n}$ will receive a negative sign if and only if they occur between the sets X and Y. Since each set has n elements, the total number of negative edges is $|X||Y|n^2$.

Case 1: When r is even, $|X| = |Y| = \frac{r}{2}$. Hence, $|X||Y| = \frac{r^2}{4}$.

Therefore, $\sigma_c^-(K_{n,n,\ldots n}) = \frac{r^2}{4}n^2$.

Case 2: When r is odd, $|X| = \frac{r-1}{2}, |Y| = \frac{r+1}{2}$. Hence, $|X||Y| = \frac{r^2-1}{4}$.

Therefore, $\sigma_c^-(K_{n,n,\ldots nn}) \frac{r^2-1}{4}n^2$. Hence the proof.

We observe that the chromatic rna number of bipartite graphs, complete graphs, and complete multipartite graphs with respect to proper coloring is equal to the number of negative edges in them respectively. Next, we discuss a class of graphs for which it does not hold true.

Proposition 4.5. *For any cycle* C_k,

$$\sigma_c^-(C_k) = \begin{cases} k, k \text{ is even.} \\ 2, k \text{ is odd.} \end{cases}$$

https://doi.org/10.17993/3ctecno.2023.v12n2e44.148-161

Proof. For any cycle C_k, we have the following two cases:

Case 1: The cycle on the even number of vertices is a bipartite graph. From Theorem 3.5, the S_c of the cycle is negatively homogeneous.

Therefore, $\sigma_c^-\left(C_k\right) = k$ (k is even).

Case 2: Let the vertices of the cycle be vi such that $v_i v_{i+1} \in E\left(C_k\right)$ and $v_k v_1 \in E\left(C_k\right) \forall i, 1 \leq i < k$. From Theorem 2.3 and Theorem 2.4, C_k is balanced, and C_k will have at least one negative edge. Therefore, at least two negative edges exist in C_k. Let the edges be v1vk, and $v_k - 1 v_k$. Since the chromatic number of the odd cycle is three, let $C : V\left(C_k\right) \rightarrow \{1,2,3\}$ be the vertex coloring function. Consider the following coloring.

The vertices $v_1, v_3, \ldots v_{k-2}$ are colored with 1. The vertices $v_2, v_4, \ldots v_{k-1}$ are colored with 3, and the vertex v_k is colored with 2. This coloring gives two negative edges in the C_k. Therefore, $\sigma_c^-\left(C_k\right) = 2$ (k is odd).

Proposition 4.6. *Le G is a graph having k cycles with exactly one vertex in common and the length of each cycle is greater than or equal to 3. If m cycles are of odd length and the remaining cycles are of even length then,*

$$\sigma_c^-(G) = \begin{cases} |E(G)|, & \text{If all cycles are even.} \\ 2k, & \text{If all cycles are odd.} \\ 2m, & \text{otherwise} \end{cases}$$

Proof. Consider a graph G having k cycles with exactly one vertex in common. We arrange the cycles in such a way that the first m cycles are of odd length and the remaining cycles are of even length.

Case 1: If G contains cycles only on an even number of vertices, then G is a bipartite graph. From Theorem 3.5, $\sigma_c^-(G) = |E(G)|$.

Case 2: If G contains cycles only on the odd number of vertices, then $\chi(G) = 3$. From Theorem 3.5, cycles on the odd number of vertices will have a minimum of two negative edges. From Proposition 4.5, $\sigma_c^-(G) = 2k$.

Case 3: If G contains cycles on odd and even numbers of vertices, then clearly $\chi(G) = 3$. In this case cycles on even number vertices can be colored with 1 and 3 such that they have zero negative edges. From Proposition 4.5, cycles on the odd number of vertices will have a minimum of two negative edges. Therefore, $\sigma_c^-(G) = 2m$. Hence the proof.

Proposition 4.7. *For a triangular snake graph $TS(L), \sigma_c^-(TS(L)) = 2L$.*

The following result gives the characterization of a graph with respect to a specific rna number associated with it.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.148-161

Proposition 4.8. *$\sigma_c^-(G) = 1$ if and only if G is P_2.*

We know that there exists more than one graph whose rna number is $n \in \mathbb{N}$, for $n \geq 2$. Is it possible to construct S_c with a given rna number? The answer is yes.

Theorem 4.9. *There exists S_c for every natural number n such that $\sigma_c^-(G) = n$.*

Proof. For every n ∊ N, consider a path P_{n+1} on $n + 1$ vertices. From Theorem 3.1, the path is always negative homogeneous. Therefore, there exists S_c with a given rna number.

We also have some other graphs such as $K_{1,n}$ with fixed rna numbers.

5. CONCLUSION

In the paper, we have initiated a study on S_c. We have given the characterization of S_c on some classes of graphs. We have investigated the rna number with respect to the proper coloring of some classes of graphs and we have also shown the existence of graphs with a given rna number.

6. ACKNOWLEDGMENT

We thank the referees and express gratitude for their valuable suggestions.

REFERENCES

(1) Acharya, B. D. (2012). Set-valuations of a signed digraph. Journal of Combinatorics, Information & System Sciences, 37, 145-167.

(2) Acharya, M. (2017). C- Cordial coloring in Signed Graphs. Electronics Notes of Discrete Mathematics, 63, 11-22.

(3) Acharya, M., & Kureethara, J. V. (2021). Parity coloring in Signed Graphs. J. Prime Research in Math., 17(2), 1-7.

(4) Acharya, M., Kureethara, J. V., & Zaslavasky, T. (2021). Characterizations of some parity signed graphs. Australasian Journal of Combinatorics, 81(1), 89-100.

(5) Aniyan, A., & Sudev, N. K. (2020). Induced Signed Graphs of some classes of Graphs. Proceedings of the Jangjeon Mathematical Society, 2, 283–291.

(6) Chartrand, G., & Zang, P. (2011). Chromatic Graph Theory. Chapman and Hall/ CRC Press.

(7) Harary, F. (1953). On the notion of balance of a signed graph. Michigan Math. J., 2(6), 143-146.

(8) Jensen, T. R., & Toft, B. (2011). Graph Coloring Problems. John Wiley and Sons.

(9) Kureethara, J. V. (2020). New developments in the study of parity signed graphs. AIP Conference Proceedings, 2261(1), 020001.

(10) Reshma, R., Gayathri, H., & Rajendran, S. (2021). On some parameters of parity signed graphs. Turkish Journal of Computer and Mathematics Education, 12(13), 1992-1998.

(11) Sehrawat, D., & Bhattacharjya, B. (accepted). rna number of some parity signed generalized Peterson graphs. Communications in Combinatorics and Optimization.

(12) West, D. B. (1999). Introduction to Graph Theory. Prentice Hall of India.

(13) Zaslavsky, T. (1982). Signed Graphs. Discrete Applied Mathematics, 4(1), 47-74.

/10/

ANALYSIS OF THE CURRENT SITUATION OF UNIVERSITY-CITY INTEGRATION DEVELOPMENT BASED ON DATA MINING TECHNOLOGY AND EXPLORATION OF THE OPTIMIZATION PATH

Xin Ma*

College of Foreign Languages, Zhengzhou Normal University, Zhengzhou, Henan, 450044, China.

School of Humanities and Social Sciences, University Sutera Malaysia, Kuala Lumpur, 56000, Malaysia.

focusmaxine@163.com

Siew Eng Lin

School of Humanities and Social Sciences, University Sutera Malaysia, Kuala Lumpur, 56000, Malaysia.

Reception: 16/03/2023 **Acceptance**: 22/05/2023 **Publication**: 08/06/2023

Suggested citation:

Ma, X. and Eng Lin, S. (2023). **Analysis of the current situation of university-city integration development based on data mining technology and exploration of the optimization path**. *3C Tecnología. Glosas de innovación aplicada a la pyme, 12(2)*, 163-182.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.163-182

ABSTRACT

University is an inevitable product of a city's development to a specific stage. In different social environments and historical stages, universities always develop symbiotically with cities, and the integration of the higher education system and emerging technologies can accelerate the regional economic development of universities and cities. Based on data mining technology, this study uses a neural network algorithm to establish an algorithmic model and sigmoid function as the incentive function to analyze the integration development of emerging technology industry and universities in Dongguan city and provide an optimization path for the integration development of city and universities. The research results show that in the field of scientific and technological research results, the universities in Dongguan City applied for 49,726 patents in 2021 and authorized 25,523, with an efficiency rate of 51.33%. In the area of urban economic development, Dongguan's GDP in 2021 showed strong momentum, achieving a regional GDP of 108.554 billion yuan, an increase of 8.2% over the previous year.

KEYWORDS

Higher education; regional economy; data mining; integration development; optimization path

INDEX

https://doi.org/10.17993/3ctecno.2023.v12n2e44.163-182

1. INTRODUCTION

The 21st century is an era dominated by the knowledge economy, and knowledge innovation and technological innovation are the main features of the era. It is the basic requirement of the era to lead industrial transformation and upgrading through scientific and technological innovation, and to drive the integration and development of cities [1]. Facing the call of the new era and the profound transformation of social life, universities have started to re-examine their functions and status, and cities are also facing new choices in their development, and the integration of universities and cities is the trend [2]. The research on university-led urban economic and social development is of great theoretical value in reconceptualizing the relationship between universities and society, especially the relationship between universities and local communities [3]. In the knowledge economy society, universities are axial institutions with extensive ties to society, which helps to deepen the understanding of basic issues such as the relationship between epistemology and political theory philosophy of higher education, the functions of universities, and universities and society, etc. In the era when the knowledge economy is prevalent, strengthening the ties between universities and enterprises and enhancing the interaction between university science and technology innovation and the development of new industries in cities is the reform and development of universities, innovation of enterprises, and leading The inevitable requirement of society is the way to enhance the core competitiveness of cities, and it is also an effective way to build a national innovation system [4]. Studying the issues related to the interaction mode between university science and technology innovation development and urban emerging industry development is not only an important issue in the field of higher education but also a cross-cutting issue in the fields of sociology, urban economics, and urban political science [5].

Data mining technology is the process of analyzing the correlation between data or studying its data patterns to obtain information of application value from a large amount of data that contains useless information [6]. Unlike traditional data analysis, the process of data mining has no clear assumptions, and the knowledge obtained from data analysis and mining needs to be valid and practical [7]. Among other things, knowledge here refers not to truths, scientific theorems, or pure mathematical formulas in the traditional sense, but rather to relative, new relationships, patterns, and trends that hold under specific conditions and in a specific domain [8]. Data mining technology emerged in the 1980s when its application was mainly oriented to the problems encountered in traditional data processing applications. With the advent of the big data era, more and more open source data have become easily accessible, and these complex and massive data are rich in value, but the huge amount of useful information is often mixed with useless data, which is difficult to identify, resulting in the phenomenon of "data explosion and knowledge paucity" [9]. This requires a more efficient way to find and explore the value in the huge amount of data, and data mining is one of the key technologies. Data mining technology has been widely used in the fields of urban air environment monitoring, urban traffic management, and urban

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.163-182

emerging technology industry combination, among which Zhang L et al [10] selected the weather monitoring data of a city and analyzed the haze weather using a general joint matrix decomposition framework for data integration and its systematic algorithm, and gave a case proof of the proposed data mining algorithm, and the results showed that the algorithm was high accuracy. Mcevoy D et al [11] proposed a data mining algorithm to support climate-adaptive urban development and empirically analyzed the impact of meteorological elements on urban haze. Masey et al [12] used data mining techniques based on bilinear transformation and ICEEMDAN framework to analyze the main reasons for the degradation of urban air quality from an economic point of view, which are the rapid development of urban economy, high-emission industrial and energy structure, and backward environmental protection technology, Korres M P et al [13] used the clustering algorithm in data mining technology to drill down and analyze the causes of haze formation and its impact on all sectors, and indirectly and directly give adjustment suggestions and optimization paths to achieve urban haze management at the source. In urban traffic management, Zhang Q [14] and Cali S [15] et al. mined big data through the integration of intuitionistic fuzzy multi-criteria evaluation for marketing, supply, and purchasing decisions. B Z Z [16], Simovici D [17] et al. provided an idea to discriminate traffic status based on data mining techniques and validated the idea by observing the traffic flow information that The features such as average occupancy, green light phase saturation, and traffic flow were selected for traffic state discrimination, and how to build a traffic state data mining clustering matrix was discussed. Using data preparation techniques, traffic engineering techniques collect traffic data through the loop coil detector of the road, through which four clustering matrices of smooth flow, stable flow, congested flow, and blocked flow can be calculated. Broto [18] based on data mining techniques through spatiotemporal analysis and deep residual networks to analyze the problems in urban governance and construction, and can to some extent realistically reflect the bottlenecks of development and provide a reference for the steady development of cities, Zhang Y [19] based on data mining using big data and knowledge mining methods oriented to intelligent production found that emerging technology industries are most closely related to economic growth, and considered that vigorous development of high-tech industries is a key strategy for stable economic growth, Yan Q [20] used the clustering algorithm in data mining for the integration, data mining, and decision support in informatics of integration, data mining, and decision support, and found that high-tech industries have obvious development advantages and prospects. The continuous development and progress of cities, it is bound to affect the construction process of universities. Kim D Y [21], by establishing an analytical model of simplification and integration methods of data between strategic urban industries and university talent training, concluded that universities should accelerate the cultivation of science and technology innovation talents that adapt to the development of emerging industries in cities and accelerate the pace of university-enterprise interaction, besides, there are scholars who, from the perspective of professional construction, give In addition, some scholars give suggestions on the cultivation of talents from the perspective of professional construction. There are three main characteristics of universities supporting urban development: first, highlighting technical disciplines to support

https://doi.org/10.17993/3ctecno.2023.v12n2e44.163-182

technological innovation, second, deep cross-fertilization of disciplines to contribute to breakthroughs in urban industrial groups, and third, the combination of disciplinary layout points to synergize urban industrial development [22]. To achieve the integrated sustainable development of strategic cities, universities should promote the research and development of urban technology in professional construction on the one hand, and provide a continuous supply of scientific and technological innovation talents on the other hand [23].Tang M et al [24] based on the application of multi-attribute large-scale group decision-making in circular economy development by data mining and group leadership, which is considered to be inextricably linked to the development of urban emerging industries Therefore, it is necessary to optimize the professional structure setting of universities to better connect with the upgrading of urban emerging industrial structure and market demand. From the perspective of science and technology innovation results, the effective docking mechanism between university science and technology innovation results and urban industrial demand development is discussed in depth, and local universities should strive to enhance the ability of science and technology innovation results transformation to provide scientific and technological support for urban industrial development [25-27]. Regarding the research on the integration mode of university science and technology innovation and urban emerging industry development, Sain K et al [28] found that after exploring the academic behaviors of university researchers by developing an integrated early warning system based on artificial intelligence, the interaction modes between universities and urban industries mainly include four categories of joint participation, mutual influence, joint action, and close relationship, due to the different starting points and interest-driven degrees of research behaviors Ali M [29] and Mariani D [30] suggested that through the integration of demand analysis and local cultural wisdom, it is possible to scientifically differentiate talent teams, establish a differentiated talent evaluation system, innovate a "comprehensive + dynamic" training model for scientific and innovative talents, and establish a talent pool for urban development. Zabit M N [31] took the development and validation of the integrated learning method of problem learning as an example of the science and technology evaluation system of "basic research for the world and applied research for the market", revised the relevant policies and texts, innovated the interaction mode with evaluation as the main body, and promoted universities to actively adapt to the development of urban emerging industries. Son K S et al [32] proposed a triple interaction model of "R&D platform-research team-technology innovation" based on the integration of university and city, taking into account the development characteristics of urban emerging industries and the impact of common cause failure and periodic testing.

In summary, at this stage, researchers have conducted a lot of research on data mining technology and analyzed it's supervising and promoting effects on urban development, but often ignore the correlation between cities and universities, and use data mining technology in the research of integration development of cities and universities is almost not involved. In this paper, we use data mining technology to systematically study the interaction mode between university science and technology innovation and urban emerging industry development, and propose specific innovation

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.163-182

paths, and the study amends and supplements the existing theories in light of China's reality and the special characteristics of higher education development, which is important for enriching and developing theories of higher education, education economics, and urban sociology in China. According to the current situation of regional development, the optimal path for the integration and development of cities and universities is explored.

2. CITY AND UNIVERSITY INTEGRATION DEVELOPMENT

Urban culture provides rich nourishment for the formation of local university culture. The role of city culture in local university culture is mainly expressed in rich soil, sufficient nutrients, and innovative sources. What kind of characteristic city culture there is, there will be what kind of characteristic local university culture. The city culture puts a distinctive regional imprint on the local university culture, and the two forms a unique cultural form through extensive interaction, communication, and penetration. In the process of building the university culture, the university will continuously draw on the cultural nutrients of the city, such as the city's history and humanities, excellent traditional culture, red culture, etc., and then become a participant and creator of the city culture, further revealing the connotation and essence of the city culture. As an important part of the city culture, the local university culture is inevitably influenced by the subtle influence of the city culture, and the city culture supports the construction and development of the local university culture.

2.1. CHARACTERISTICS OF INTEGRATION DEVELOPMENT

University is the product of the development of urban civilization to a specific stage, and likewise, the city is the fertile ground for the emergence and development of the university. From the perspective of human civilization, a history of higher education development is also a history of interactive development between universities and cities and continuous integration with society, which runs through all stages of higher education from elitism to popularization and has profound inner inevitability. The relationship between universities and cities can be traced back to medieval Europe. The majority of medieval universities, formed by the market or founded by the church, emerged in the central cities of Europe. In the United States, for example, universities were generally established in the economically prosperous "cities" of the future. The American Civil War accelerated the process of urbanization, and by the end of the 19th century, a network of American cities had taken shape nationwide. The gradual urbanization of universities had a great impact on higher education in terms of enrollment scale, types of institutions, sources of students, etc. In the 1960s, universities, and cities not only strengthened their spatial ties with cities, but also developed comprehensive interactions in the fields of economy, science and technology, and culture. After the 1990s, as the U.S. entered the metropolitan era, universities and cities became more and more interdependent in various fields,

https://doi.org/10.17993/3ctecno.2023.v12n2e44.163-182

forming a symbiotic relationship of "you in me, I in you", showing an obvious endogenous demand. In the process of constant balancing and coordination, universities and cities find common needs and balance points for their development and increasingly become a community of relationships, interests, and destiny.

2.2. INTEGRATION DEVELOPMENT ADVANTAGES

In the large system of social development, universities, and cities are two interdependent, mutually cooperative, and mutually promoting subsystems. The university subsystem provides talent training, science and technology innovation, and other services for the strategic layout of the city development through the interaction and opening with the city and other external environment, while the city subsystem provides various kinds of rich resources for the survival and development of the university, providing a constant source of nutrients for the leapfrog development of the university. It can be seen that the integration and development of universities and cities is a process of mutually beneficial cooperation, two-way empowerment, and two-way service between universities and cities, which is characterized by interactive two-way nature. From the macroscopic point of view, a stable two-way interactive flow is formed between the two systems of university and city, which is mainly reflected in the continuous flow and exchange of capital, technology, information, human resources, and culture between the two systems, and both sides strive to find the right integration and power point in spatial layout, talent cultivation, collaborative innovation, and cultural leadership, to realize the win-win development of university and city with two-way empowerment and two-way service. Microscopically, the development of various high-tech industries, financial services, transportation, medical security, housing reform, and community construction within the city system provides important social security for the university's schooling needs and also put forward higher level and multi-level service demands for the university's social services. By focusing on the advantages of disciplines within the university system, and taking into account applied and development research while emphasizing basic research, the university system continues to enhance its role in serving the promotion of scientific and technological innovation and transformation of scientific and technological achievements in the city, forming a two-way synergistic innovation service system with the city innovation system, and focusing on the major needs of the city development, actively integrating with the subsystems of the city system through the integration of industry and education, science and education, etc. It also promotes the formation of different types and levels of diversified service modes by combining the university's characteristics and forms two-way empowerment development with the city in political, economic, and cultural fields.

2.3. DATA MINING TECHNOLOGY ALGORITHMS

In the same data mining process, the process mainly includes three steps: data preprocessing, model building, and model evaluation, and the commonly used models

https://doi.org/10.17993/3ctecno.2023.v12n2e44.163-182

are the clustering algorithm and neural network algorithm. Clustering analysis is the analysis process of grouping objects into multiple clusters composed of similar objects, which is an important branch of data mining technology. The clustering process is based on certain attributes of the data, and the data is divided into different categories or clusters by setting rules, and the data within the same cluster are more similar, and the data within different clusters are more different. Cluster analysis is a kind of unsupervised learning, and no classification or grouping information in each cluster indicates the class of data. In data mining techniques, neural network algorithms can efficiently mine the correlation between one or more sets of data and the target data based on a large amount of known data. Therefore, it is often widely used in scenarios such as data prediction or analyzing the influence weight of multiple groups of data on a single group of data, while the neural network algorithm is selected for data mining techniques in this study, and its main model is as follows.

$$\sigma(Z) = \frac{1}{1 + e^{-Z}} \tag{1}$$

Where $\sigma(Z)$ is the sigmoid excitation function, Z represents the input data of the neuron, and the input in the sigmoid neuron can be any value between 0 and 1, from which the excitation function of the Sigmoid neuron can be derived, as in equation (2).

$$f(x) = \frac{1}{1 + e^{-(wx+b)}} \tag{2}$$

where denotes the weight value corresponding to each input data and is the threshold value of that neuron.

When using a neural network, it is necessary to train first and adjust the weight threshold to make the network adapt to the correlation between data and achieve the purpose of prediction. Training includes the following steps: (1) Neural network initialization. The number of nodes in each layer of the network is determined according to the system input and output (x, y), the weight threshold is given an initial value, and the excitation function $f(x)$ is given. Calculate the output of the hidden layer. Based on the input data x, the weights w_{ij} between the input layer and the hidden layer, and the hidden layer threshold a_j, the hidden layer output H is calculated.

$$H_j = f\left(\sum_{i=1}^{n} w_{ij}x_i - a_j\right) \tag{3}$$

Calculate the output value of the output layer. Calculate the neural network output value based on the hidden layer output H, the weight between the hidden layer and the output layer as w_{jk} and the threshold of each neuron in the output layer as b_k.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.163-182

$$O_k = \sum_{j=1}^{t} H_j w_{jk} - b_k \tag{4}$$

According to the neural network output value O and the actual value Y, the error of each neuron in the output layer is calculated e.

$$e_k = Y_k - O_k \tag{5}$$

3. ANALYSIS AND DISCUSSION

The interaction mode of university science and technology innovation and urban new industry development not only reflects how the two sides interact but also reflects the different interests of each subject in the interaction. On the one hand, we should analyze the practice subjects and practice elements of the interaction mode, and grasp and sort out the interaction mode of China on a deeper level from the whole, on the other hand, we should actively study the interaction cases of foreign universities' science and technology innovation and urban emerging industry development, and explore the interaction law and compare the experience through the method of comparative research, so this study takes Dongguan city as an example and uses data mining technology to fully explore the Therefore, this study takes Dongguan City as an example and uses data mining technology to fully explore the path of integration and development of city and university.

3.1. UNIVERSITY-COMPANY PROJECT COOPERATION

The ultimate goal of the cooperation between universities and urban emerging industries is to transform science and technology into real productivity and obtain economic benefits. In the operation process of the interaction mode between the two sides, the selection of projects determines to a certain extent the participation of the interaction subjects and the way of interaction. Generally speaking, the government tends to play the role of macro regulation and actively guides universities and emerging enterprises to participate in pre-collaborative innovation through organizing science and technology project exchange meetings and other means. However, based on the difference in starting points and interest demands of different subjects, the cooperation rate of the project cannot be raised, or the cooperation is interrupted halfway, which makes the project cooperation effect not reach the expected goal, and the possibility of achieving cluster innovation development is smaller and the cluster effect is insufficient. The said R&D activities are mainly divided into three categories: basic research, applied research, and experimental development, which is an act of innovation and novelty in one by using scientific methods to generate new knowledge or create new applications, and it has a wide range of cooperation objects. The project cooperation between universities and enterprises in Dongguan is shown in Table 1 and Figure 1.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.163-182

Table 1. Number and distribution of project topics

Projects	Number of subjects	Inputs (hundred people)	Investment in R&D (ten million yuan)
National Science and Technology Projects	285	883	120
Local Science and Technology Projects	438	548	11
Other Science and Technology Projects	145	315	17
Self-selected Science and Technology Projects	168	164	4.5
Projects entrusted by enterprises	53	107	4.2

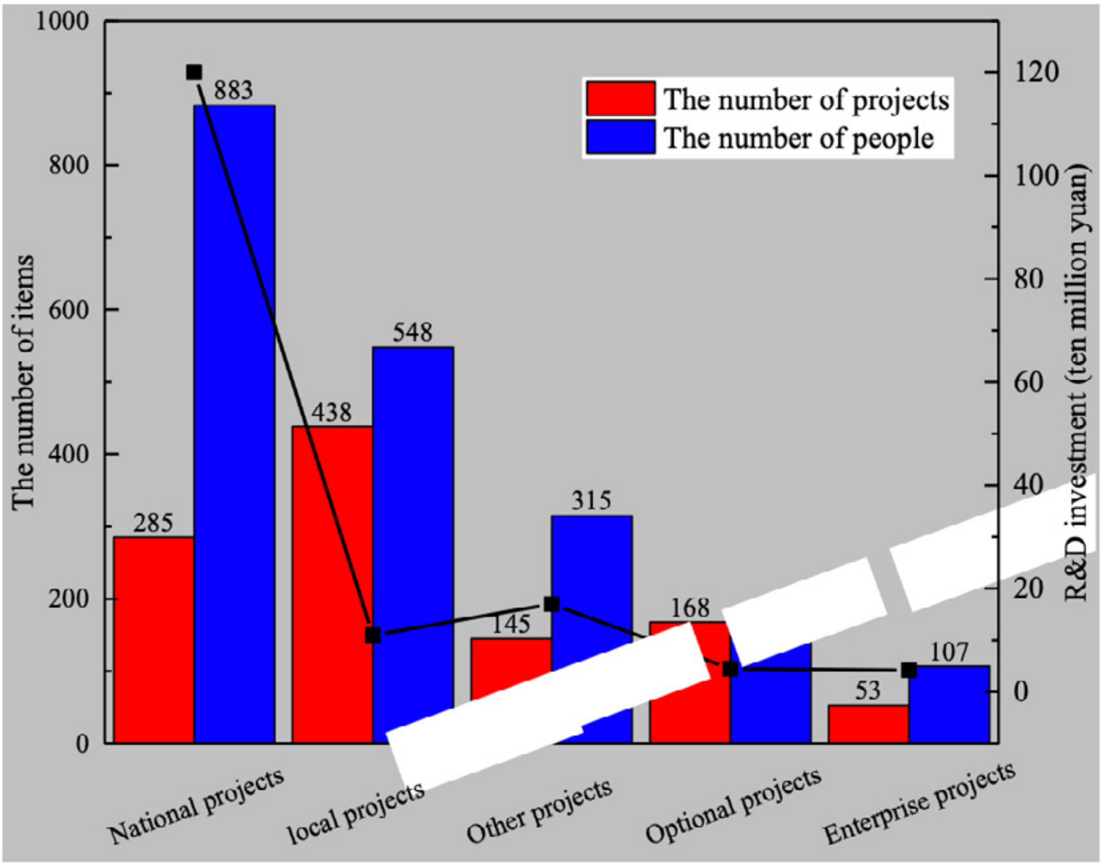


Figure 1. The situation of each index of the subject project

https://doi.org/10.17993/3ctecno.2023.v12n2e44.163-182

The analysis of the data shows that, firstly, the participation of enterprises in R&D activities entrusted by science and technology projects is low, accounting for only 4.9% of the overall projects, indicating that enterprises, as the main body of applied and experimental research, have less demand for cooperation in producing new products and conducting new R&D. Secondly, the participation of domestic universities is also low, indicating that, as one of the main bodies of basic research, the original intention of universities is to advance scientific and technological knowledge and Not much consideration is given to long-term economic benefits or social benefits. In summary, universities are not committed to applying their scientific and technological achievements to solve practical problems or to transfer them to sectors dedicated to their application, such as emerging enterprises, and similarly, enterprises are not willing to seek partners, such as universities, thus resulting in a situation where the concept of cooperation between the two sides lags and project cooperation is not strong, and the chances of cluster innovation development resulting from the clustering of projects are reduced.

3.2. R&D INVESTMENT

The characteristics of new urban industries vary at different stages of development, but they all grow and develop gradually in the midst of various unknown risks. After the birth of scientific and technological achievements, new products begin to transform from theories and concepts to physical experiments. Faced with the unknown market prospect at this stage, traditional venture capital institutions such as banks and insurance companies tend to adopt a wait-and-see policy first, preferring well-known enterprises or enterprises that have reached a mature level of development in the selection of investment targets. At the same time, due to the incomplete relevant safeguard policies, the mismatch of the legal system of venture capital, the lack of professional investment talents, and the fragile exit mechanism of venture capital, the current venture capital system is slightly single, which is unable to guarantee the normal funding operation of the interaction between university science and technology innovation achievements and the market of emerging industries in the city, the research expenditure in Dongguan in recent years is shown in Table 2 and Figure 2.

Table 2. Expenditures of funds by year (billion yuan)

Year	Basic Research	Applied Research	Experimental Development
2016	0.62	3.1	11.06
2017	0.73	3.57	11.45
2018	0.82	3.68	12
2019	1.12	3.93	12.23
2020	1.32	4.02	12.65
2021	1.43	4.63	13.27

https://doi.org/10.17993/3ctecno.2023.v12n2e44.163-182

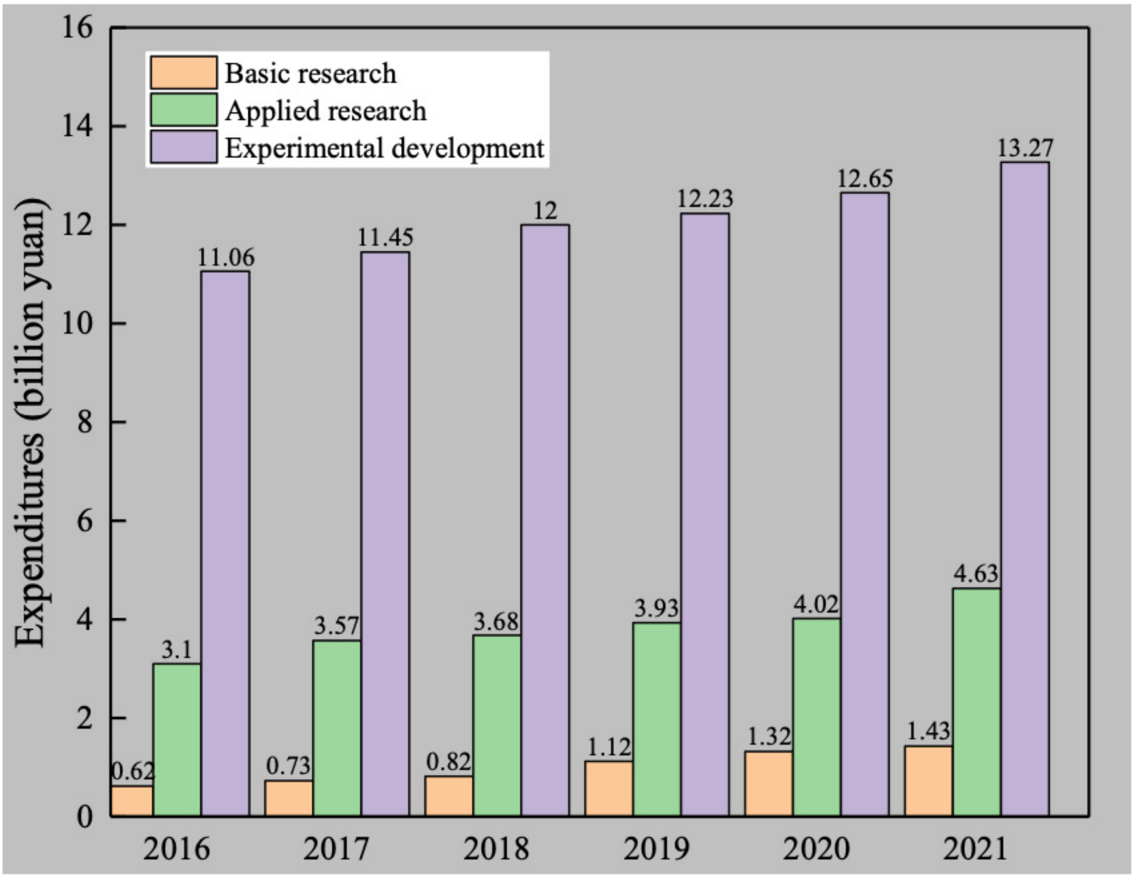


Figure 2. Expenditures

As can be seen from the graph, the funding expenditures become progressively larger over time, while the funding for experimental development accounts for a relatively large share, accounting for 68.65% of all funding expenditures by 2021. For the integration of universities and cities, regardless of the mode of interaction, its smooth operation or not is inseparable from financial support. The scientific and technological innovations born in Chinese universities face the problem of shortage of funds, whether in the early stage of research and development, in the middle stage of technology diffusion, or the late stage of industrialization. Although universities have been supported by special state funds in establishing university science and technology parks, science and technology innovation bases, business incubators, and even in the process of matching with enterprises, they have played a role in supporting the transfer and diffusion of technology. However, in recent years, investment in R&D in China is still at a low level and the proportion of GDP has been low, as shown in Table 3 and Figure 3.

Table 3. Comparison of R&D spending to GDP volume by country (%)

Year	China	American	Japan	France	Germany
2017	1.51	2.75	3.35	2.20	2.76
2018	1.76	2.55	3.30	2.24	2.85
2019	1.87	2.67	3.51	2.23	2.78
2020	1.98	2.78	3.67	2.22	2.87
2021	2.01	2.84	3.48	2.21	3.89

https://doi.org/10.17993/3ctecno.2023.v12n2e44.163-182

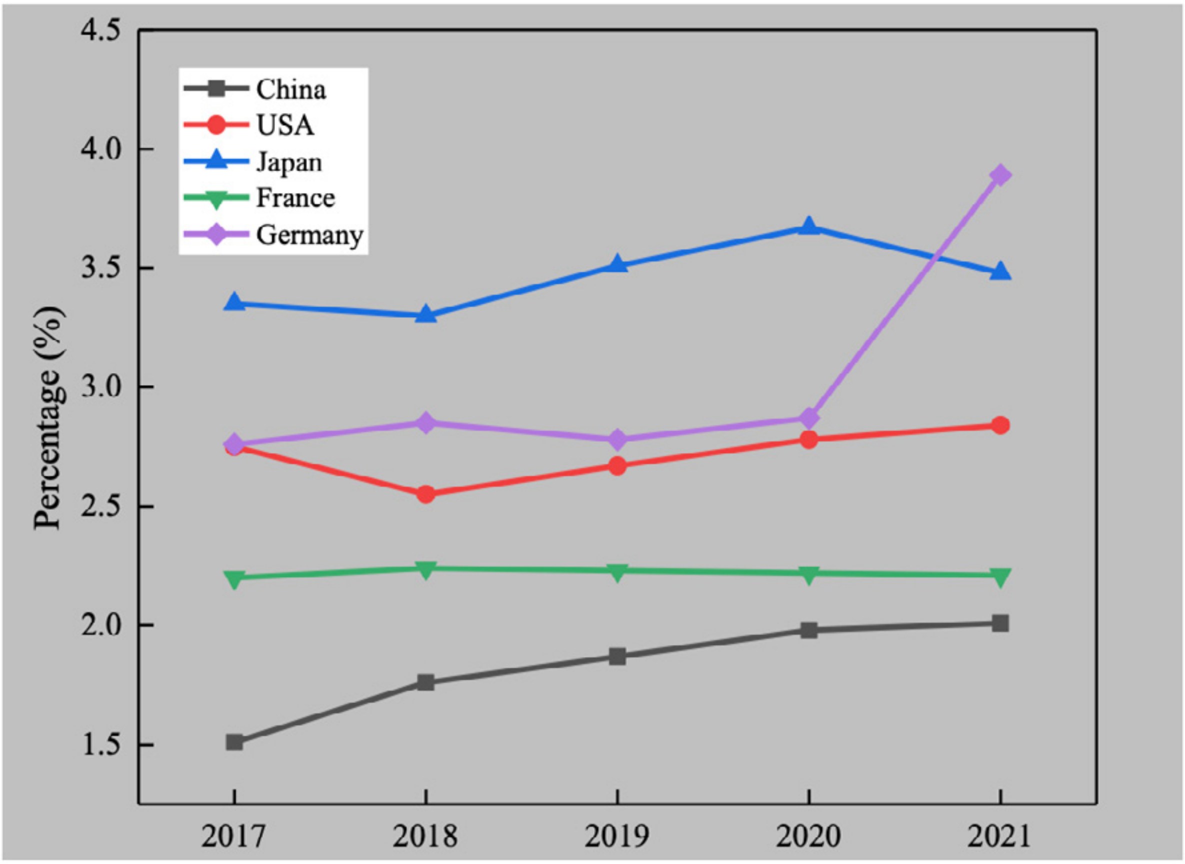


Figure 3. Comparison of R&D expenditure as a share of GDP

As shown in Chart 3 and Figure 3, the Chinese government's investment effort in R&D funding has developed from 1.51% in 2017 to 2.01% in 2021, which is an increasing trend but clearly lags behind by a large margin compared to developed countries such as the United States, Japan, Germany, and France. Looking closely at the data for 2017-2021, it is easy to see that the level of investment that China will reach in 2021 has been put in place or even exceeded by many in countries such as the United States a few years ago. The limited investment in R&D in China, which cannot meet the actual needs of the market, objectively hinders the transformation of university science and technology innovation results into urban emerging industries.

3.3. RESEARCH RESULTS

Through data mining techniques, it is found that the conversion of university science and technology innovation results is an important way to build a cooperation platform between universities and urban emerging industries, and is also the key to the smooth operation of each interaction model, and the study takes the high or low conversion rate as an important indicator of the value of science and technology activities. A lower conversion rate of science and technology innovation results causes waste of university science and technology innovation resources on the one hand, and affects the timeliness of enterprises' access to the latest science and technology innovation results on the other, leading to problems such as slow product upgrading and weak market competitiveness of urban emerging industries. In addition, an

https://doi.org/10.17993/3ctecno.2023.v12n2e44.163-182

important manifestation of scientific and technological innovation results is the patent application, the development of new products must first pass patent approval, and then can be put into production and then transferred to the market operation, so the efficiency of the patent is also one of the important indicators to determine the value of scientific and technological innovation activities. In the past five years, although the Dongguan government has encouraged universities and enterprises to actively apply for patents under the premise of scientific and technological innovation, the number of applications and authorizations has been increasing year by year, as shown in Table 4 and Figure 4.

Table 4. Patent applications and grants

Year	Patent Application	Patent Licensing	Authorization rate (%)
2017	25680	15901	61.9
2018	27803	16553	59.54
2019	33620	21740	64.66
2020	44826	22967	51.24
2021	49726	25523	51.33

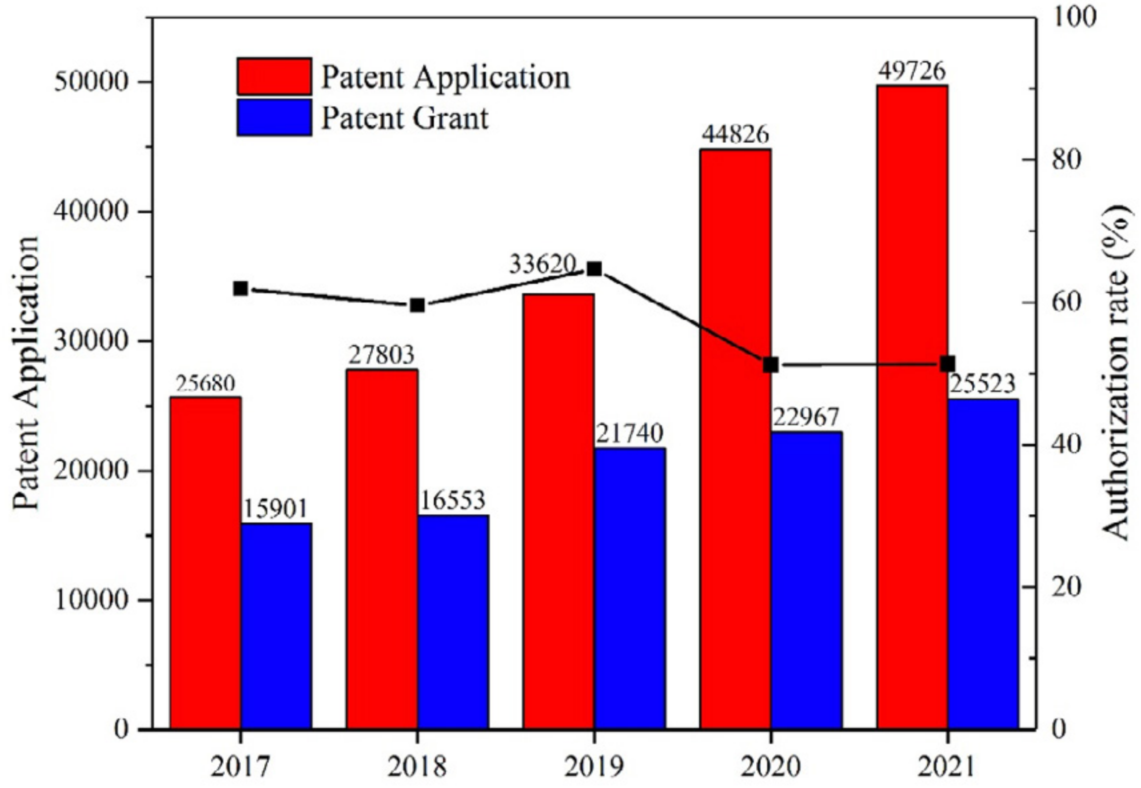


Figure 4. Patent Applications and Grants

https://doi.org/10.17993/3ctecno.2023.v12n2e44.163-182

The above analysis data show that the results of scientific and technological innovation often do not match the market demand. The reasons for this are mainly the following: firstly, the universities' awareness of the transformation of scientific and technological innovation results is weak, and the purpose of scientific research is slightly single; secondly, in the process of the patent application, the situation of emphasizing quantity rather than quality is very common; again, compared with the United States and other countries with the mature transformation of scientific and technological achievements, the incentive mechanism of scientific and technological innovation results in China has great problems, focusing on spiritual incentives such as title evaluation, which is difficult to mobilize teachers and student's motivation. As can be seen from Table 4 and Figure 4, the growth of patent efficiency rate, however, is not obvious, and even appears to regress. 61.9% of patent efficiency rate in Dongguan City in 2017, with signs of decline in 2018 and 2020, and a slight turnaround in 2019, but still lower than in 2017.

The patents and emerging technologies developed by universities, as important research results, have to be applied in actual production life to play an important role. The patents and technology transfer of universities in Dongguan in recent years are shown in Table 5 and Figure 5.

Table 5. Patents and Technology Transfer in Higher Education Institutions

	Technology transfer (yuan)		Patent assignment (yuan)	
Year	Amount sold	Actual income	Amount sold	Actual income
2013	3894	2913	9229	8460
2014	111345	71911	15102	7855
2015	131805	75437	20109	12663
2016	102149	64994	18491	10150
2017	97301	66282	27471	14855
2018	62149	72423	44766	17665

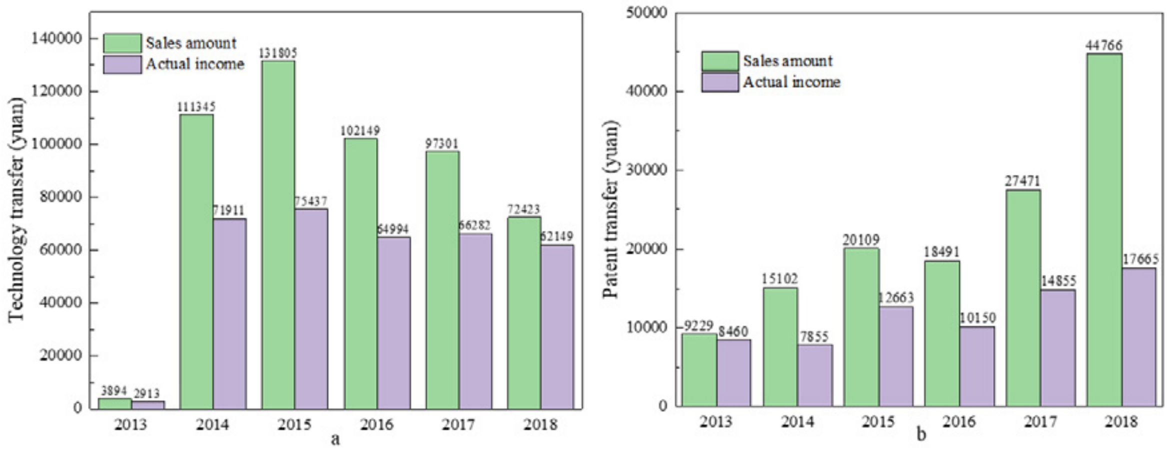


Figure 5. Patents and Technology Transfer

https://doi.org/10.17993/3ctecno.2023.v12n2e44.163-182

Where Figure a shows the transfer of university technology and Figure b shows the transfer of patents, it can be seen through Figure 5 that for the transfer of university technology, its sales gradually decreased from 2015, but the overall change in actual income is small, which shows from the side that with the continuous research and the gradual development of high precision technology, resulting in a significant increase in the amount of transfer of individual technologies, thus ensuring sufficient revenue. For patent transfer, from 2013 to 2018 in an upward trend, the actual income increased from 8460 to 17665.

3.4. URBAN INDUSTRIAL STRUCTURE

Under the progress of the integration and development of the university and the city, the gross product of Dongguan City is shown in Table 6 and Figure 6, in which Dongguan achieved a gross regional product of 108.554 billion yuan in 2021, an increase of 8.2% over the previous year. Among them, the value added of primary industry is 3.466 billion yuan, an increase of 11.8%, contributing 0.4% to the growth of regional GDP; the value added of the secondary industry is 631.941 billion yuan, an increase of 10.5 %, contributing 73.0% to the growth of regional GDP; the value added of tertiary industry is 450.128 billion yuan, an increase of 5.1%, contributing to the growth of regional GDP 26.6%, overall strong economic development, thanks to the city's support and assistance to universities, the comprehensive quality of various undergraduate and higher vocational institutions in Dongguan has also continued to progress and always maintained a strong momentum of development.

Table 6. The growth rate of gross production

Year	Gross production value (billion yuan)	Growth rate (%)
2016	7260.92	8
2017	8079.2	8.3
2018	8818.11	7.5
2019	9474.43	7.4
2020	9756.77	1.1
2021	10855.4	8.2

https://doi.org/10.17993/3ctecno.2023.v12n2e44.163-182

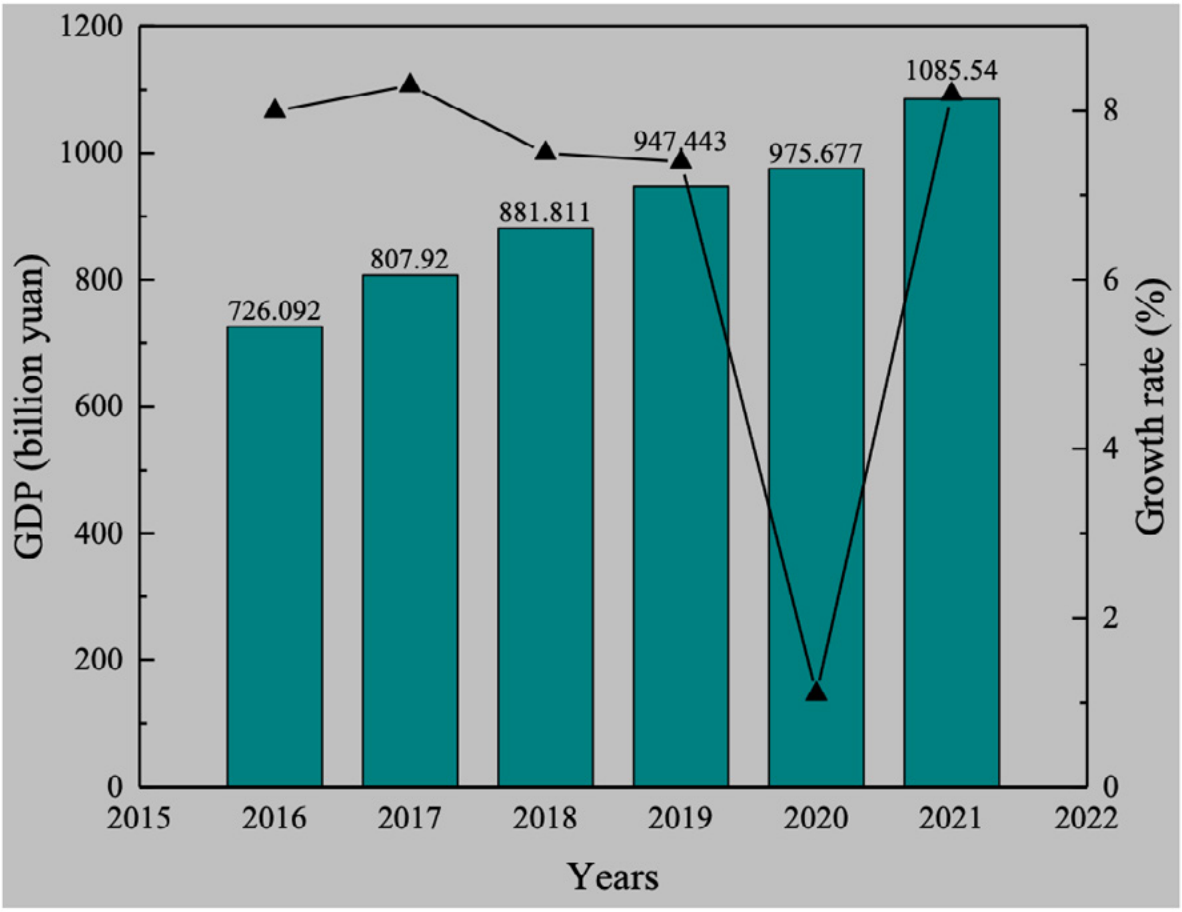


Figure 6. City GDP and Growth Rate

4. CONCLUSION

In the context of a knowledge-based economy, universities, and enterprises, as important subjects in the interactive development of university science and technology innovation and new industries in cities, realize the interaction mode of interdependence, close connection, and seeking a win-win situation, which is of great significance to the in-depth implementation of the concept of integration of industry and education and the construction of national innovation system. This paper analyzes the cooperation between urban development and various universities in Dongguan City with data mining technology as the research method and proposes suggestions for the integration development path, the specific research findings are as follows:

1. The interconnection and development between urban enterprises and universities are not close enough. Currently, urban enterprises in China commission fewer science and technology projects to participate in R&D activities, accounting for only 4.9% of the overall projects, indicating that enterprises, as the main body of applied and experimental research, have less demand for collaborative production of new products.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.163-182

2. Through data mining technology to analyze between universities, enterprises, research institutions, and the government of Dongguan City, based on integration and innovation, to build a model of the inner action mechanism of regional universities and the development of science and technology innovation in the city, and analyze the path selection relationship between technology trading and integrated operation mode, the results show that with continuous investment and research and development each university's patent application and technology transfer increase in 2021 No., Dongguan City applied for a total of 49,726 patent applications, 25,523 authorized, with an authorization rate of 51.33%.

3. The scientific and technological research and development achievements of the university will act on the development of the city, promote the transformation and upgrading of urban industries and improve the competitiveness of the city. The research results show that the GDP of Dongguan City in 2021 showed strong momentum, achieving a regional GDP of 108.554 billion yuan, an increase of 8.2% over the previous year, and the rapid development of the city will also drive the university to progress together, forming a good closed-loop development.

REFERENCES

(1) Cetin, M., Aksoy, T., Cabuk, S. N., et al. (2021). Employing remote sensing technique to monitor the influence of newly established universities in creating an urban development process on the respective cities. Land Use Policy, 109.

(2) Winston, N. (2022). Sustainable community development: Integrating social and environmental sustainability for sustainable housing and communities. Sustainable Development, 30.

(3) Koch, J. R. , Wagner, B. G. , & Roberts, A. E. . (2021). Christian universities as moral communities: drinking, sex, and drug use among university students in the united states. The Social Science Journal(1), 1-13.

(4) Wang, J. (2018). Integrating Indigenous with Scientific Knowledge for the Development of Sustainable Agriculture: Studies in Shaanxi Province. Asian Journal of Agriculture and Development, 15.

(5) Mohamed, N., & Salama, M. (2022). Data Mining-Based Cyber-Physical Attack Detection Tool for Attack-Resilient Adaptive Protective Relays. Energies, 15.

(6) Schmidt, C. (2017). Viability of alternative online news media in developing and transition countries. In Universities, Entrepreneurship and Enterprise Development in Africa, 5.

(7) Wang, J., Jiang, K., & Wu, Y. (2022). On congestion games with player-specific costs and resource failures. Automatica, 142, 110367.

(8) Kashan, A. J., Lay, J., Wiewiora, A., et al. (2022). The innovation process in mining: Integrating insights from innovation and change management. Resources Policy, 76, 102575-.

(9) Tang, Y., & Lan, Y. (2021). Design of University Financial Decision-Making Platform Based on Data Mining. Journal of Physics: Conference Series, 1881(4), 042063-.

(10) Zhang, L., & Zhang, S. (2019). A General Joint Matrix Factorization Framework for Data Integration and Its Systematic Algorithmic Exploration. IEEE Transactions on Fuzzy Systems, PP(99), 1-1.

(11) Mcevoy, D., Iyerraniga, U., Ho, S., et al. (2019). Integrating Teaching and Learning with Inter-Disciplinary Action Research in Support of Climate Resilient Urban Development. Sustainability, 11.

(12) Masey, Nicola, Hamilton, Scott, Beverland, & Iain, et al. (2017). Estimation of spatial patterns of urban air pollution over a 4-week period from repeated 5-min measurements. Atmo spheric Environment.

(13) Korres, M. P. (2022). Integrating Evaluation as a Componential Element in the Development of the Course: The Case of Two Courses in the Faculty of Education (AUTH) during the Pandemic. Journal of Education and Training Studies, 10.

(14) Zhang, Q., Lian, B., Cao, P., et al. (2020). Multi-Source Medical Data Integration and Mining for Healthcare Services. IEEE Access, 8, 165010-165017.

(15) Cali, S., & Balaman, S. Y. (2019). Improved decisions for marketing, supply and purchasing: Mining big data through an integration of sentiment analysis and intuitionistic fuzzy multi criteria assessment. Computers & Industrial Engineering, 129(MAR.), 315-332.

(16) B Z Z A, B X Z A, A Q S, et al. (2017). Integrated sustainable development evaluation based on human well-being indices and pressure indices: A case study of the South China Sea Neighboring Countries. The Social Science Journal, 54(3), 346-357.

(17) Simovici, D. (2018). Mathematical Analysis for Machine Learning and Data Mining || Integration. 10.1142/10702: 485-593.

(18) Castán Broto, & Vanesa. (2017). Urban governance and the politics of climate change. World Development, 93, 1-15.

(19) Zhang, Y., Chen, K., Tao, F., et al. (2018). Data and knowledge mining with big data towards smart production. Journal of Industrial Information Integration, 9, 1-13.

(20) Yan, Q. (2017). Data Integration, Data Mining, and Decision Support in Biomedical Informatics. In Translational Bioinformatics and Systems Biology Methods for Personalized Medicine (pp. 41-52).

(21) Kim, D. Y., Lim, B., Kim, J. M., et al. (2022). Integrated transcriptome analysis for the hepatic and jejunal mucosa tissues of broiler chickens raised under heat stress conditions. Journal of Animal Science and Biotechnology, 13(1), 1-17.

(22) Zhou, W., & Yang, T. (2021). Application Analysis of Data Mining Technology in Ideological and Political Education Management. Journal of Physics: Conference Series, 1915(4), 042040 (7pp).

(23) Thisse, & Jacques-Fran?ois. (2018). Human capital and agglomeration economies in urban development. Developing Economies.

(24) Tang, M., & Liao, H. (2021). Multi-attribute large-scale group decision making with data mining and subgroup leaders: An application to the development of the circular economy. Technological Forecasting and Social Change, 167(6), 120719.

(25) Turugare, M., & Rudhumbu, N. (2020). Integrating technology in teaching and learning in universities in Lesotho: opportunities and challenges. Education and Information Technologies, 25(1).

(26) Wu, Y., Zhang, J., & Shen, T. (2022). A logical network approximation to optimal control on continuous domain and its application to HEV control. Science China Information Sciences.

(27) Zheng, C., & Zhou, W. (2021). Research on Information Construction and Management of Education Management Based on Data Mining. Journal of Physics: Conference Series, 1881(4), 042073 (6pp).

(28) Sain, K. (2022). Need for Development of AI-based Integrated Warning System (IWS) for Mitigation of Glaciers/Glacial-lakes Related Hazards with Special Reference to Uttarakhand Himalaya. Journal of the Geological Society of India, 98(7), 1012-1014.

(29) Ali, M., Wahjoedi, Wahyono, H., et al. (2017). Analysis of the development requirement of democratic economy-based integrated entrepreneurship education program on higher education program in East Lombok Regency. International Journal of Applied Business & Economic Research, 15(20), 473-483.

(30) Mariani, D., & Usmeldi. (2019). Needs analysis in the development of natural science student books connected type integrated of local cultural wisdom. Journal of Physics Conference Series, 1185(1), 012071.

(31) Zabit, M. N. M., Zachariah, T. Z., Abdullah, N., et al. (2020). The Development and Validation of an Integrated Learning Method Based on Problem-Based Learning in a Pedagogy, Technology and Assessment Course at Malaysia Public Universities. International Journal of Asian Social Science, 10.

(32) Meng, S., & Zhang, X. (2021). Translog function in government development of low-carbon economy. Applied Mathematics and Nonlinear Sciences. https://doi.org/10.2478/AMNS.2021.2.00138

/11/

UNDER THE BACKGROUND OF GREEN ARCHITECTURE, THE AESTHETIC ELEMENTS OF HENAN'S TRADITIONAL ANCIENT ARCHITECTURE AND MODERN ARCHITECTURE BASED ON BIM TECHNOLOGY

Yonggang Qiao*

College of Marxism, Suqian College, Suqian, Jiangsu, 223800, China.

qiaoyg1979@163.com

Reception: 02/04/2023 **Acceptance**: 24/05/2023 **Publication**: 099/06/2023

Suggested citation:

Qiao, Y. (2023). **Under the background of green architecture, the aesthetic elements of Henan's traditional ancient architecture and modern architecture based on BIM technology**. *3C Tecnología. Glosas de innovación aplicada a la pyme, 12(2)*, 184-202. https://doi.org/10.17993/3ctecno.2023.v12n2e44.184-202

ABSTRACT

With the introduction of the "double carbon" target in China, green building has gradually become a trend in the development of China's construction industry. The combination of traditional architecture and modern architecture based on the concept of green architecture has become a new pursuit for architects. Based on this, this study integrates the aesthetic elements of traditional ancient architecture in Henan with modern architecture in the context of green building design. This paper first introduces the basic theory of the green building evaluation system and compares and analyzes the green building evaluation system at home and abroad. Secondly, the feasibility of using BIM technology in green buildings is demonstrated in terms of usage cost, and the application of BIM technology in green building evaluation is introduced with the modernization design of an ancient building in Henan. Finally, we calculated and analyzed the key indicators of the energy performance of a building in Henan. According to the results, the studied case building has a 13% reduction in the system-integrated part-load performance coefficient and a 6.6% reduction in the integrated heat gain coefficient of the envelope structure.

KEYWORDS

Green building; evaluation system; BIM; traditional elements; modern architecture

INDEX

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.184-202

1. INTRODUCTION

China has a long history of architectural culture, and different local architectural forms have their characteristics and are integrated with local human characteristics. These buildings are the crystallization of the wisdom of ancient Chinese working people, with perfect structural forms, unique architectural styles, and ingenious and varied design techniques [1-3]. Modern architecture is widely used because of its social needs and represents the course of social development. Modern architecture needs the connotation and heritage of traditional architecture, and traditional architecture needs the comfort and practicality of modern architecture [4-6], which are complementary to each other. Therefore, it is very necessary to study how to combine the two together in a reasonable way. In addition, many traditional ancient architectural aesthetic elements can be applied in urban construction. We should combine the development needs of modern cities, and between traditional and modern architecture, we should find a common point between the two, and design architecture that is both new and historical [7-9].

In today's increasingly severe energy and environmental problems, the country insists on the concept of green development. The concept of "green development + ecological priority" has become a major direction to lead China's economic development, in which the concept of "green development" has become a fundamental guideline and direction [10-12]. As a pillar industry of the national economy, the construction industry has a huge negative impact on resources and the environment [13,14]. Therefore, it is very necessary to develop green buildings to provide healthy, comfortable, and efficient living space and living environment for human beings and to realize the harmonious coexistence between human beings and nature. It is also a fundamental way to effectively improve China's living environment, reduce building energy consumption, solve energy problems and achieve sustainable development of the construction industry [15-17]. Xu et al [18] detailed the design criteria for green buildings based on a parent-child theme park design case. They analyzed the design of this park from two major aspects: general layout planning and architectural design and discussed how the architectural design influenced the achievement of green building goals. The results show that following their design approach to architectural design can effectively reduce building energy consumption and achieve green goals. In addition, this case provides a reference for other projects. Umaroullar et al [19] conducted a comparative study of green building certification systems (GBCS) in developed and developing countries in the context of energy policy developments. They developed a matrix to numerically assess the GBCS of

https://doi.org/10.17993/3ctecno.2023.v12n2e44.184-202

different countries. The results showed that the GBCS of different countries have similar characteristics to their regional development levels in terms of sustainable development. Anggraeni et al. [20] applied the green building concept to the design of a university laboratory complex, focusing on energy efficiency, water use, and air quality from the planning stage to the building maintenance stage. According to the results of the acceptance of the completed integrated laboratory, it can be found that this green building plan has high land utilization, energy efficiency and building environmental management level, thus saving some costs. Xing et al [21] concluded that vigorous development of the green building industry (GBI) is one of the effective ways to achieve a green economy and energy saving and emission reduction. Based on this, they analyzed the promotion strategy of China's green building industry from the perspective of social network theory by developing an evolutionary game model. Through this model, they examined the interactions between technology, knowledge sharing, and firm behavior in innovation networks and found that the cost of collaborative innovation is the key to determining the evolutionary steady state. In addition, government financial support as well as grants are crucial for the development of green building construction.

However, the Chinese construction industry has been slow to promote information technology, and the upgrading of the industrial structure has been severely constrained. Since the 1940s, most reports from government and professional organizations have shown that the construction industry is characterized by fragmentation, lack of efficient communication between the various parties involved, lack of formal protocols and structural confusion in the construction process. The emergence of BIM (Building Information Modeling) has broken the traditional management and technology model of the construction industry and enabled information sharing. The software can improve project refinement management and engineering efficiency, while enabling the unification of the client's interests and the design function of the building [22-24]. It plays a very important role in early investment control as well as in the operation, integration and control of the entire construction project, enabling the joint development of the corresponding engineering information management, time, quality and cost management, and improving the technical level of the building. Green building, as a more popular construction method nowadays, has the characteristics of large amount of information, extensive sources, scattered storage, complex types and high energy consumption control requirements. And BIM, as a data interaction platform that can efficiently transfer information and improve data management, digitizes the information of relevant attributes in all phases of the building. At the same time, this technology also guarantees the inherent unity of information in the planning and design, construction and operation phases of computable buildings, which provides new ideas and opportunities for the development of green buildings. management and green technology [25,26]. Specifically, it is a seamless integration of the spatial and temporal dimensions. In the temporal dimension, the collection, organization, summarization and analysis of green building design information can be realized through the parametric model of BIM. For example, coordinated design and data centralization on a single data platform, and

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.184-202

integration of cross-discipline and cross-phase design and management information into the BIM model. This also provides a mobile, automated and intelligent data platform for later post-project evaluation and even operation evaluation. In the spatial dimension, the BIM model can realize data sharing through a variety of software, giving strong data support and guarantee for performance simulation and evaluation of green buildings [27,28].

In addition, the integration of traditional architectural elements with modern architecture is a new development mode in the architectural industry [29]. Where traditional architecture is concentrated, there exists a large amount of historical information, which is the materialization of people's aesthetics of an era, and the connotation of the architecture can be grasped to a certain extent by studying to understand the spiritual qualities of a place. The organic combination of traditional architectural design concepts and modern architectural design can be reflected as a combination of spiritual essence, a process of abandonment and absorption, and an experience of interaction between traditional culture and modern life. At the same time, the working methods and design ideas that combine tradition and modernity are more worth exploring, and we hope to make urban architectural design not only improve the living environment and economic growth, but more importantly, inheritance, coordination, and development of humanistic spirit and other aspects [30,31]. Jia et al [32] appreciated the architectural design of the Yucheng Museum. The traditional Chinese architectural culture applied in the design process was analyzed from various aspects of the building, such as the planar shape of the museum, the patterns of the doors and windows, the carved objects inside the house, the roof shape, and the color palette of the whole building. They found that the Yucheng Museum well integrated traditional architectural elements within the building and promoted the development and transmission of traditional Chinese architectural culture. Vijulie et al [33] found that the traditional Romanian architectural style is gradually disappearing and the development of architectural styles in European countries and modern society has caused a great impact on traditional Romanian architecture. By means of a field survey of local people's and tourists' views on these issues, they found that older people have more conservative views, while younger people generally prefer foreign modern architecture. In response to this the authors argue that it is necessary to preserve the traditional architecture of Romania, and at the same time to keep up with the times, combining some features of modern architecture with traditional architectural elements.

To sum up, the combination of tradition and modernity in architecture is an eternal proposition. Since the modernist architectural style of Europe and America was introduced to China, many architects have done a lot of research on the application of traditional architectural elements in modern architecture. And in order to conform to the main theme of today's social development, it is also very necessary to apply green architecture and information technology to this research. In this paper, in the context of green architecture, the aesthetic elements of traditional ancient architecture in Henan are designed to be integrated with modern architecture. At the same time, BIM

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.184-202

technology is used to make scientific decisions and management of the whole process application of this design to achieve the optimization of the value of the BIM application. Finally, this study tries to build a bridge between traditional and contemporary architectural creation, so that it can get out of the shadow of global convergence and realize the inheritance and promotion of traditional architectural culture.

2. THE BASIC THEORY OF GREEN BUILDING EVALUATION SYSTEM

Since the establishment of a green building evaluation system involves a wide range of specialties and a wide range of disciplines, it requires the full cooperation of experts from various neighborhoods to complete this important and complex task. Therefore, a series of index systems and clear regulations are needed to guide the practice of green building and to certify the greenness of buildings. A set of scientific and perfect green building evaluation system can effectively regulate the green building market and promote the healthy development of the green building market. It also helps to guide and regulate the practice of green building, which can effectively save resources, improve economic efficiency and reduce energy consumption, etc.

2.1. EVALUATION SYSTEM

2.1.1. U.S. LEED EVALUATION SYSTEM

The U.S. Green Building Council (USGBC) has developed the U.S. Green Building Rating System, LEED, and is promoting the development and improvement of LEED through education, advocacy, research, networks, committees and academic programs, etc. LEED is currently the most influential and authoritative green building rating standard in the world. The evaluation system mainly assesses buildings in terms of water use, building energy efficiency and atmosphere, and indoor air quality. The biggest advantage is its open and transparent evaluation process, as well as its strong flexibility.

The LEED rating system has six major products: LEED-NC (LEED for New Construction), LEED-EB (LEED for Existing Building), LEED-CI (LEED for Commercial Interior), LEED-CS (LEED for Core & Shell), LEED-H (LEED for Home), and LEED-ND (LEED for Neighborhood Development). LEED-NC and LEED-EB improve the measures of sustainable development for office buildings, and LEED-CI and LEED-CS constitute a model for integrating the inside and outside of commercial development.

The main evaluation elements of the LEED evaluation system are: site selection, water use efficiency, energy use efficiency and atmospheric protection, effective use of materials and resources, and indoor environmental quality. The evaluation points

https://doi.org/10.17993/3ctecno.2023.v12n2e44.184-202

are divided into: evaluation prerequisites, score points, and innovation points, and the specific certification levels are.

1. Certified level, meeting at least 40% of the assessment points.
2. Silver level, meeting at least 50% of the assessment points.
3. Gold level, meeting at least 60% of the assessment points.
4. Platinum grade, at least 80% of the assessment points are met.

2.1.2. BRITISH BREEAM EVALUATION SYSTEM

BREEAM is the world's most successful green building rating system, assessing single buildings, mixed-use buildings, etc. BREEAM guides the practice of green building, directs market demand, reduces the burden on the environment and ensures the health of users.

The BREEAM system takes the global, local, indoor environment and management as the starting point, and the evaluation results are divided into four levels: pass, good, excellent and outstanding. The BREEAM system introduces a new concept "eco-points", which is an important concept for understanding the BREEAM system; the eco-points score is based on The score is based on the extent to which a part or the whole of an individual unit affects the environment as a whole.

2.1.3. CANADIAN GBTOOL EVALUATION SYSTEM

In 1996, Canada launched the Green Building Challenge (GBC), with the participation of the UK, France, and the US. Through the efforts of many countries, a green building evaluation system, GBTooL, was finally developed to reasonably evaluate the environmental performance of buildings, and the GBC developed an evaluation system through research to adapt to the uniqueness of different countries and regions. Experts in each country can adjust the criteria and weighting system appropriately according to the specificity of the region, so that the GBTooL evaluation criteria can be applied to each region and become an international standard.

The GBTooL evaluation index system basically covers all aspects of environmental performance evaluation of green buildings. The GBTooL environmental performance evaluation framework is divided into four standard levels: environmental performance issues, classification, criteria and sub-criteria. The GBTooL evaluation system has three functions: simple assessment, detailed assessment, and design guidance [34]. The evaluation levels are set in seven scales from -2 to 5. A score of -2 indicates that the building's performance does not meet the requirements. a score of 0 indicates the minimum required building performance, as defined by local standards. A score of 1-4 indicates intermediate different levels of building performance. a score of 5 indicates the best building performance. The building performance is expressed in the form of

https://doi.org/10.17993/3ctecno.2023.v12n2e44.184-202

charts, including classification charts, group charts, comprehensive charts, etc. These charts can visually reflect the environmental performance of the buildings at each level and the areas that need further improvement.

2.1.4. JAPAN CASBEE EVALUATION SYSTEM

The Japan Sustainable Building Council has developed a local green building evaluation system, CASBEE, which emphasizes the evaluation of the emergency response function and service life of buildings and equipment, as well as the full utilization of existing buildings, due to Japan's special conditions such as scarce resources and frequent earthquakes. To accelerate the reform of the resource production model, developed countries have proposed the concepts of "4-fold factor" and "10-fold factor", which can be summarized as resource efficiency; in addition, the concept of eco-efficiency has been proposed. Based on the above concepts, CASBEE has proposed the concept of BEE for built environment efficiency.

$$BEE = \frac{Q}{L} = \frac{25 \times \left(S_Q - 1\right)}{25 \times \left(5 - S_{LR}\right)} \tag{1}$$

Where Q is the quality and performance of the built environment and L denotes the load of the external environment. S_q denotes the total score of the evaluation items in the category Q and S_{LR} denotes the total score of the evaluation items in the category L.

2.1.5. AUSTRALIAN NABERS EVALUATION SYSTEM

The Australian Department of Environment and Resources has developed a simple, comprehensive, and easy-to-use evaluation system, NABERS, based on the New South Wales evaluation system SEDA, concerning the BREEAM evaluation system, and taking into account the national conditions of Australia.

NABERS evaluates the environmental impacts of existing buildings during their operational life cycle, including greenhouse gas emissions, waste emissions, water use, energy use, and indoor environment. The NABERS evaluation method is to divide the sum of the star values obtained from each index by the sum of the star values obtained from the full score of each index, and the calculated percentage is the green performance evaluation result of the building.

2.1.6. CHINA'S GREEN BUILDING EVALUATION STANDARD

The first "Green Building Evaluation Standard" applicable to China's national conditions was promulgated in 2006. The standard covers the main technical contents

https://doi.org/10.17993/3ctecno.2023.v12n2e44.184-202

including: land saving, energy saving, water saving, material saving, indoor environment, construction management, operation management, improvement, and innovation. Its outstanding advantage is that it is extremely flexible and can be specifically adjusted to the actual situation of weather, geographical location, and construction methods.

2.2. GREEN BUILDING EVALUATION SYSTEM USING BIM TECHNOLOGY

The application of BIM in the whole process of green building evaluation generates input costs of equipment, personnel, and technology costs. To further reflect the relevance and implementability of BIM application, this study provides a comprehensive analysis of the cost components generated by the application of BIM.

2.2.1. HARDWARE INPUT COST

BIM application mainly realizes its basic functions through the intelligent system, which generally includes the BIM platform, computer, and server, platform network switch, large screen TV wall, environmental monitoring system, etc. The calculation formula is as follows.

$$C_1 = C_{11} + C_{12} + C_{13} \tag{2}$$

Among them, C_1 indicates the hardware input cost of the BIM application, C_{11} is the cost of computers and servers, etc., C_{12} is the maintenance cost incurred to ensure the daily operation of the BIM platform, and C_{13} is the renewal cost of the hardware after a certain service life.

2.2.2. PERSONNEL INPUT COSTS

The input cost of personnel refers to the additional cost of BIM technicians' salary and the cost of training for project management personnel than the traditional project management mode. The specific calculation formula is as follows.

$$C_2 = C_{21} + C_{22} \tag{3}$$

Among them, C_2 is the new personnel input due to the application of BIM, C_{21} is the salary input of BIM technicians, and C_{22} is the training input of project management personnel.

2.2.3. SOFTWARE INPUT FEE

$$C_3 = C_{31} + C_{32} \tag{4}$$

https://doi.org/10.17993/3ctecno.2023.v12n2e44.184-202

Among them, C_3 is the technical input of BIM-related system software, C_{31} is the acquisition cost of BIM system software, and C_{32} is the update cost of BIM system software.

In this section, we introduce in detail the green building evaluation systems that are widely used in various countries around the world and explain the corresponding evaluation methods, and we also apply BIM technology to them. In order to make the whole system more reasonable and further reflect the realistic meaning and implementability of BIM application, we make a theoretical analysis of the cost of the system. This section lays the theoretical foundation for the subsequent design of the integration of aesthetic elements of traditional ancient architecture and modern architecture in Henan.

3. RESULTS AND DISCUSSION

In the context of green building, this paper conducts a statistical analysis of the green energy-saving performance of a building in Henan, which fully integrates the aesthetic elements of traditional ancient architecture in Henan in the design phase. This section analyzes the energy-saving performance of this building in terms of the integrated heat gain coefficient of the envelope structure, the integrated part-load performance coefficient of the system, the renewable energy application ratio, and the maximum lighting power density, and establishes a new type of green building group energy-saving performance evaluation system.

3.1. COMPREHENSIVE HEAT GAIN COEFFICIENT OF THE ENCLOSURE STRUCTURE

As the case is located in Henan Province, the heating heat source comes from municipal hot water, and the main HVAC energy consumption of the building comes from cooling, so the air conditioning U evaluation is taken here. After calculating the temperature difference heat transfer and radiation heat transfer of each envelope structure such as the exterior walls, exterior windows, and non-transparent roof of the building, the calculation results are summarized in Table 1.

According to the results in Table 1, the difference between the air conditioning U-value of the case building and the air conditioning U-value of the corresponding reference building is calculated to be 6.6%. According to this difference, it is divided into 10 grades, from 1% to 10%, with 1 to 10 points respectively, so the case gets 6 points. The advantages of using this score classification method are as follows.

1. The score grade is carefully divided. The national standard GB/T 50378-2014 is divided into two grades for the evaluation of the thermal performance of the envelope structure, such as the heat transfer coefficient K is 5% lower than the standard required value of 5 points, is reduced by 10% is 10 points. The comprehensive heat gain coefficient U of the enclosure structure is divided

https://doi.org/10.17993/3ctecno.2023.v12n2e44.184-202

from 1% to 10% of the overall performance of the enclosure structure, which can more accurately reflect the performance of the enclosure structure.

2. From the perspective of comprehensive performance, it can accurately evaluate all kinds of situations. For example, in a similar case, the building envelope, except for the non-transparent roof, meets the requirement of 5% improvement in thermal performance, only the non-transparent roof does not meet the requirement, and even if the non-transparent roof accounts for a very small proportion of the total envelope, the article does not score. The integrated heat gain coefficient U of the envelope structure, considering the envelope structure as a whole and calculating its single flat overall heat gain value, has a more accurate evaluation for the case that the performance of part of the envelope structure is not improved.

Table 1. Summary of calculation results

	Case building air conditioning	Refer to building air conditioning	Case building heating	Refer to building heating
External wall temperature difference heat transfer	1979	2120.5	-15058.4	-16134
Exterior window temperature difference heat transfer	5148	5169.5	-37545.3	-39333.1
Non-transparent roof temperature difference heat transfer	621	552	-4725	-4200
Radiant heat from external windows	15756.8	17332.5	11568.5	12725.4
Total	23504.8	25174.5	-45760.1	-46941.8
U(W/㎡)	12.8	13.7	-24.9	-25.6
Relative Difference	6.60%		3 %	

3.2. SYSTEM-INTEGRATED PART-LOAD PERFORMANCE FACTOR

Henan is located in the central region of China, and the heating heat source comes from municipal hot water, and cooling is mainly through HVAC. Therefore, the hourly weighting coefficient of the air conditioning period is taken here for evaluation. Henan generally enters summer with air conditioning from mid-May to September. The legal time for heating is from November 15 to March 31 of the following year. Therefore, the air-conditioning season is divided from May 15 to September 15. The hour-by-hour energy consumption of the building is calculated to calculate the time factor W/X/Y/Z, and the results are shown in Figure 1 below. The positive value is the heating energy consumption and the negative value is the air conditioning and cooling energy consumption. The values of W/X/Y/Z were determined by counting the number of

https://doi.org/10.17993/3ctecno.2023.v12n2e44.184-202

hours in the zones of 100%~75%, 75%~50%, 50%~25%, and 25%~0 during the air conditioning period, respectively, and the results are shown in Table 2 below.

Based on the data in Table 2, the total SIPLV consumption of the building is 100.7, and the total air conditioning consumption of the reference building is 116.9. By making a difference between the SIPLV value of the case building and the SIPLV value of the reference building, the reduction is calculated to be 13%. According to this difference, it is divided into 15 classes, from 1% to 15%, and scored 1 to 15 points respectively. 13 points are scored in this case, which is converted to 8.7 points proportionally. This evaluation index has the following advantages.

1. The score grade is carefully divided. In the national standard GB/T 50378-2014, the evaluation of the HVAC system is divided into three levels according to the reduction of energy consumption D e. 5% ≤ D e <10% scores 3 points, 10% ≤ D e <15% scores 7 points, and D e ≥15% scores 10 points. The partial comprehensive performance factor SIPLV, which divides the overall HVAC energy consumption level from 1% to 15%, can more accurately reflect the HVAC system performance.

2. From the perspective of comprehensive functionalization, it can evaluate the system's performance more accurately. Specifically divided into three points ① chilled water / hot water temperature difference * flow rate to calculate the cooling and heating calculation results are more accurate. ② Electricity consumption is expanded to the HVAC system to better measure the overall energy consumption of the system. ③ The efficiency of the HVAC system calculated with time weighting coefficients is more scientific.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.184-202

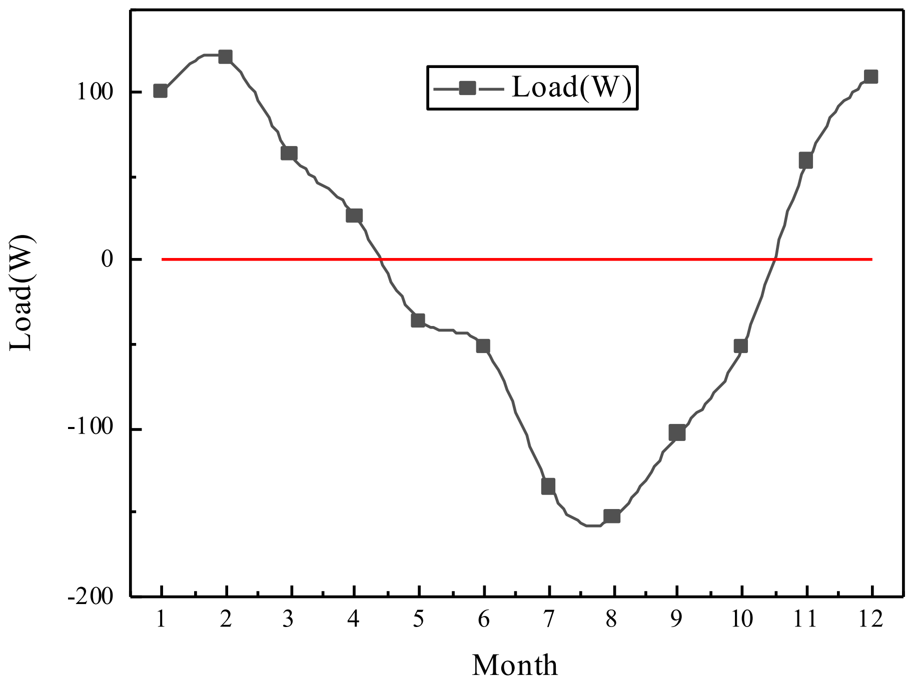


Figure 1. Yearly hourly air conditioning load

https://doi.org/10.17993/3ctecno.2023.v12n2e44.184-202

Table 2. Summary results of hours

	Load ratio	Number of hours	Weighting factor
W	100%~75%	45	0.03
X	75%~50%	229	0.15
Y	50%~25%	690	0.45
Z	25%~0	586	0.38

3.3. RENEWABLE ENERGY APPLICATION RATIO

The solar hot water system is installed on the top floor of this case building, which provides about 2200 tons of hot water throughout the year, accounting for about 40% of the domestic hot water. The amount of 60°/50° hot water produced in winter and summer is about 533 tons/1182 tons respectively, which is converted into about 6220KWH/13793kWh. According to the calculation of the equivalent electricity method index X, the overall energy consumption of the building is first calculated in DEST, which is converted into equivalent electricity by applying the formula. By setting the relevant parameters in DEST, the overall electricity consumption of each system for the whole year can be obtained and converted into equivalent electricity value output results as shown in Figure 2.

For this case, its renewable energy equivalent electricity ratio X is 1.08%, and it can score 4 points according to the rating. The advantage of this evaluation system is that all renewable energy and building energy consumption can be integrated into equivalent electricity, and the unified unit of measurement facilitates accurate evaluation of renewable energy utilization level. The traditional evaluation scheme scores solar energy, geothermal energy, and other energy forms and sources separately, and does not unify the energy metric, but only scores heat and cold, electricity and hot water separately. There will be a situation where due to the different forms of the system, the difficulty of obtaining the score is different, resulting in less accurate evaluation. The method of equivalent electricity is used to unify the non-conventional energy and building energy consumption into equivalent electricity, and the score is made according to the proportion of equivalent electricity provided by non-conventional energy. This effectively avoids the above problems and can evaluate the level of building renewable energy use more directly, objectively, and accurately.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.184-202

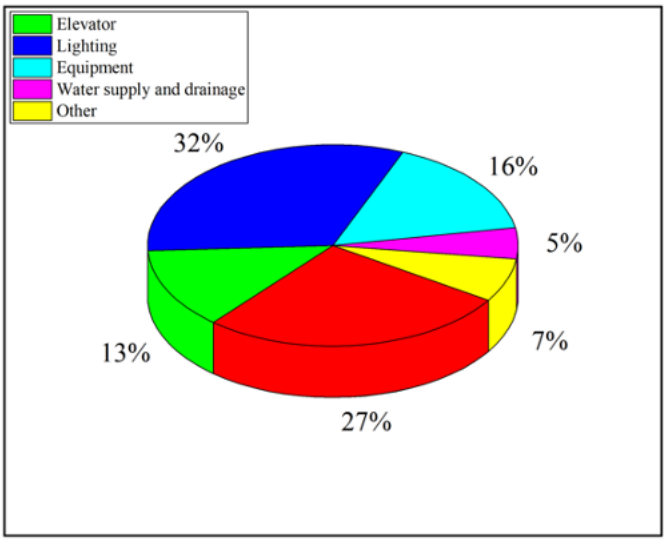


Figure 2. Calculation of annual electricity consumption of the case building

3.4. MAXIMUM LIGHTING POWER DENSITY

According to the relevant parameters of the case building, the hour-by-hour calculation of its model lighting power consumption, and the unit conversion are divided by the total area of the building to get the case building annual hour-by-hour lighting power density. As the current value of lighting power density of high-grade offices in the current national standard GB 50034-2013 is 15W/m2 and the target value is 13.5W/ m2, it is calculated that the reduction range is 10%, and according to this difference, it is divided into 10 grades. From 1% to 10%, the score is 1~10 points respectively. In this case, the L max of the building is 13.8W/ m2, and the reduction rate is 8%, and the building scores 8 points according to the calculation result. This evaluation index has the following advantages.

1. The score grade is carefully divided, to facilitate accurate evaluation. National standard GB/T 50378-2014 for lighting power density evaluation in accordance with the main functional area to meet all areas of the building to meet the 2 levels, the main functional area to meet the 4 points, and all areas to meet the 8 points. The maximum lighting power density L max, the overall lighting power density of the building is divided into 10 classes according to the proportion of the current value, which can more carefully and accurately reflect the level of lighting power density.

2. From the perspective of the overall lighting power of the building can measure the energy performance of the lighting system more accurately from two dimensions. I max is the maximum annual lighting power density value of the

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.184-202

building as a whole, which includes not only the physical dimension of the whole building but also the time dimension of the annual time-by-time value, which can reflect the energy performance of the lighting system more truly and accurately.

In summary, this section proposes a novel green building evaluation system that incorporates BIM to score the performance of green buildings. Specifically, key indicators such as the integrated heat gain coefficient of the envelope structure, the integrated part-load performance coefficient of the system, the renewable energy application ratio, and the maximum lighting power density of a building in Henan were calculated.

4. CONCLUSION

In this paper, the performance of a green building in Henan is calculated and evaluated based on BIM technology in the context of green buildings. The building fully integrates the aesthetic elements of traditional ancient architecture in Henan in the design stage. According to the calculation and scoring results, the building has better energy-saving effects in key indexes such as integrated heat gain coefficient of envelope structure, integrated partial load performance coefficient of system, renewable energy application ratio, and maximum lighting power density. The specific results of the study are as follows.

1. In terms of the integrated heat gain coefficient of the envelope, the difference between the air-conditioning U-value of the case building and the air-conditioning U-value of the corresponding reference building is calculated and the reduction is 6.6%. According to the evaluation criteria proposed in this paper, the integrated heat gain coefficient of the building envelope is scored as 6.

2. In the system-integrated partial load performance factor, the total SIPLV power consumption of the building is 100.7 and the total air conditioning power consumption of the reference building is 116.9. By making the difference between the SIPLV value of the case building and the SIPLV value of the reference building, the reduction is calculated to be 13%. According to the evaluation criteria proposed in this paper, the system-integrated partial load performance factor of this building is scored as 13.

3. For the renewable energy application ratio of the building, after calculation, the renewable energy equivalent electricity ratio X is 1.08%. According to the evaluation criteria mentioned in this paper, the score can be 4 points.

4. The building's maximum lighting power density, according to the calculation results, its maximum lighting power density is 13.8W/m2, compared with the national standard of 15W/ m2, and its reduction rate is 10%. According to the

https://doi.org/10.17993/3ctecno.2023.v12n2e44.184-202

evaluation criteria mentioned in this paper, the maximum lighting power density of the building scored 8 points.

REFERENCES

(1) Lin, X. D., & Qi, L. U. (2018). The Discussion of Entrance Transformation of Chinese Traditional Architecture From the Gable Side to the Eaves Side. South Architecture.

(2) Ren, T. (2021). A Study on the Symbolic Significance of Decorative Art of Huizhou Traditional Residential Buildings. Open Access Library Journal, 8(8), 7.

(3) Zhou, H. J., & Huang, J. (2020). Analysis of the Differences between Chinese and Japanese Traditional Wooden Architecture. IOP Conference Series Earth and Environmental Science, 510, 052017.

(4) Maha, S. , & Yara, S. . (2021). Adapting modernity designing with modern architecture in east jerusalem, 1948–1967. Journal of Design History(2), 2.

(5) Cao, Y. (2018). The Historical Context of Chinese Modern Architecture Discourse in the 1950——The Discussions on Chinese Modern Architecture Published in Architectural Journal During 1955-1959. Chinese & Overseas Architecture.

(6) Fortmeyer, R. . (2020). Modern architecture and climate: design before air conditioning. Architectural record(10), 208.

(7) Bloch, V., Degani, A.,& Bechar, A.. (2018). A methodology of orchard architecture design for an optimal harvesting robot. Biosystems Engineering, 166, 126-137.

(8) Mu, X. N. , Zhang, H. M. , Chen, P. W. , Cheng, X. W. , Yang, L. , & Chang, S., et al. (2022). Achieving well-balanced strength and ductility in gnfs/ti composite via laminated archite cture design. Carbon, 189, 173-185.

(9) Akhtar, M. S. , Adhya, A. , Gupta, J. , & Majhi, S. . (2021). Cost-optimal architecture design for adaptive multi-stage twdm-pon with ptp w dm overlay. Optical Engineering, 60(1).

(10) Allende, A. L., & Stephan, A. (2022). Life cycle embodied, operational and mobility-related energy and greenhouse gas emissions analysis of a green development in Melbourne, Australia. Applied Energy, 305.

(11) Li, Z., Jin, Y., Zhao, J., et al. (2021). Differential Clustering Analysis of Power Grid Green Development Based on Hierarchical Cluster Method. IOP Conference Series: Earth and Environmental Science, 634(1), 012077 (5pp).

(12) Li, S., Yang, Y., Zhang, D. (2021). The Effect of Product-Harm Crises on the Financial Value of Firms under the Concept of Green Development. Complexity.

(13) Shahzaib, K. J., Rozana, Z., Eeydzah, A., et al. (2018). Web-based automation of green building rating index and life cycle cost analysis. IOP Conference, 143, 012062-.

(14) Alohan, E. O., Kolawole, O. A. (2021). Hindrance and Benefits to Green Building Implementation: Evidence from Benin City, Nigeria. Real Estate Management and Valuation, 29.

(15) Zhou, J., et al. (2021). Seepage channel development in the crown pillar: Insights from induced microseismicity. International Journal of Rock Mechanics and Mining Sciences, 145, 104851.

(16) Koseleva,N,&Ropaite,G.(2017).Big data in building energy efficiency understandi-ng of big data and main challenges.Procedia Engineering,172(Complete),544-549.

(17) Buenning, F. , Sangi, R. , & Mueller, D.. (2017). A modelica library for the agent-based control of building energy systems. Applied Energy, 193(MA Y1), 52-59.

(18) Xu, L., Wu, J. (2020). Research on the green building design of a parent-child theme park. Shanxi Architecture.

(19) Umaroullar, F., Kartal, S., Aydn, D. (2020). A Comparative Study on Turkey's National Green Building Certification System Under Energy Policy Developments. International Journal of Architecture and Planning.

(20) Anggraeni, M. E. (2020). Redesain Perencanaan Gedung Integrated Laboratory for Engineering Biotechnology dengan Konsep Green Building dalam Peningkatan Peringkat dari Bronze Menuju Gold.

(21) Xing, Z., Cao, X. (2019). Promoting Strategy of Chinese Green Building Industry: An Evolutionary Analysis Based on the Social Network Theory. IEEE Access, PP(99), 1-1.

(22) Christian, Y., Setyandito, O., Juliastuti, et al. (2022). Integration of land survey data using aerial photogrammetry method on 3 dimensional BIM (Building Information Modeling) Modeling. IOP Conference Series: Earth and Environmental Science, 998(1), 012023 (11pp).

(23) Ansah, M. K., Chen, X., Yang, H., et al. (2019). A review and outlook for integrated BIM application in green building assessment. Sustainable Cities and Society, 48, 101576.

(24) Xu, J. (2022). Research on energy consumption control method of green building based on BIM technology. International Journal of Industrial and Systems Engineering, 40.

(25) Wang, N., Liu, C. H., Architecture, S. O., et al. (2019). Efficient Integration and Application of BIM and Green Building. Building Energy Efficiency.

(26) Zhu, N., Yang, B., Zhang, Z., et al. (2021). Application of BIM in green building materials management. Journal of Physics: Conference Series, 1986(1), 012024-.

(27) Jiang, Y., Liu, F., Zhang, J. (2020). Integrated Strategy of Green Building Model Optimization Based on BIM Technology. In 2020 5th International Conference on Smart Grid and Electrical Automation (ICSGEA).

(28) Zanni, M., Ruikar, K., Soetanto, R. (2020). Systematising multidisciplinary sustainable building design processes utilising BIM. Built Environment Project and Asset Management.

(29) Duan, P. (2018). Analysis on the application and inheritance of traditional elements in modern architecture design. Shanxi Architecture.

(30) Ouyang, L. (2019). Analysis on Zhuang Ziyu's Modern Deductive Techniques of Traditional Architecture. Urbanism and Architecture.

(31) Gawell, E., Grabowiecki, K. (2021). Modern Details in Meaningful Architecture. Sustainability, 13.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.184-202

(32) Jia, Y. (2019). Discussion on the Integration of Modern Architecture and Traditional Architecture by the Design of Yucheng Museum. Urbanism and Architecture.

(33) Liu, Hailiang, Hou, Chenglong, & Ramzani, Sara Ravan. (2021). Construction and reform of art design teaching mode under the background of the integration of non-linear equations and the internet. Applied Mathematics and Nonlinear Sciences.

/12/

BIG DATA TECHNOLOGY FRAMEWORK AND DATA UTILIZATION FOR URBAN ENVIRONMENTAL POLLUTION MANAGEMENT

Nan Li*

School of Marxism, Capital Normal University, Beijing, 100089, China.

linanxa@126.com

Zheng Ma

Foshan Electric Construction Group Limited, Foshan, Guangdong, 528000, China.

Reception: 06/04/2023 **Acceptance**: 30/05/2023 **Publication**: 26/06/2023

Suggested citation:

Li, N. and Ma, Z. (2023). **Big data technology framework and data utilization for urban environmental pollution management**. *3C Tecnología. Glosas de innovación aplicada a la pyme, 12(2)*, 204-218. https://doi.org/10.17993/3ctecno.2023.v12n2e44.204-218

ABSTRACT

Urban environmental pollution management is of great practical significance to achieving sustainable urban economic development. To improve the efficiency of urban environmental pollution management, we have established a big data technology framework for urban environmental pollution treatment. The relevant pollution data collected are used for targeted pollution treatment. The results show that the average efficiency of environmental pollution control in the whole province of China has increased from 33.67% to 63.67%, an increase of 46%. Among them, the efficiency of environmental pollution control in Guangdong has increased most significantly, with a relative position of 26.47%, which is at the top of the list. Inner Mongolia has the weakest increase in environmental pollution control efficiency, with an appreciation of 6.89% relative to its position, while the other 16 provinces and cities have little change in environmental pollution control efficiency. between 2010 and 2020, the urban pollution and environmental treatment costs that residents need to bear changed significantly, with fluctuations of around 30%.

KEYWORDS

Environmental pollution; pollution management; big data; pollution management efficiency; economic analysis

INDEX

https://doi.org/10.17993/3ctecno.2023.v12n2e44.204-218

1. INTRODUCTION

Environmental pollution control is an important initiative to promote the construction of ecological civilization [1, 2]. For ordinary people, a high-quality living environment with blue skies and white clouds is the basic condition for building an ecological civilization of beautiful China and realizing the Chinese dream of rejuvenation of the Chinese nation [3]. In building an ecological civilization society, comprehensive prevention and control of air pollution should be solidly promoted [4, 5]. Further significant reduction of heavily polluted weather and gradual improvement of air quality [6]. Environmental pollution control is a powerful grip to create an upgraded version of China's economy [7, 8]. At present, China's crude development mode of high input, high consumption, high pollution, and low efficiency has not been fundamentally transformed, which is the fundamental cause of serious pollution [9]. In recent decades, China's economy has been developing steadily and rapidly. China has made remarkable achievements in economic construction in the world [10], but along with the economic development, China has paid a huge environmental cost. Along with China's rapid economic growth, China's ecological environment is deteriorating and pollution problems are becoming increasingly serious. The pollution problem has now become a major challenge to China's sustainable economic development [11, 12]. In China, with the advancement of urbanization, more and more people are living in cities. The corresponding urban environmental pollution has become an important part of China's environmental pollution, so it is of epochal significance to do a good job in urban environmental pollution management to build a beautiful China and promote China's modern economic construction.

In China, ecological and environmental problems brought about by urbanization are gradually emerging [13]. Therefore, the issue of urban environmental pollution management has received great attention, and people are eager to solve a series of environmental pollution problems such as water shortage and pollution, and rapid reduction of air quality [14]. People are eager to aspire to and pursue a healthy, green, and sustainable ecological living environment. Faced with the current rapid population growth, excessive consumption of resources, and serious environmental pollution, the sustainable development path is the inevitable way of development nowadays [15-22]. At present, for urban environmental pollution management, there are still problems such as small investment in environmental protection, insufficient urban environmental infrastructure construction, and insufficient policies and laws and regulations for environmental protection [23, 24]. In urban environmental pollution management, the lack of environmental protection investment has led to weak comprehensive urban pollution management capacity. Further, the slow pace of urban environmental infrastructure construction, urban domestic waste, hazardous waste treatment capacity, etc. is not able to keep up with the pace of urban development, thus leading to serious pollution problems over time.

In terms of urban environmental pollution management, urban environmental pollution management is closely related to people's lives [25]. Therefore, prevention and treatment of urban environmental pollution management has received wide

https://doi.org/10.17993/3ctecno.2023.v12n2e44.204-218

attention. Zhang, X [26] surveyed the environmental concentration and change characteristics of ozone and its precursors in Beijing from May-June 2014-2017 to study heavy ozone pollution. Their study showed the need to adjust control measures according to the changes in ozone precursors and strengthen the coordinated control of urban environmental pollution prevention and control in long-term planning. Fei, F [27] considered municipal biological waste as an organic part of municipal solid waste and a major waste type in low- and middle-income countries. They used the concept of industrial ecology to conduct a complete planning exercise for urban bio-waste disposal systems. Their study showed that conducting urban environmental pollution management has significant economic, environmental, and social benefits. In a study by Guo, J.X [28], they studied showed that in large cities, the coordinated development of pollutants and carbon reduction in the transportation sector can help to achieve urban pollution prevention and carbon reduction. They proposed a bottom-up mathematical model of vehicle development for multiple periods, analyzing the air pollution emission paths and energy restructuring paths, as well as the synergistic benefits of CO2 emission reduction. Further, Zhao, B [29] argued that spatially explicit urban air quality information is important for developing effective air quality control measures. They did this by collecting real-time spatially resolved data on fine particulate matter concentrations. A decision tree model was developed to infer the distribution of PM2.5 concentrations. Tang, W [30] considered water pollution as the main environmental problem among urban environmental pollution. They analyzed various long-term water quality, wastewater treatment plants, and pollutant discharge data to systematically understand the process of water pollution control in China over the past two decades. They suggested that wastewater collection and treatment capacity should be further improved to address the gap between effluent discharge limits of wastewater treatment plants and environmental quality standards for surface water. Xiong, W [31] proposed wastewater recycling as the most effective strategy to reduce the impact of urban water ecosystems. Wang, R [32] in their study pointed out that polluted urban river systems may be an important source of atmospheric methane and nitrous oxide sources. Xiao, Q [33] suggested that environmental investments could reduce the partial pressure of CO2 in small eutrophic urban lakes. Their results show that anthropogenic activities strongly influence the dynamic distribution of lake CO2 and that environmental investments, such as ecological restoration and reduction of nutrient discharges, can significantly reduce CO2 emissions from inland lakes. In all the above studies, we can find that for urban environmental pollution prevention and control, mainly includes several aspects such as air pollution, water pollution, and pollution emission. In conducting urban pollution prevention and control, previous studies tend to focus on one direction to carry out. However, urban environmental pollution treatment is a comprehensive system that needs to be carried out in several aspects such as air pollution, water pollution, and pollution discharge.

Urban environmental pollution management is of great practical significance to achieve sustainable development of the urban economy. In urban environmental pollution management, it involves several aspects such as air pollution, water pollution, and pollution discharge. Therefore, when pollution prevention and control is

https://doi.org/10.17993/3ctecno.2023.v12n2e44.204-218

carried out, a large amount of data on the generation of pollutants and the treatment of pollutants will be generated. Therefore, in urban pollution control, we need to analyze a large amount of data to determine the areas that need to be dealt with in urban pollution control. In this research work, we establish a big data technology framework for urban environmental pollution treatment. Through the collected pollution data for pollution prevention and treatment, then improve the efficiency of urban environmental pollution treatment.

2. CONSTRUCTION OF AN EVALUATION PLATFORM FOR URBAN ENVIRONMENTAL POLLUTION MANAGEMENT BASED ON BIG DATA

As urban environmental pollution problems become increasingly serious, a large amount of real environmental pollution data are collected and made public by government agencies [34, 35]. Big data technology is used to automatically extract important pollution causes from these environmental pollution big data and establish a big data-based urban environmental pollution management evaluation platform to better solve a series of problems in urban environmental pollution management in China. In environmental pollution big data, a large amount of environmental pollution data covers the detailed records of environmental pollution generated within the city. Specifically, by using frontier technologies of information science such as big data and artificial intelligence, we can propose to solve the drawbacks of monolithic urban environmental pollution governance and improve the quality and efficiency of urban environmental governance.

2.1. BASIC CONCEPTS OF BIG DATA

Big Data on environmental pollution is different from the traditional data management model in that it brings radical changes in the way data is collected, data pre-processing (stream processing vs. batch processing), and data algorithm approach. At present, we have experienced the evolution of the operational phase, user original phase, and perceptual system phase. This is mainly reflected in the following aspects.

1. Data scale. Due to the booming development of urban informatization, emerging services such as the Internet of Things can collect unprecedented data types as well as data quantities.

2. Processing tools. At this stage, there are 4 paradigms, based on the new data thinking approach of environmental pollution big data collection for processing various research objects as well as various heterogeneous data. The above 4 paradigms are introduced as shown in Table 1.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.204-218

Scientific Paradigm	Methodology
Empirical	Description of natural phenomena
Theoretical	Use of models, generalization
Computational	Simulation of complex phenomena
Data Exploration	Instrument-captured or simulator-generated data; software processing; computer-stored information; scientists analyzing databases

Table 1. Comparison of big data processing paradigms

3. Data types. Traditional data management models have a single type of data while emerging services such as IoT can capture a wide variety of big data types (structured, semi-structured, and unstructured). Of these, the latter two data types account for the largest share.

2.2. TECHNICAL FRAMEWORK

This paper constructs a big data-based urban environmental pollution management evaluation platform including three parts: environmental pollution big data access layer, environmental pollution big data processing layer, and environmental pollution big data application layer, as shown in Figure 1. In the environmental pollution big data access layer, for the problems of diverse sources and different structures of factory emission information system data within the city, Spark distributed is used to pre-process the environmental pollution big data, and the quality and reliability of the environmental pollution big data are ensured by integrating and classifying the environmental pollution big data. In the environmental pollution big data processing layer, the big data-based urban environmental pollution governance evaluation platform constructs a series of environmental pollution big data engines by selecting appropriate environmental pollution big data analysis technologies to conduct efficient and in-depth data mining and fusion analysis of environmental pollution big data. At the application layer of environmental pollution big data, the big data-based urban environmental pollution governance evaluation platform transforms the problem of excessive emissions of factory enterprises into a big data analysis problem by transforming them into a big data analysis problem. The evaluation model of urban environmental pollution management, such as establishing effective pollutant treatment measures and finding low-cost solutions, realizes sustainable development of the urban economy and environment, etc.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.204-218

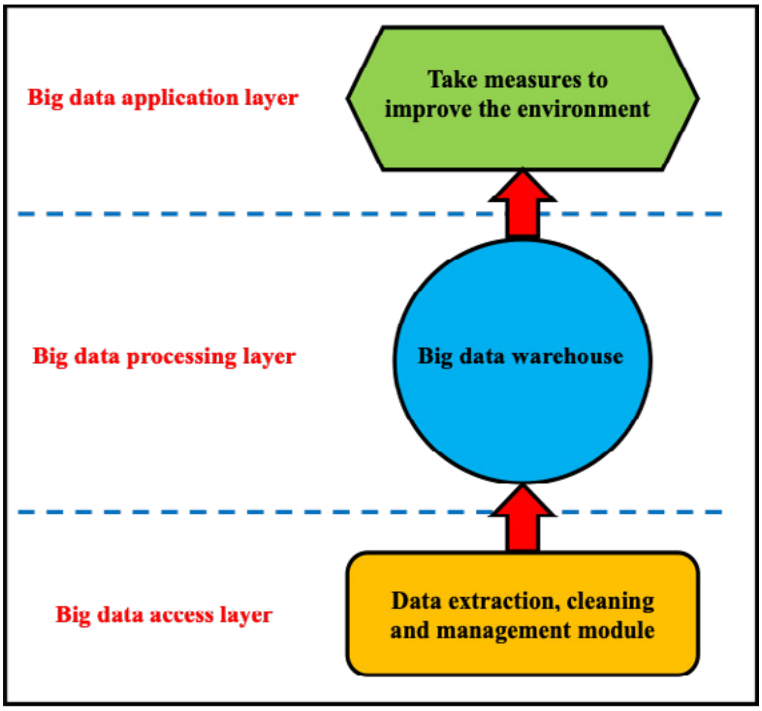


Figure 1. The framework of urban environmental pollution management evaluation platform based on big data.

2.3. RESEARCH PROGRAM

This paper proposes a big data-based urban environmental pollution management evaluation platform that enables a customizable implementation approach based on the environmental governance needs of Chinese cities. We investigated exhaustive projects of environmental governance across China, summarized common problems prevalent in intra-city factory emissions, developed specific research solutions for these problems, and finally validated and analyzed the research content using the environmental pollution big data from the above-mentioned research.

It is worth mentioning that the big data's urban environmental pollution management evaluation platform flags the waste emissions of each factory in the city. We extract irregular waste emission events from environmental pollution big data and automatically build a risk assessment model of environmental pollution damage from relevant waste based on the waste composition, emission cycle, and total emission of the factory. Improve laws and regulations to clarify the obligations of the public and enterprises in participating in urban environmental pollution control, and the government to promote green and low-carbon consumption concepts. Eliminate the backward production equipment as well as improve the production process of urban factories, increase pollution control, and complete the task of pollution reduction. To provide a strong solution for urban environmental pollution management.

2.4. ENVIRONMENTAL POLLUTION BIG DATA PROCESSING PROCESS

https://doi.org/10.17993/3ctecno.2023.v12n2e44.204-218

The data sources of environmental pollution big data are widely available, and the application requirements and data types are different, but the most basic processing process is consistent, as shown in Figure 2 Basic processing process of big data. The entire processing process of environmental pollution big data can be defined as the extraction and integration of a wide range of heterogeneous data sources with the assistance of suitable tools, and the results are stored uniformly according to certain standards. The stored environmental pollution big data is analyzed using appropriate data analysis techniques, and the relevant environmental pollution factors are extracted from the environmental pollution big data and the results are fed back to government agencies in an appropriate way so that they can enact policies and take action for pollution control.

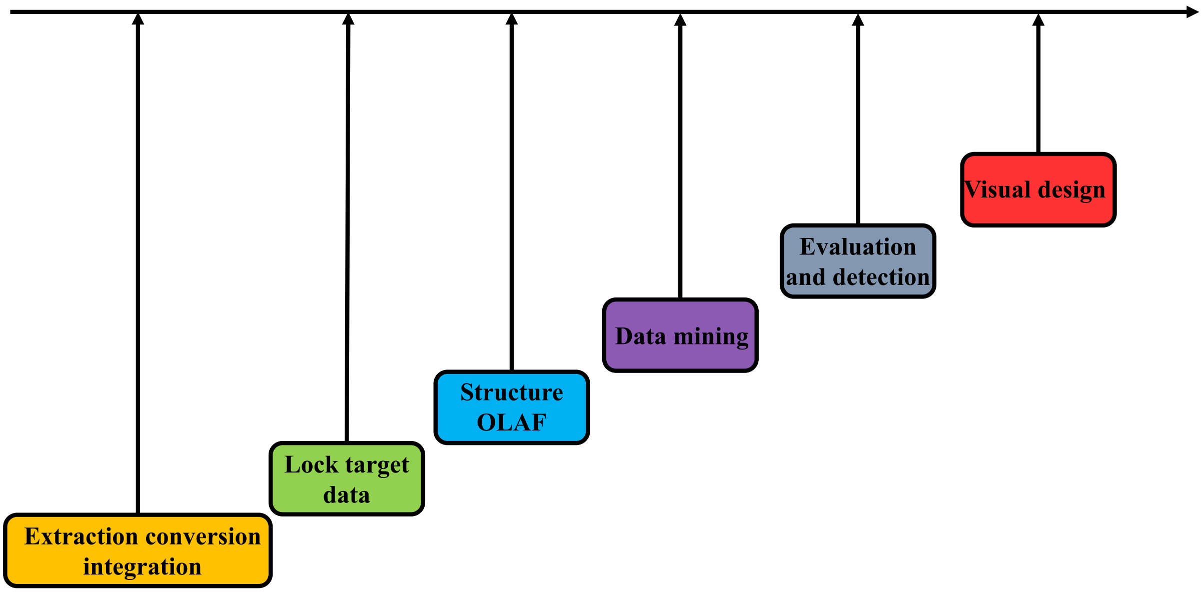


Figure 2. Basic processing flow of big data

3. TECHNICAL EFFICIENCY OF URBAN ENVIRONMENTAL POLLUTION MANAGEMENT

This paper evaluates the technical efficiency of urban environmental pollution control based on data envelopment analysis (DEA). DEA solves the optimal production frontier surface through linear programming and compares the production possibilities of each multi-input and multi-output similar decision-making unit (DMU) with the previous optimal frontier surface to obtain a measure of the relative efficiency of each DMU. The specific evaluation criteria process is as follows.

$$F_i(y, x \mid C, S) = \min \left\{ \lambda : \lambda_x \in L(y \mid C, S) \right\} \tag{1}$$

$$s \cdot t \cdot L(y \mid C, S) = \left\{ (x_1, x_2, \ldots x_N) : \sum_{k=1}^{K} Z_k y_{km} \geqslant y_m, \sum_{i=1}^{K} z_i x_{in} \leqslant \theta_k x_{kn}, \sum_{k=1}^{K} z_k x_{kn} \leqslant x_n \right\} \tag{2}$$

Where, x is the input; y is the output; z is the weight; N, M and K denote the number of input variables, output variables and DMUs, respectively; F_i is the technical

https://doi.org/10.17993/3ctecno.2023.v12n2e44.204-218

efficiency of the ith DMU; C is the total number of different types of big data; S is the total number of big data samples. In addition, 34 provincial regions in China are selected as DMUs in this paper, and the period for analysis is from 2010 to 2020. To store, manage and analyze environmental pollution big data, we use Spark distributed computing framework for technical implementation. This paper based on Spark distributed computing can reduce the overhead caused by data movement and transparently provide high reliability and high-performance computing for upper-layer applications

4. ANALYSIS AND DISCUSSION

4.1. OVERALL ENVIRONMENTAL POLLUTION CONTROL EFFICIENCY PERFORMANCE

To realize the sustainable development of the urban ecological environment, we introduce big data technology, which should firstly collect the urban ecological environment data according to the urban environmental pollution situation and the governance needs, and build the corresponding standard system structure according to the results obtained from the collection. Finally, pollution treatment should be completed in strict accordance with the corresponding standard indicators. The average efficiency scores of environmental pollution control for the whole province of China, eastern China, central China, and Western China are compiled in Figure 3, which shows that in the early 21st century, the efficiency of environmental pollution control in all regions of China was below 50%. With the proposed policies of energy conservation and emission reduction, carbon peaking, and carbon neutrality in China, the efficiency of environmental pollution management gradually began to improve across China. Between 2010 and 2020, the average efficiency score for environmental pollution control across China's provinces increased from 33.67% to 63.67%, an improvement of 46%. Overall, the efficiency of environmental pollution control across China is increasing, thanks to strong government support for environmental protection. The average efficiency score of environmental pollution control in eastern China increased from 47.02% to 63.67%, an increase of 26.15%. This can indicate that there are large differences in environmental pollution control across China, although local environmental pollution is more serious in central and western China than in eastern China. However, comparing the average efficiency of environmental pollution control in the three regions, the relative environmental cost of economic development is greater in central China and western China, and it is more difficult to balance high economic development with environmental protection. The average efficiency score of environmental pollution control in central China increased from 32.15% to 61.34%, an increase of 47.59%, while the average efficiency score of environmental pollution control in western China increased from 22.28% to 56.72%, an increase of 60.72%. This result further reflects that Central China and Western China are sacrificing the environment to catch up with the economic development of the Eastern region. At the same time, we find that there are large regional differences

https://doi.org/10.17993/3ctecno.2023.v12n2e44.204-218

in the efficiency of environmental pollution control and its dynamics among Chinese localities, which generally show a distribution pattern of high in the east and low in the west.

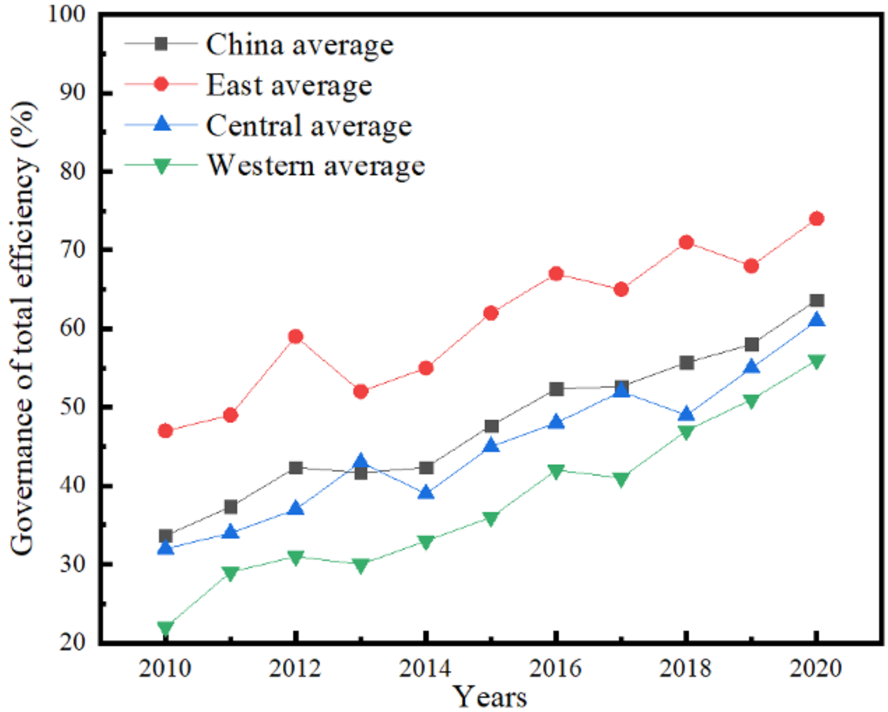


Figure 3. Changes in the average efficiency scores of environmental pollution control in China as a whole and in the three major regions

4.2. PERFORMANCE OF ENVIRONMENTAL POLLUTION CONTROL EFFICIENCY BY PROVINCES AND CITIES

Urban pollution environmental data can accurately reflect the current stage of urban environmental problems. In turn, it can fully reflect the quantity, quality, distribution, and other relevant information of various elements in the process of urban environmental pollution management. In the process of urban ecological environmental protection, urban pollution data can fully reflect the changing characteristics of the environment. To facilitate the comparison of environmental pollution control efficiency in various regions of China, regional differences in environmental pollution control efficiency in eastern China, central China, and western China are explored in depth. We extracted the environmental pollution control efficiency of 17 provinces and municipalities in China for observation and studied the changes in environmental pollution control efficiency in ten years (2010 to 2020), and the results are shown in Figure 4. From Figure 4, it can be seen that the city with the most obvious increase in the efficiency of environmental pollution control within ten years is Guangdong, which is at the top of the list with an upward relative position value of 26.47%. This indicates that the Guangdong government has been able to achieve a common and harmonious development between two hard indicators for economic development and environmental protection. In addition, the city with the

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.204-218

weakest increase in environmental pollution control efficiency is Inner Mongolia, with an increase of 6.89% relative to its position, and little change in environmental pollution control efficiency compared to the other 16 provinces and cities. The above results fully indicate that central and western China provinces and cities have seriously neglected environmental protection while developing their local economies, resulting in a serious decline in the relative position of environmental pollution control efficiency. Eastern provinces and cities in China have achieved a relatively harmonious co-development between environmental protection and economic development, and have been performing relatively well or have achieved a significant increase in the relative ranking of environmental pollution control efficiency.

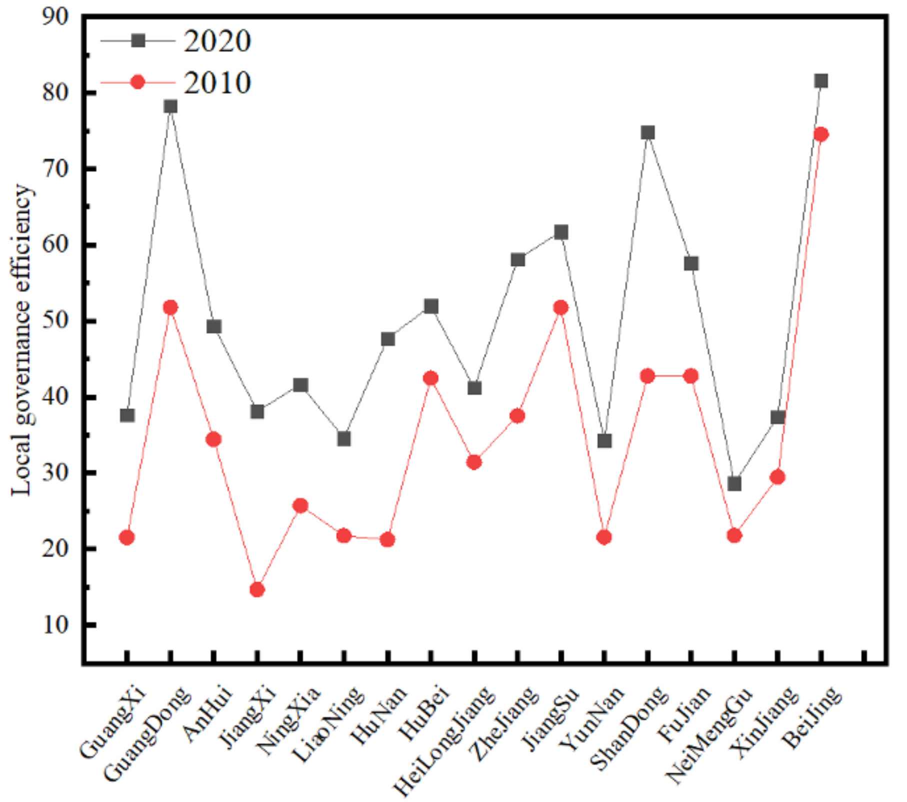


Figure 4. Change in the average efficiency score of environmental pollution control in a region of China

4.3. ECONOMIC ANALYSIS OF URBAN POLLUTION ENVIRONMENTAL MANAGEMENT

To comprehensively improve urban pollution environmental management, first of all, it is necessary to focus on the classification of urban pollutants and the economics of the recycling process. In the process of building the urban environmental data-based management system, this part should be the focus. By transferring information such as the type of urban pollutants collected by the government and relevant departments to the big data framework, and using this as the basis, we can realize the analysis of the economics of urban pollutants classification and recycling more scientifically. Next, the data obtained is analyzed in terms of social group participation

https://doi.org/10.17993/3ctecno.2023.v12n2e44.204-218

rates using market research, and the proposed measures are revised several times by integrating the results of the market research. The analyzed economic data is transmitted to the information. Urban residents, as emitters, should be financially responsible for the management of the domestic pollution they cause. Therefore, we have compared the economic analysis of sewage treatment and domestic waste treatment, which are common in urban pollution. Figure 5 shows the change in urban pollution treatment costs for urban residents between 2010 and 2020. We can see that for urban sewage treatment, the cost is significantly higher than the cost of urban domestic waste treatment. In 2010, residents need to bear the cost of urban sewage treatment of 283.56 yuan and the cost of garbage treatment of 132.59 yuan. In comparison, the cost of sewage treatment is 2.14 times higher than the cost of garbage treatment. The overall trend seems to be that there is a trend toward lowering the cost of municipal sewage treatment. In 2019, the lowest cost of sewage treatment that urban residents need to bear is only 208.6 yuan, which is 26.44% lower than the highest 283.56 yuan in 2010. This indicates that in the process of urban pollution and environmental management, sewage treatment is becoming more and more efficient, and the cost that residents need to bear gradually decreases. Similarly, in terms of urban waste disposal costs, the highest cost required to be spent in 2011 was 176.2 yuan. In 2016, the lowest cost of municipal waste treatment was required to be borne, requiring 128.9 yuan, a decrease of 26.84% year-on-year. The change in the cost of urban sewage treatment and urban domestic waste treatment can be seen through the change in the cost of urban pollution environment treatment that residents need to bear between 2010 and 2020, with fluctuations of about 30%.

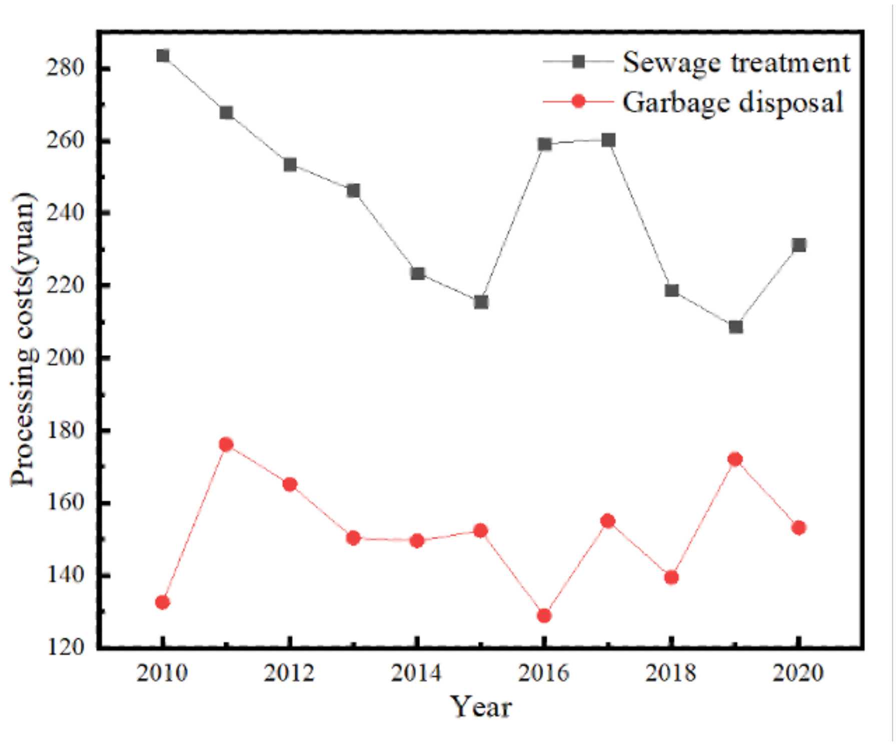


Figure 5. Change in urban pollution treatment costs for urban residents from 2010 to 2020

5. CONCLUSION

https://doi.org/10.17993/3ctecno.2023.v12n2e44.204-218

We address air pollution, water pollution, and other pollution sources that need to be dealt with for urban environmental pollution management. We establish a big data technology framework for urban environmental pollution treatment, collect relevant pollution data, and further use the collected data for pollution prevention and treatment. The results are expressed as follows.

1. Between 2010 and 2020, thanks to the government's strong support for environmental protection, the average efficiency score of environmental pollution control in China's provinces rose from 33.67% to 63.67%, an efficiency increase of 46%, and the efficiency of environmental pollution control across China has been rising. At the same time, we find that there are large regional differences in the efficiency of environmental pollution control and its dynamics across Chinese localities generally showing a distribution pattern of high in the east and low in the west.

2. The environmental pollution control efficiency of 17 provinces and municipalities in China from 2010 to 2020, Guangdong's environmental pollution control efficiency increased the most significantly, with a relative position of 26.47%, which is at the top of the list. Inner Mongolia has the weakest increase in environmental pollution control efficiency, with an increase of 6.89% in relative position, and little change in environmental pollution control efficiency when compared with other 16 provinces and cities.

3. In 2010, residents had to bear the city's sewage disposal cost of $283.56 and garbage disposal cost of $132.59. In comparison, the cost of sewage treatment is 2.14 times higher than the cost of garbage treatment. The overall trend seems to be that there is a trend toward lowering the cost of municipal wastewater treatment. In 2019, urban residents need to bear the lowest cost of sewage treatment, which costs only 208.6 yuan, 26.44% lower than the highest 283.56 yuan in 2010. This indicates that the process of urban pollution environment management, and sewage treatment efficiency is getting higher and higher, and the cost that residents need to bear gradually decreases. between 2010 and 2020, the cost of urban pollution environment treatment that residents need to bear changed significantly, fluctuating at about 30%.

REFERENCES

(1) Shi, J., et al. (2021). Pollution control of wastewater from the coal chemical industry in China: Environmental management policy and technical standards. Renewable and Sustainable Energy Reviews, 143(4), 110883.

(2) Zhang, Y., Song, Y., & Zou, H. (2020). Transformation of pollution control and green development: Evidence from China's chemical industry. Journal of Environmental Management, 275, 111246.

(3) Zhu, J., & Xu, J. (2022). Air pollution control and enterprise competitiveness – A re-examination based on China's Clean Air Action. Journal of Environmental Management, 312(6), 114968.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.204-218

(4) Geng, et al. (2018). Research on Decision Support System (DSS) of Atmospheric Environment Management in Anhui Province Based on Air Quality Forecasting. Meteorological and Environmental Research, 9(04), 65-69.

(5) Qiao, B., et al. (2017). Ship emission reduction effect evaluation of air pollution control countermeasures. Transportation Research Procedia, 25, 3610-3622.

(6) Liu, J., et al. (2020). Has the mortality risk declined after the improvement of air quality in an ex-heavily polluted Chinese city-Lanzhou? Chemosphere, 242(Mar.), 125196.1-125196.9.

(7) Luo, X., et al. (2020). Empirical analysis based on grey relational theory: is industrial integration conducive to environmental pollution control and technological innovation? In AADNIC-ABMECR 2020: The 2nd Africa-Asia Dialogue Network International Conference on Advances in Business Management and Electronic Commerce Research.

(8) Hao, Y., & Zheng, S. (2017). Would environmental pollution affect home prices? An empirical study based on China's key cities. Environmental Science & Pollution Research.

(9) Kamal, M., et al. (2021). Revisiting the Role of Fiscal Policy, Financial Development, and Foreign Direct Investment in Reducing Environmental Pollution during Globalization Mode: Evidence from Linear and Nonlinear Panel Data Approaches. Energies, 14.

(10) Zhang, Z., Duan, Y., & Zhang, W. (2019). Economic gains and environmental costs from China's exports: Regional inequality and trade heterogeneity. Ecological Economics, 164(OCT.), 106340.1-106340.13.

(11) Yang, Q., et al. (2021). Comparison of the impact of China's railway investment and road investment on the economy and air pollution emissions. Journal of Cleaner Production, 293(7), 126100.

(12) Xiong, J., & Xu, D. (2021). Relationship between Energy Consumption, Economic Growth and Environmental Pollution in China. Environmental Research.

(13) Fang, C., et al. (2019). Modeling regional sustainable development scenarios using the Urbanization and Eco-environment Coupler: Case study of Beijing-Tianjin-Hebei urban agglomeration, China. The Science of the total environment, 689(NOV.1), 820.

(14) Armeanu, D. S., et al. (2021). Understanding the multidimensional linkages among renewable energy, pollution, economic growth and urbanization in contemporary economies: Quantitative assessments across different income countries' groups. Renewable and Sustainable Energy Reviews, 142.

(15) Fikret, B.. (2017). Environmental governance for the anthropocene? social ecological systems, resilience, and collaborative learning. Sustaina bility, 9(7),1232.

(16) Wei, W., & Zhang, Q.. (2022). Evaluation of rural financial ecological environment based on machine learning and improved neural network. Neural computing & applications(12), 34.

(17) Huang, Y. . (2021). Destruction process and restoration countermeasures of the ecological environment of a comprehensive geological structure. Earth Sciences Research Journal, 24 (4), 429-437.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.204-218

(18) Duda, A. M. . (2017). Leadership and political will for groundwater governance: indispensable for meeting the new sustainable development goals (sdgs). Brazilian J ournal of Microbiology.

(19) Donia, Mineo, AM, Mascali, & Sgroi. (2017). Economic development and agriculture: managing protected areas and safeguarding the environment. ECOL ENG.

(20) ZhBiermann, F. , Kanie, N. , & Kim, R. E. . (2017). Global governance by goal-setting: the novel approach of the un sustainable development goals. Current Opinion in Environmental Sustainability, s 26–27, 26-31.

(21) Broman, G. I., & Robert, K. H. . (2017). A framework for strategic sustainable de-velopment. Journal of Cleaner Production, 140(pt.1), 17-31.

(22) Joachim, Maes, Sander, & Jacobs. (2017). Nature-based solutions for europe's sustainable development. Conservation Letters.

(23) Xie, Q., & Liu, J. (2019). Combined nonlinear effects of economic growth and urbanization on CO_2 emissions in China: Evidence from a panel data partially linear additive model. Energy, 186(Nov.1), 115868.1-115868.13.

(24) Luo, K., et al. (2018). PM2.5 mitigation in China: Socioeconomic determinants of concentrations and differential control policies. Journal of Environmental Management, 213(MAY1), 47-55.

(25) Rahman, M. M., & Alam, K. (2021). Clean energy, population density, urbanization and environmental pollution nexus: Evidence from Bangladesh. Renewable Energy, 172(7).

(26) Zhang, X., et al. (2021). Heavy ozone pollution episodes in urban Beijing during the early summertime from 2014 to 2017: implications for control strategy. Environmental Pollution.

(27) Fei, F., et al. (2021). Redesign of urban biowaste sustainable management system based on industrial ecology concept: A case study in China. Science of The Total Environment, 148425.

(28) Guo, J. X., et al. (2021). Vehicle mix evaluation in Beijing's passenger-car sector: From air pollution control perspective. Science of The Total Environment, 785, 147264.

(29) Zhao, B., et al. (2021). Urban Air Pollution Mapping Using Fleet Vehicles as Mobile Monitors and Machine Learning. Environmental Science and Technology.

(30) Tang, W., et al. (2022). Twenty years of China's water pollution control: Experiences and challenges. Chemosphere, 295, 133875-.

(31) Xiong, W., et al. (2020). Improving water ecosystem sustainability of urban water system by management strategies optimization. Journal of Environmental Management, 254(Jan.15), 109766.1-109766.9.

(32) Wang, R., et al. (2020). An urban polluted river as a significant hotspot for water–atmosphere exchange of CH4 and N2O. Environmental Pollution, 264, 114770.

(33) Xiao, Q., et al. (2020). Environmental investments decreased partial pressure of CO2 in a small eutrophic urban lake: Evidence from long-term measurements. Environmental Pollution, 263(Pt A), 114433.

(34) Sun, Y., et al. (2021). Resource extraction, environmental pollution and economic development: Evidence from prefecture-level cities in China. Resources Policy, 74.

/13/

SMART HOME SERVICE TERMINAL DESIGN FOR ELDERLY FAMILIES INTEGRATING THE KANO MODEL AND PERCEPTUAL ENGINEERING

Wei Chen*

College of Arts, Chongqing Technology and Business University, Chongqing, 400067, China.

px13677699899@126.com

Hong Tang

College of Arts, Chongqing Technology and Business University, Chongqing, 400067, China.

Tingting Yan

College of Arts, Chongqing Technology and Business University, Chongqing, 400067, China.

Reception: 04/04/2023 **Acceptance**: 02/06/2023 **Publication**: 30/06/2023

Suggested citation:

Chen, W., Tang, H. and Yan, T. (2023). **Smart home service terminal design for elderly families integrating the KANO model and perceptual engineering**. *3C Tecnología. Glosas de innovación aplicada a la pyme, 12(2)*, 220-235. https://doi.org/10.17993/3ctecno.2023.v12n2e44.220-235

ABSTRACT

In recent years, smart homes have gradually come into our lives and have brought many positive impacts to our lives. However, in specifically targeted application design planning, the designer community is not always able to consider and analyze every factor. This paper proposes an integrated nonlinear design that incorporates the KANO model as well as a mathematical model of sensible engineering coupled with design science. The application of different design solutions in different types of households is evaluated after dividing the different types of living of elderly households into specific situations. The results show that for elderly households of type 1 versus 4, scenario 2 generally has more accurate application feasibility compared to scenario 1. The maximum increase in application accuracy for Scenario 2 compared to Scenario 1 was 6.28%. However, the frequency of use decreased by 3.09%. And for elderly households of type 2 and 3, which tend to live alone, the feasibility of application of scenario 2 is similar or even worse than that of scenario 1. The improved Scenario 3 both have higher application feasibility than Scenarios 1 and 2 and has a more user-friendly visual aid to understand the design, which helps the elderly group to better use the smart home service terminal system.

KEYWORDS

Smart home; terminal design; elderly home; KANO model; perceptual engineering

INDEX

https://doi.org/10.17993/3ctecno.2023.v12n2e44.220-235

1. INTRODUCTION

In recent years, smart homes have gradually come into our lives and brought a lot of positive impacts to our lives [1, 2]. Compared with ordinary homes, smart homes have been greatly improved, which can not only meet users' needs for living, provide a suitable, convenient, and reliable living environment, but also give intelligence to traditional living spaces [3, 4]. First of all, smart home products help us to save resources. Intelligent home lighting systems can realize automatic adjustment of the brightness of lamps and lanterns, which can ensure the brightness of the room while minimizing energy consumption [5]. In addition, the intelligent lighting system can achieve the light on when people come and go, giving us very much convenience, on the other hand, it can also prevent forgetting to turn off the lights and cause power waste [6, 7]. Secondly, in the smart home, the smart cat's eye can be installed on the home security door, which has a wider visual range, infrared night vision function, and can be connected to the network, which in turn can realize real-time monitoring of the situation at the doorstep [8]. The smart home is a technologically intelligent product closely related to people's daily life. The smart home is intended to serve our life and bring comfort and convenience to our life [9, 10]. With the development of new technologies such as the Internet of Things, cloud computing, and wireless communication, smart home has been developed rapidly more convenient for people's life [11-18]. Smart home enables users to control the devices in their homes using smartphones to achieve remote control, scene control, linkage control, and timing control. In terms of smart homes for the elderly, due to the arrival of aging and the special physiological, psychological, and social needs of the elderly group for smart homes, there are also some special needs for home products.

The smart home is mainly realized by applying the Internet of Things (IoT) technology, where many home objects in the home, etc. are connected to the Internet through sensors [19]. Secondly, for smart home, the main thing is that he has a variety of control methods [20]. For the elderly, the smart home has added many new functions and services, the smart home control is more abstract, and its control methods have changed a lot [21]. For these changes, it is generally difficult for the elderly to adapt. Compared with ordinary homes, the operation and control of smart homes require higher abstract thinking skills, and these increase the information burden of the elderly [22, 23]. Therefore, it is necessary to optimize the design of smart homes to meet the needs of the elderly. Dhanusha, C [24] detected Alzheimer's disease in the elderly by recording the daily activities of residents equipped with sensor devices in their home appliances as smart homes. To obtain deeper features of the sensor dataset that differ from the existing traditional supervised learning paradigm, they constructed an optimized self-learning model. The model produced better results on a smart home testbed and can be used to investigate the presence of Alzheimer's disease in the elderly. Huu, P . N [25] proposed a system for recognizing gestures and actions in smart homes. They used actions such as walking, sitting, backing, putting on shoes, waving, falling, smoking, infant crawling, standing, reading, and typing for recognition. In this system, data is captured from the camera of the

https://doi.org/10.17993/3ctecno.2023.v12n2e44.220-235

mobile device used to detect the object. The results are obtained from the objects on the frame through the bounding box. The results show that the system meets the requirements with an accuracy of more than 90% and is suitable for practical smart home applications for the elderly. Alzahrani. T [26] explored the main barriers and facilitators to the use of smart home technology, remote monitoring, and telemedicine systems to support healthcare and enable older people to maintain their independence, and showed that lack of information about the functionality and usability of the technology was the main barrier to adoption. Human issues such as cost, platform management and infrastructure, and privacy are also barriers to the diffusion of smart homes. Heon. R.J. [27] systematically reviewed the adoption and user perception of health and environmental monitoring devices, highlighting the difference between wearable and non-wearable. We identify user perceptions based on usefulness, ease of use, and privacy. In terms of user experience, as wearable devices compensate for their limitations, making an integrated model can improve user perception. Kong, H [28] argues that the development of smart homes has driven the concept of user authentication. This not only protects user privacy but also provides personalized services to users. They developed a deep learning-based method to extract behavioral features of finger gestures for highly accurate user identification. The results of their study show that their optimized smart home achieves a great user experience. Enhancing the intrinsic human inclination towards nature for optimal health and well-being and supporting the physical, mental, and social health of the elderly are goals that smart homes need to strive for. Yang, H [29] develop a comprehensive research model that can explain the behavioral intentions of potential customers to adopt and use smart home services. This will enable people to access smart home services on the move using mobile devices through control and monitoring functions, enhancing the sense of user experience. Liu, J [30] argues that current smart home control terminals have many shortcomings and limitations in terms of interaction methods and level of intelligence. They combined the theories of context and behavior analysis to build a product design process based on behavior context analysis, and through the analysis of building and unit behavior context, they obtained the user's needs for control terminals in each context unit, and transformed them into design elements for product concept design, and then designed smart home control terminals to meet the needs of elderly people. Renaud, J [31] proposed that product design should be human-centered, and they suggest that product use should be considered through behavioral analysis and its user's behavior combined with functionality. In the above studies, we can see that systematic research has been made on the optimal design of smart homes for elderly families in terms of elderly user experience, elderly operation, and elderly health monitoring. In addition, in the smart home for the elderly, due to their safety protection, psychological and other special needs. We need to make more emotional designs and simpler service terminals for the elderly smart home so that they can have a better experience.

Traditional smart homes focus on improving reliability, functionality, usability, appearance, and other design features. For older adults, however, their satisfaction is influenced not only by perception but also by emotion. Therefore, in our research, we

https://doi.org/10.17993/3ctecno.2023.v12n2e44.220-235

construct a framework through perception engineering to express the perception of services through users' own words to understand smart home product attributes and user perceptions. In addition, to better classify the needs attributes of the elderly on the client side, and then better design smart home products for the elderly according to their needs, we try to meet customer needs and improve customer satisfaction. We combine the Kano model and perception engineering. We hope our work can make some contributions to the application and service of smart homes for the elderly, and provide a reference for building a green, low-carbon, environmentally friendly, and low-cost smart home.

2. PRINCIPLE OF SMART HOME SERVICE TERMINAL

The main purpose of this study is to attach the smart home to the elderly living space, link the smart home devices involved in the elderly home living environment based on various smart home technologies, build a smart space suitable for the elderly, help the elderly manage the smart home devices in the living environment, and provide a multifunctional, reliable, and satisfactory living environment for the elderly. In addition, the smart home service terminal for elderly families designed in this study meets the multifaceted needs of the elderly living space. It has the following characteristics.

1. Networked elderly living environment and smart home device control

The smart home devices involved in the elderly living environment are networked online through the Internet of Things so that the elderly family members can not only share and communicate the internal information of the smart home devices but also control the working status of the smart home and obtain the required important information in the places covered by the network in the elderly living environment.

2. Intelligent elderly living environment and smart home device control

Intelligent home equipment control intelligence provides a lot of convenience to the elderly home life. First of all, the security of the living space for the elderly is greatly guaranteed, which can make the children of the elderly home a lot of worries; on the other hand, the addition of smart home devices can improve the quality of life of the elderly, and facilitate the elderly to remote control the smart home devices involved in the living environment, etc. Smart home device control intelligence can make the elderly enjoy the benefits of technological progress. Therefore, the research on smart home products suitable for elderly users has great practical significance.

2.1. PRINCIPLES OF PERCEPTUAL ENGINEERING

Perceptual engineering is a new product development technology that transforms the elderly's requirements for the quality of future family life into the design of home-smart homes and home-smart services. It is seeking the correlation between the

https://doi.org/10.17993/3ctecno.2023.v12n2e44.220-235

elderly's response to the quality of life in the future home and the attributes of designing the home smart service to develop a quantitative model for smart home design and optimization.

Ergonomics establishes a framework through the self-expressed requirements of the elderly for their future home quality of life, and then uses experts in the relevant fields to design smart home functions; in addition, the special requirements of the elderly are measured and their smart home attributes are optimized to a certain extent to enhance their applicability and increase flexibility. There are two advantages of perceptual engineering for the design of smart home service terminals in elderly homes. One is to visually convey the real feelings of elderly users through smart home design; the second is to establish a regression analysis model to determine the interaction between customers' emotional responses and design features.

2.2. PRINCIPLE OF THE KANO MODEL

The main feature of the KANO model is to meet the requirements of the elderly for future home life quality as much as possible to provide a multi-functional, reliable, and satisfactory living environment for the elderly, but also to minimize the elderly's discomfort with the smart home. The attributes can be divided into five categories: charm attributes (A), expectation or one-dimensional attributes (O), essential or basic attributes (M), reverse attributes (Q), and undifferentiated attributes (I), as shown in Figure 1. The details are described as follows.

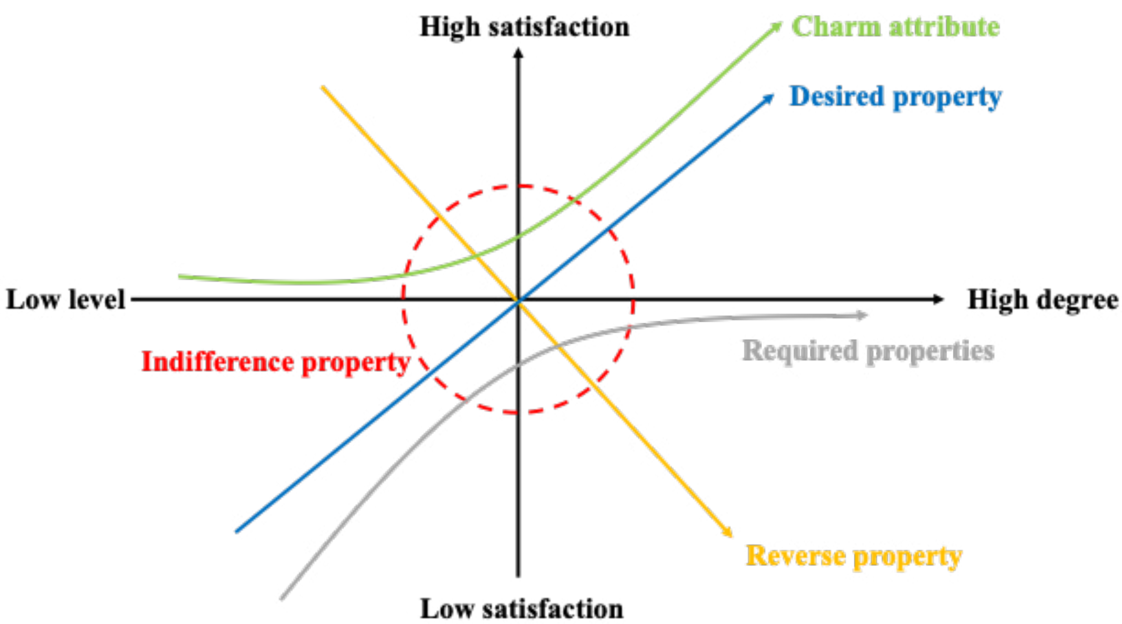


Figure 1. KANO model attribute diagram

Attraction attribute (A). This attribute intuitively expresses the elderly's expectation of the appearance of the smart home, and the improvement of the charm attribute of the home will bring great satisfaction to the elderly users.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.220-235

Expectation or one-dimensional attribute (O). This attribute shows the linear relationship between the satisfaction of the elderly with the smart home and whether the design concept of the smart home matches each other, i.e., the more the design concept of the smart home matches the actual conditions, the higher the satisfaction of the elderly with the smart home.

Essential or Basic Attributes (M). This attribute indicates the functional attributes that seniors take for granted in the smart home and that are not explicitly mentioned by the seniors' customers. The absence of this attribute causes a decrease in the satisfaction of the elderly with the smart home, but the addition of this attribute does not cause interest in the elderly.

Reverse attribute (Q). This attribute indicates that seniors do not want the functional attributes in the smart home, and providing this functional attribute will decrease seniors' satisfaction with the smart home, while the lack of this attribute will increase seniors' satisfaction with the smart home.

No difference attribute (I). This attribute indicates the functional attributes that seniors feel dispensable in the smart home, and providing this functional attribute or the lack of this functional attribute will not affect seniors' satisfaction with the smart home.

3. EVALUATION MODEL BASED ON LEAST SQUARES ALGORITHM (PLS)

This paper applies the PLS algorithm to evaluate the relationship between perceptual engineering and the KANO model coupled with each other to analyze the relationship between annual people's satisfaction with smart homes. the PLS algorithm needs to be tested by calculating the residual sum of squares after extracting the principal components, and the residual sum of squares needs to be smaller than the maximum allowable error r. firstly, n observations are made, i.e. n sample points are selected to study the relationship between the dependent and independent variables. The partial least squares-based correlation analysis is similar to the typical correlation analysis in that it requires the extraction of principal components in the independent variable X and the dependent variable Y, respectively, and calculates the specific computational procedure as follows.

$$r = min(p, q) \tag{1}$$

$$\mathrm{PRESS}_j(k) = \sum_{i}^{n} \left(y_{ij} - \hat{y}_{ij}(k) \right)^2 \tag{2}$$

Where $\mathrm{PRESS}_j(k)$ is the residual sum of squares; i denotes the i sample point j denotes the j indicator; k denotes the number of extracted principal components; p is

https://doi.org/10.17993/3ctecno.2023.v12n2e44.220-235

the independent variable $X\{x_1, x_2, \ldots x_p\}$; and q is the dependent variable $Y\{y_1, y_2, \ldots y_p\}$.

There are q dependent variables $\{Y_1 \ldots Y_q\}$ and p independent variables $\{X_1 \ldots X_p\}$, and n sample points are observed, thus forming the data tables of independent variables and dependent variables $X = \{X_1 \ldots Xp\}$ and $Y = \{Y_1 \ldots Y_q\}$. Partial least squares regression extracts components t_1 and u_1 from X and Y respectively (that is, t_1 is the linear combination of $X_1 \ldots X_P$; u_1 is the linear combination of $Y_1 \ldots Y_Q$). t_1 and u_1 should represent the data table X and Y as well as possible, and the component t_1 of the independent variable has the strongest explanatory ability to the component u_1 of the dependent variable. After the first components t_1 and u_1 are extracted, the regression of X to t_1 and Y to t_1 is carried out respectively. If the regression equation reaches satisfactory accuracy, the algorithm terminates; Otherwise, the residual information after X is interpreted by t_1 and Y is interpreted by t_1 for the second round of component extraction. Such reciprocation, until a more satisfactory accuracy can be achieved. If m components $t_1 \ldots t_m$ are finally extracted for X, partial least squares regression will be implemented by implementing Y_k's regression of $t_1 \ldots t_m$, and then expressed as Y_k's regression equation about the original variable $X_1 \ldots X_m$, $k = 1,2 \ldots q$. This completes the modeling of partial least squares regression.

4. ANALYSIS AND DISCUSSION

In recent years, smart home has gradually come into our lives and brought a lot of positive impacts to our lives. Among them, smart home applications and services for elderly families are gradually being emphasized and put on the agenda in China. However, in the specific design planning of targeted applications, the designer community is not always able to consider and analyze every factor. At the same time, the overall process factors of the design are strongly non-linear in nature, and some of them are even coupled and influenced by each other. In some cases, some of these performance metrics are difficult to reconcile and may even conflict.

Imagine a real case scenario. When designing a smart home application and service system for the elderly, it is difficult to improve the accuracy and total usage frequency of the elderly group at the same time. As the memory of elderly users decreases, some shortcut operations to improve the accurate usage rate often cause tedious operation processes, which makes the total usage frequency decline. Therefore, it is necessary to make a trade-off between the accuracy rate and the total frequency of use in the design process. The weighting of the trade-off should be matched with the more sensitive index factor in the overall benefit of the elderly group. For the elderly, the error rate factor of smart home product usability is more important than the usage efficiency factor, that is to say, the error rate should be reduced as much as possible while meeting the basic usage efficiency of the elderly, which is more compatible with the special physiological and psychological characteristics and lifestyle of the elderly.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.220-235

4.1. DIVISION OF DIFFERENT TYPES OF FAMILIES

Therefore, in this paper, we envision an integrated nonlinear design that incorporates the KANO model as well as a mathematical model of sensible engineering coupled with design. Our design ideas are firstly divided into different types of life in elderly households in specific situations. The key points in different types of elderly households are screened out, and the key indicators with higher sensitivity in the smart home applied to elderly households are matched with the key features for the design. As we all know, the group of elderly people is generally divided by age, and people over 65 years old are internationally classified as elderly people. And in China, people over 60 years old are considered an elderly group. However, classifying older people only by calendar age makes the group of older people have great variability. Some groups are in the older age group by calendar age, but they are still physically functioning and thinking fast. Therefore, their physiological age does not exactly match the traditional elderly group. Therefore, the target population cannot be divided by calendar age in general but should be defined according to specific research needs. In this paper, we focus on the living environment, interpersonal relationships, and autonomy of the elderly group, and the division types and important characteristics are shown in Table 1. For the living environment and interpersonal relationships of the elderly group, we have identified four types: living with relatives, living alone, living with relatives, and living together. For the main characteristics of type 1, we collected information about 572 elderly households in a city in China based on an open questionnaire. The key characteristics were summarized to focus on family relationships and autonomy. For example, elderly families with relatives living together have good health status and relatively complex family relationships. The self-care type of elderly families has better self-care abilities and do not need more help and care from others.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.220-235

Table 1. Basic types of elderly households and smart home service terminal design scheme

Family Type	Description	Features	Design Solutions	Features
Type 1: Relative cohabitation	Living with their children or relatives	1. good for health; 2. relatively complex interpersonal relationships;	Solution 1: Infrastructure distributed intelligent system	Visualization of basic functions such as air conditioners, refrigerators, and switches for TVs and other devices
Type 2: Living alone	Living alone, largely independent of children or relatives	1. need strong self-care ability; 2. relatively single family relationship.	Solution 2: Infrastructure Intelligent Integration System	Such as air conditioners, refrigerators and televisions are controlled from a single mobile terminal.
Type 3: Relative Neighbor	Live separately from relatives, but take care of each other	1. maintain separate and independent lives with relatives; 2. visit and care for each other frequently	Program 3: Complete intelligent integrated system for home appliances and facilities	All appliances and other devices are integrated in the mobile terminal and have visual interaction function
Type 4: Centralized housing	Concentrated residence in service institutions	1. the cost is divided into three ways: government funding, social sponsorship and personal commitment; 2. but the number of institutions is small and the fees are high.	Intelligent Integration system with KANO model and perceptual engineering	All air conditioners, refrigerators and televisions are controlled by a general control system.

4.2. PLS ANALYSIS PROCESS

SmartPLS is an application running on the Java platform. It provides three different internal weight modes: centroid weight, factor weight, and path weight, as well as the default maximum number of iterations, iteration accuracy, and initial weight. It can process the original sample data. Therefore, this paper uses smartPLS2.0 path analysis software to calculate the model in this paper, obtain the path coefficient, and investigate the hidden variables and the relationship between the hidden variables and the measured variables. As for the path coefficient, it can directly reflect the influence of each implied variable. The higher the value of the path coefficient, the greater the direct influence of an implied variable on the implied variable pointed by the arrow. The path coefficient between functionality and perceived effect is 0.0893,

https://doi.org/10.17993/3ctecno.2023.v12n2e44.220-235

which is explained by the non-linear relationship between these two implied variables, or the path coefficient is not obvious, indicating that the high functionality of smart homes has little direct impact on the perception of the elderly. For Figure 2, through comparative analysis, it is found that most of the observed variables have high Outer weights. This shows that the observed variables can better reflect their corresponding hidden variables. The specific results are shown in Table 2 and Figure 2.

Table2. Path coefficient

	Elderly satisfaction	Perceived effect	Smart home services	Reliability	Functionality
Elderly satisfaction	0.2641	0	0	0.4078	0.3192
Perceived effect	0	0	0	0.1288	0.0893
Smart home services	0	0	0	0	0.5351
Reliability	0	0	0	0	0.5763
Functionality	0	0	0	0	0.6242

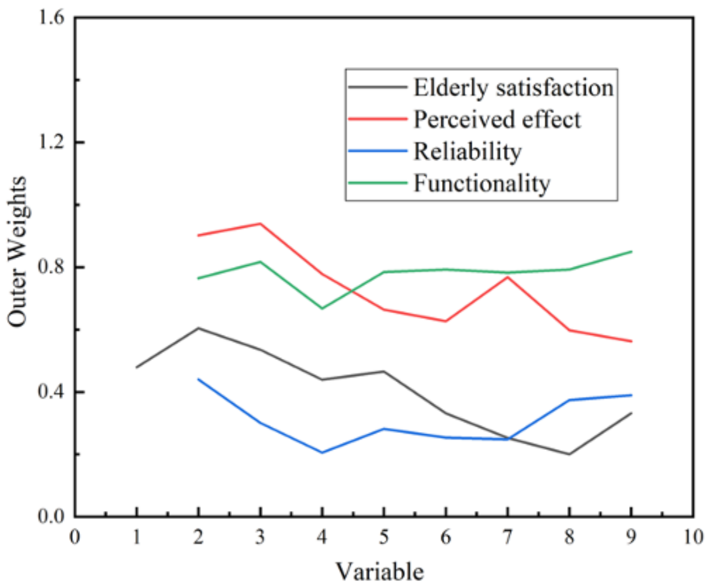


Figure 2. Outer weights of each factor

4.3. EVALUATION OF DIFFERENT CONVENTIONAL PROGRAM APPLICATIONS

We matched the built smart home service terminal system incorporating the KANO model as well as sensible engineering with the smart homes of 572 elderly households in a city in China. Different smart home service terminal systems were

https://doi.org/10.17993/3ctecno.2023.v12n2e44.220-235

applied to different basic types of elderly households in Table 1, and the application accuracy and usage frequency percentages of each system design solution in different types of elderly households were observed. The statistical results of the application accuracy rate are shown in Figure 2(a), where it is observed that for type 1: elderly households with relatives living together, scheme 2 has more accurate application feasibility compared to scheme 1. The application accuracy rate of scenario 2 reached 88.98%, which is an improvement of 6.28% compared to scenario 1. However, in terms of application frequency in Figure 2(b), the usage frequency of Scenario 2 decreased by 3.09%. This indicates that the combined accuracy of air conditioners, refrigerators and TVs controlled centrally from mobile terminals has more room for application in elderly households with young people living with them, but is not often used by the elderly group when the young people are not at home. For type 2: elderly households living alone, the application accuracy rate of scenario 2 decreases to 69.58%, which is 4.31% lower than that of scenario 1. At the same time, the frequency of use of scenario 2 decreased by 26.55%. This indicates that such as air conditioning, for the traditional elderly group living alone, the overly intelligent design of Scenario 2 may make the application accuracy and frequency of use significantly lower. As for Type 3: Relative Neighbors, the family relationship with relatives living separately but taking care of each other makes the difference in application accuracy between Scenario 1 and Scenario 2 not significant. It can be surmised from the illustrations in Table 1 that frequent visits and mutual care among relatives somewhat alleviate the degree of convenience in application for the elderly group living alone. However, the frequency of use for scenario 2 still decreased by about 20.33% compared to scenario 1. As for the type of Type 4: Concentration, the application accuracy of Scenario 2 and Scenario 1 is not much different for the elderly group living centrally in service institutions as the communication between the groups becomes closer. It is 81.76% and 79.49%, respectively. And the gap between the frequency of use of scenario 1 and scenario 2 also gradually decreases, with 81.76% and 73.63%, respectively.

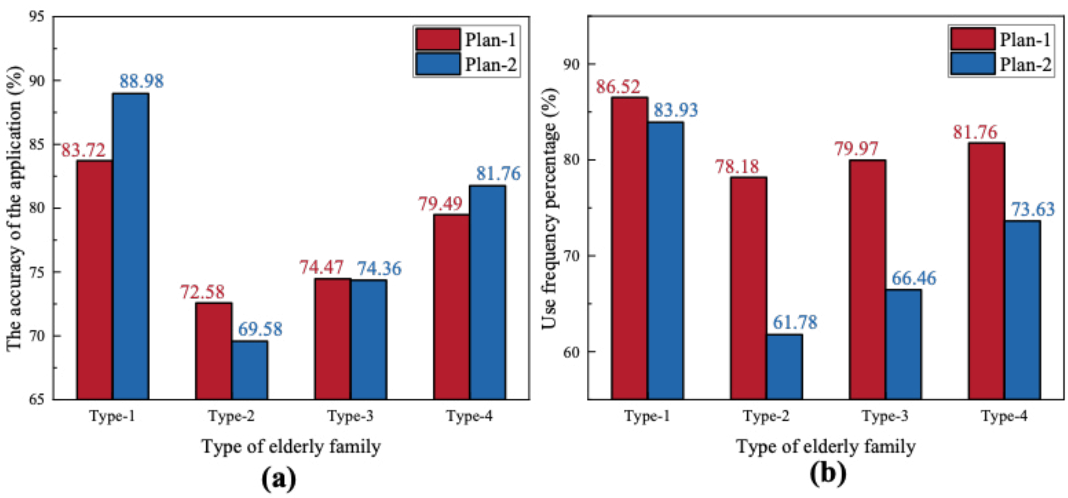


Figure 3. Evaluation of smart home service terminal design solutions for different types of households

https://doi.org/10.17993/3ctecno.2023.v12n2e44.220-235

4.4. EVALUATION OF IMPROVEMENT PROGRAM APPLICATIONS

Finally, we improved and adapted Scheme 1 and Scheme 2, where we integrated all appliances and other devices into a mobile terminal and made them visual and interactive. The improved system design was named Scenario 3, which was applied to different basic types of elderly households, and the results are shown in Figure 3. It is observed that for type 1 households, scenario 3 has the most accurate application feasibility of 92.91%. For type 2, 3, and 4 households, the feasibility of the application of scenario 3 is higher than that of scenarios 1 and 2, with 73.58%, 76.9%, and 86.41%. In terms of frequency of use, Scenario 3 has a more friendly visual aid understanding design compared to the equally intelligent Scenario 2, which helps the elderly group to better apply the smart home service terminal system. Therefore, the application frequency of Scenario 3 is higher than that of Scenario 2 in the elderly households of Types 1, 2, 3, and 4.

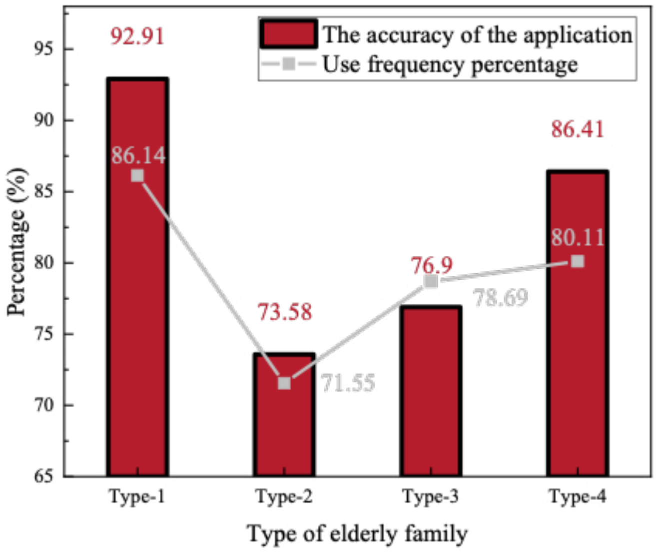


Figure 4. Evaluation of smart home service terminal improvement solutions for different types of households

5. CONCLUSION

In recent years, smart homes have gradually come into our lives and have brought many positive impacts to our lives. However, in specifically targeted application design planning, the designer community is not always able to consider and analyze every factor. In this paper, we envision an integrated nonlinear design that combines the KANO model and the mathematical model of sensual engineering with design coupling. The application of different design solutions in different types of households is evaluated after classifying the different types of life of elderly households in specific situations. The conclusions are as follows:

https://doi.org/10.17993/3ctecno.2023.v12n2e44.220-235

1. The study population was defined according to specific research needs. In this paper, we focus on the living environment, interpersonal relationships, and autonomy of the elderly population and classify the types to match the important characteristics. The types of living environment and interpersonal relationships of the elderly group are cohabitation with relatives, living alone, cohabitation with relatives, and centralized living.

2. For elderly households of type 1 and 4, scenario 2 generally has more accurate application feasibility than scenario 1. The maximum improvement of Scenario 2 over Scenario 1 is 6.28%. However, for the application frequency, the maximum decrease of 3.09% was observed for Scenario 2. For elderly households living alone in Types 2 and 3, Scenario 2 has similar or worse application feasibility than Scenario 1. This suggests that, as in the case of air conditioning, overly intelligent designs may not be popular for the traditional elderly group living alone.

3. It is observed that for type 1 households, scenario 3 has the most accurate application feasibility of 92.91%. For Type 2, 3, and 4 households, Option 3 has a higher application feasibility than Options 1 and 2, at 73.58%, 76.9%, and 86.41%. In terms of frequency of use, Scenario 3 has a more friendly visual aid understanding design compared to the equally intelligent Scenario 2, which helps the elderly group to better use the smart home service terminal system.

REFERENCES

(1) Zheng, Z., et al. (2022). Hierarchically Designed Nanocomposites for Triboelectric Nanogenerator toward Biomechanical Energy Harvester and Smart Home System.

(2) Arifin, Z., Pamungkas, W. H., & Servanda, Y. (2021). The Application of Smart Home System to Manage Electric Prepaid Type R1 KWH Meter Using Lattepanda Single Board Computer. Journal of Physics: Conference Series, 1807(1), 012024 (6pp).

(3) Khan, M. A., et al. (2021). A Machine Learning Approach for Blockchain-Based Smart Home Networks Security. IEEE Network, 35(3), 223-229.

(4) Yao, K. C., et al. (2021). Establishing an AI Model on Data Sensing and Prediction for Smart Home Environment Control Based on LabVIEW. Hindawi.

(5) Drachsler, H. (2021). Mobile Sensing with Smart Wearables of the Physical Context of Distance Learning Students to Consider Its Effects on Learning. Sensors, 21.

(6) Sharer, R. (2018). Bluetooth Mesh creates new infrastructure for lighting controls. Electrical Engineering, (JUN.), 26-26.

(7) Wu, M., et al. (2018). Spectrally Selective Smart Window with High Near-Infrared Light Shielding and Controllable Visible Light Transmittance. ACS Applied Materials & Interfaces.

(8) Anagnostopoulos, M., et al. (2020). Tracing Your Smart-Home Devices Conversations: A Real World IoT Traffic Data-Set. Sensors, 20(22).

(9) Sovacool, B. K., & Rio, D. (2021). Corrigendum to "Smart home technologies in Europe: a critical review of concepts, benefits, risks and policies" [Renew Sustain Energy Rev 120 (2020) 109663]. Renewable and Sustainable Energy Reviews.

(10) Chatterjee, R., et al. (2021). Real Time Speech Emotion Analysis for Smart Home Assistants. IEEE Transactions on Consumer Electronics, PP(99), 1-1.

(11) Ansari, N. , & Sun, X. . (2018). Mobile edge computing empowers internet of things. Ieice Transactions on Communications, 101(3), 604-6 19.

(12) Ouaddah, A., Mousannif, H., Elkalam, A. A., & Ouahman, A.A. . (2017).Access control in the internet of things: big challenges and new opportunities. Computer Networks, 112, 237-262.

(13) Stojkoska, B. L. R., & Trivodaliev, K. V. . (2017). A review of internet of things for smart home: challenges and solutions. Journal of Cleaner Production, 140(pt.3), 1454-1464.

(14) Li, Zhenlong, Yang, Chaowei, Hu, & Fei, et al. (2017). Big data and cloud compu-ting: innovation opportunities and challenges. International journal of digi tal Earth.

(15) Langmead, Ben, Nellore, & Abhinav. (2018). Cloud computing for genomic data analysis and collaboration. Nature reviews. Genetics.

(16) Liu, W. . (2017). Channel equalization and beamforming for quaternion-valued wi- reless communication systems. Journal of the Franklin Institute, 354(18), 8721-8733.

(17) Kevin, & Hayley. (2017). The present state and future application of cloud computing for numerical groundwater modeling. Ground water.

(18) Wu, R. , & Chu, Q. X. . (2018). Multi-mode broadband antenna for 2g/3g/lte/5g wireless communication. Electronics Letters, 54(10).

(19) Al-Ali, A. R., et al. (2018). A smart home energy management system using IoT and big data analytics approach. IEEE Transactions on Consumer Electronics, 63(4), 426-434.

(20) Meng, Y., et al. (2019). Securing Consumer IoT in the Smart Home: Architecture, Challenges, and Countermeasures. IEEE Wireless Communications, 25(6), 53-59.

(21) Wang, J., et al. (2020). Optimal scheduling of gas and electricity consumption in a smart home with a hybrid gas boiler and electric heating system. Energy, p. 117951.

(22) Zhang, H. (2021). Regression function model in risk management of bank resource allocation. Applied Mathematics and Nonlinear Sciences.

(23) Seferlis, P., et al. (2021). Sustainable Design, Integration, and Operation for Energy High-Performance Process Systems. Energy, 1, 120158.

(24) Dhanusha, C., & Kumar, A. (2021). Deep Recurrent Q Reinforcement Learning model to Predict the Alzheimer Disease using Smart Home Sensor Data. IOP Conference Series: Materials Science and Engineering, 1074(1), 012014 (9pp).

https://doi.org/10.17993/3ctecno.2023.v12n2e44.220-235

(25) Huu, P. N., Thu, H., & Minh, Q. T. (2021). Proposing a Recognition System of Gestures Using MobilenetV2 Combining Single Shot Detector Network for Smart-Home Applications. Journal of Electrical and Computer Engineering, 2021(3), 1-18.

(26) Alzahrani, T., Hunt, M., & Whiddett, D. (2021). Barriers and Facilitators to Using Smart Home Technologies to Support Older Adults: Perspectives of Three Stakeholder Groups. International Journal of Healthcare Information Systems and Informatics (IJHISI), 16.

(27) Heon, R. J., et al. (2022). Review of applications and user perceptions of smart home technology for health and environmental monitoring. Journal of Computational Design and Engineering, 3.

(28) Kong, H., et al. (2020). Continuous Authentication through Finger Gesture Interaction for Smart Homes Using WiFi. IEEE Transactions on Mobile Computing, PP(99), 1-1.

(29) Yang, H., Lee, H., & Zo, H. (2017). User acceptance of smart home services: an extension of the theory of planned behavior. Industrial Management & Data Systems, 117(1), 68-89.

(30) Liu, J., & Lian, R. (2019). Research on Intelligent Home Control Terminal based on Behavioral Situation Analysis. Art and Design.

(31) Renaud, J., et al. (2019). Product manual elaboration in product design phases: Behavioral and functional analysis based on user experience. International Journal of Industrial Ergonomics, 71, 75-83.

/14/

THE APPLICATION AND PRACTICE OF MULTIMEDIA TECHNOLOGY IN THE TEACHING OF HIGHER VOCATIONAL LOGISTICS UNDER THE BACKGROUND OF DOUBLE CARBON

Wei Wu*

College of Preschool Education, Luoyang Normal University, Luoyang, Henan, 471934, China.

College of Education, Kyrgyz National University, Bishkek, 720033, Kyrgyzstan.

nuan8511@163.com

Reception: 15/04/2023 **Acceptance**: 10/06/2023 **Publication**: 05/07/2023

Suggested citation:

Wu, W. (2023). **The application and practice of multimedia technology in the teaching of higher vocational logistics under the background of double carbon**. *3C Tecnología. Glosas de innovación aplicada a la pyme, 12(2)*, 237-251. https://doi.org/10.17993/3ctecno.2023.v12n2e44.237-251

ABSTRACT

In the context of carbon peaks and carbon neutrality, the traditional senior logistics majors generally have high investment, high consumption, and difficulty in implementation in teaching. In this paper, multimedia technology is introduced into the teaching practice of higher vocational logistics majors. Guided by the learning theory of constructing contextual cognition and the educational idea of "learn skills from practice", multimedia demonstration, multimedia experience, multimedia interaction, multimedia assessment, and other forms of teaching are carried out in multimedia practical training through several teaching steps, such as multimedia simulation teaching design, teaching implementation, and effect evaluation. In the teaching assessment, the use of multimedia teaching can make 23.2% of the students proficient in warehouse management and the process of each operation, so 88.4% of the students have a good grasp of the knowledge points of logistics professional teaching. It shows that multimedia technology can, to a certain extent, effectively crack the phenomenon of high input, high consumption, and difficult implementation in the teaching of higher vocational logistics majors and enhance the teaching effect of logistics practical training.

KEYWORDS

Carbon dafeng; carbon neutral; multimedia technology; logistics profession; higher education teaching

INDEX

https://doi.org/10.17993/3ctecno.2023.v12n2e44.237-251

1. INTRODUCTION

With President Xi Jinping's commitment to the international community to reach carbon peaks and carbon neutrality at the 75th General Debate of the United Nations General Assembly, the teaching of practical courses for higher-level logistics majors has also ushered in a major challenge[1]. At present, the setting of practical aspects in the training program of higher vocational logistics majors requires high cost of site construction and later maintenance[2], as well as the content of students' skills training is difficult to keep up with the development and changes of logistics industry because the teaching equipment is not updated for years, which leads to a serious disconnect between the skills possessed by students through practical training and the development of the industry[3]. At the same time, the teaching of logistics majors in Chinese higher vocational schools still has not got rid of the traditional teacher-oriented one-way teaching activities[4], and the student-oriented form is not fully reflected, so it is difficult for the skills practical training classes to achieve the expected effect, which makes the student's satisfaction with the teaching contents low[5]. In addition, the classroom evaluation indexes of higher-level logistics majors cannot effectively guide students to know and understand the operational process of logistics in which they can make efforts to make positive contributions to the realization of the "double carbon" (which is defined as carbon emissions and carbon neutrality) goal[6], so it is necessary to make appropriate adjustments in the teaching content setting, teaching methods and assessment mechanisms of higher-level logistics majors to meet the latest development of logistics. Therefore, it is necessary to make appropriate adjustments in the teaching contents, teaching methods, and assessment mechanisms of senior logistics majors to meet the latest requirements[7].

The "double carbon" goal is an external requirement for the high-quality development of logistics professional training in higher education institutions. The "double carbon" goal is a fundamental requirement for China's sustainable economic development and green low-carbon development[8], which means that technical and production innovations are needed at many levels to reduce the investment of energy-consuming equipment in the training process of logistics majors in higher education institutions[9]. The "double carbon" goal is complementary to the future development of logistics majors in higher education institutions, which should continuously improve the teaching quality of logistics majors in the process of serving the national development strategy[10]. "This is an important opportunity for higher education institutions to highlight the value of serving national economic and social development needs, and it is also an important driving force for building a high-quality logistics professional education system[11]. The "double carbon" goal makes logistics professional talents, integrate logistics professional talents training with the regional green development planning layout[12], and integrate the systemic concept into the construction of capacity to enhance the ability of training logistics professionals high-quality skilled talents capacity of logistics majors[13]. Multimedia teaching in Western countries, so the level of multimedia application was relatively high[14]. Since the mid-1920s, research has been conducted in the United States on computer-based

https://doi.org/10.17993/3ctecno.2023.v12n2e44.237-251

instruction in elementary[15]. The American Center for Educational Development took an experimental approach to research[16]. Some scholars have conducted experiments to study the "carrier" and "structure" characteristics of media[17]. Wu Y et al [18] used an origami test as a basis to investigate whether there is individual variability. The results showed that there were not only individual differences in the effectiveness of multimedia but also the combination of different multimedia could achieve better results[19]. The first stage started in the mid-late 1980s when multimedia teaching in China was mainly quoted from foreign multimedia technology, so the development of multimedia technology was still relatively weak[20]. The second stage was from the early 1990s, during which the application of computers in China became more and more common as the knowledge of various aspects of computers increased, and the research on multimedia teaching in foreign countries continued during this period, and multimedia education in China began to enter a concrete implementation stage[21]. The third stage is from the mid-1990s to the present, with the continuous growth of the social economy, and innovation of the improvement of China's education level, the application of multimedia teaching began to be popular in this period[22]. However, relatively speaking multimedia teaching in China is mainly applied in the classroom[23]. In terms of research directions, multimedia teaching in China is mainly studied[24-25]. For example, the development of a multimedia system of automated three-dimensional warehouses by Yang J et al[26] improved the teaching efficiency of logistics majors and enabled students to quickly grasp the operational characteristics of three-dimensional warehouses. Wu Y J et al[27] designed a three-dimensional multimedia system of an automated three-dimensional warehouse based on RSTest Stand and a multimedia system design about facilities and equipment related to the logistics simulation system of terminals and ship segments. This provides a reference example for higher-level logistics practical training teaching. Most of the multimedia simulation training platforms relying on multimedia technology are applied in higher vocational education. Turkan Y et al[28] built a Flexsim multimedia simulation training room in 2014, which can realize the simulation of almost all logistics phenomena. Różewski P et al[29] started to invest in the construction of a logistics multimedia simulation teaching laboratory in 2015, which has taken shape now. When D et al[30] built and improved the logistics multimedia simulation training center in 2016 (logistics equipment virtual simulation system, 3D interactive transportation virtual simulation system, 3D interactive distribution virtual simulation system), etc. Kong X T R et al[31] carried out virtual simulation teaching in logistics practical training, emphasizing the adoption of virtual simulation teaching in logistics majors, and the way of assessment changed from "knowledge structure assessment" to "ability standard assessment". Orona G A et al[32] proposed the specific implementation of multimedia technology in the teaching of logistics management, pointing out that the course needs to open relevant logistics simulation training courses, so that students can make full use of multimedia simulation software to operate and improve practical ability.

In summary, although Chinese scholars started to study multimedia technology relatively late, the development of multimedia technology in China is still very rapid.

The application of multimedia teaching systems supported by multimedia technology in logistics professional practical training teaching in secondary vocational schools is becoming more and more common, and the teaching function of simulation systems is becoming more and more perfect. However, the current situation of using multimedia technology to assist logistics professional practical training teaching in higher vocational schools is not optimistic. This study takes the current situation of the logistics industry and the current situation of China's traditional higher vocational logistics professional practical training teaching as the starting point, applies multimedia technology to the front line of higher vocational logistics professional practical training teaching, focuses on improving the logistics professional practical training teaching environment, reducing the cost of practical training teaching and easing the practical training teaching It also aims to improve the logistics training environment, alleviate the problems of high investment and difficult implementation of practical training, improve the logistics skills of vocational school students, promote the development of vocational education informatization, and help achieve the goal of carbon neutrality and carbon peak at an early date.

2. THE TEACHING OF HIGHER VOCATIONAL LOGISTICS MAJORS IN THE CONTEXT OF DOUBLE CARBON

In 2020, China put forward the strategic goal of "double carbon", which is defined as carbon emissions aiming to reach the maximum by 2030 and carbon neutrality by 2060. To cultivate technical talents who can adapt to society, higher education institutions discuss the education of logistics students, follow the pace of the times and study the teaching mode of logistics majors from the perspective of low carbon, to ensure the social adaptability and competitiveness of students in higher education institutions.

2.1. TEACHING CHARACTERISTICS OF THE LOGISTICS PROFESSION

It has been more than twenty years since the establishment of the Chinese logistics profession, during which the Chinese logistics industry has gradually developed from traditional simple transportation and storage to professional, multi-technology combined modern logistics, and the industry has undergone great changes. Therefore, the points that need to be noted in the teaching process are: First, logistics is closely combined with modern multimedia, in which a large number of modern multimedia are used, such as computer simulation technology, network technology, etc. To better carry out teaching activities, senior logistics students first need to master the interplay of various multimedia technologies, and combined with the actual situation, will use common logistics information processing tools, understand the latest logistics system, and even carry out the operation of the logistics system. Secondly, they should recognize the importance of multimedia technology to the modern

https://doi.org/10.17993/3ctecno.2023.v12n2e44.237-251

logistics industry in the process of learning, and establishing the correct cognitive concept. Finally, the teaching of logistics professional courses involves a large number of logistics facilities and site planning and layout knowledge, for logistics companies, the number of logistics warehouses and the planning of warehouse addresses not only directly affect the cost of logistics and logistics efficiency, but also affect natural resources environmental consumption and carbon emissions, therefore, in the teaching practice of senior logistics professional, both the number of warehouses and address planning should be based on the double carbon background of multimedia technology, using some mathematical modeling tools or mathematical algorithms, which require teachers to be able to clearly explain these modeling tools and mathematical algorithms in the teaching process. It is also necessary to combine the logistics profession with the actual industry situation, requiring teachers to teach in conjunction with industry development. The logistics profession requires teachers and students to pay attention to the real-time industry dynamics and grasp the changing trends of the industry, to help improve the future employment of students and meet the needs of society.

2.2. ADVANTAGES OF MULTIMEDIA TEACHING

The logistics profession is a specialized profession that combines practice and theory; therefore, the teaching of logistics in higher education institutions requires a high level of theoretical and practical aspects in the classroom. This profession involves the transportation, storage, processing, and distribution of goods, and these processes often require the use of modern multimedia technology for students to have a more intuitive understanding of their knowledge. The multimedia technology teaching mode provides two kinds of teaching modes including online and offline, which can make full use of the convenience of online teaching and the participation of offline teaching, and can fully adapt to the students' course arrangement and provide them with more choices. In the teaching process of using multimedia technology, it can play its great advantages, which are mainly reflected as follows: Firstly, multimedia means making students listen and watch together, changing the traditional teaching mode of the teacher talking and students listening, and also saving teaching time and completing teaching contents accurately and efficiently. In the traditional class mode, teachers mainly teach through drawing and handwriting, which leads to poor listening effects for students. With the use of multimedia technology, a lot of time can be saved, the original multiple lessons to complete the content may now take only one lesson, which significantly saves teaching hours, making the classroom transfer more information, and the dissemination of knowledge more convenient, and give teachers enough space to play. Secondly, it enables students to better understand the difficult points of learning and important content, through multimedia learning, various communication methods greatly improve the previous situation of uniform traditional learning mode, in the application of multimedia technology, educational content is summarized as follows: in the classroom to teach photos, illustrations, videos, animations, etc., so that complex and difficult knowledge becomes simple and easy to understand, the boring theory into photos and animation, intuitive and easy to

https://doi.org/10.17993/3ctecno.2023.v12n2e44.237-251

understand. But in the process of multimedia education, the dominant position of the teacher is easily weakened, in the traditional mode of education, the teacher's educational ideas are often easily conveyed directly to students through heuristic methods, and when multimedia teaching, often can not achieve the purpose of such heuristic education, therefore, the use of multimedia technology teaching tools should play a certain role in guiding learning, while conventional teaching methods can not be reduced or replaced by new technological tools. The conventional teaching process cannot rely too much on multimedia technology, teachers need to mix the old with the new and pay equal attention to what is written on the board, only then can students become more interested in multifaceted learning and improve the effectiveness of teaching and learning, achieve interactive learning and increase students' motivation and initiative.

2.3. TEACHING EFFECTIVENESS EVALUATION METHODS

Therefore, this paper tries to optimize the existing teaching quality evaluation process, establish a scientific, objective, and perfect evaluation index system, evaluate teachers' teaching quality through reasonable methods, and apply the evaluation results to improve teachers' teaching effect. The evaluation of teaching quality is an evaluation of the school and teachers. Teaching quality evaluation is the evaluation of the effectiveness of the work of schools and teachers, and also a clear understanding of student's mastery of knowledge, of which hierarchical analysis is a common method of evaluating teaching effectiveness. When conducting power allocation, a hierarchical weighted decision analysis method was proposed when applying network system theory and multi-objective comprehensive evaluation methods. The method decomposes complex evaluation metrics into several constituent elements. The complex problem is how to judge the teaching effect of multimedia teaching, and the components are the consistency index of teaching effect and the corresponding weight coefficient of each index. And groups these elements according to the dominant relationship to form a hierarchical structure, and then compares the elements in each level to determine the relative importance of each element, and finally analyzes the judgment of all personnel to determine the total weight of each solution relative to the target level, on which the qualitative and quantitative analysis of the decision-making method is based. The analysis and evaluation steps generally include: decomposing the system into its constituent elements and grouping them to form a recursive hierarchy, constructing a judgment matrix, comparing the elements of each layer, and testing the consistency of the judgment matrix. First, a judgment matrix is constructed, and a two-by-two comparison of the elements at each level is performed, as in equation (1).

$$A \triangleq \left(a_{ij}\right) \tag{1}$$

In the above equation, represents the scale of importance of element i compared with element j. A stands for judgment matrix, i and j represent numbers of matrix

https://doi.org/10.17993/3ctecno.2023.v12n2e44.237-251

elements. After constructing the judgment matrix, the consistency test of the matrix needs to be launched, and the main indicators are as in equations (2) and (3).

$$\text{C.I.} = \frac{\lambda_{\max} - n}{n - 1} \tag{2}$$

$$\lambda_{\max} \approx \frac{1}{n} \sum_{i=1}^{n} \frac{(AW)_i}{W} = \frac{1}{n} \sum_{i=1}^{n} \frac{\sum_{j=1}^{n} a_{ij} W_j}{W_i} \tag{3}$$

Where $C.I.$ is the consistency indicator, n is the matrix dimension, and $(AW)_i$ denotes the i component of vector AW. Find the corresponding random consistency index $R.I.$ according to the dimension of the matrix, and calculate the consistency ratio $C.R.$

$$\text{C.R.} = \frac{\text{C.I.}}{R.I.} < 0.1 \tag{4}$$

Based on the judgment matrix, the weight *W* of each layer of elements relative to the previous layer is calculated.

$$W = \left(W_1, W_2, \cdots, W_n\right)^T \tag{5}$$

Square root method to calculate the weight values of different dimensions:

$$W_t = \frac{\left(\prod_{j=1}^{n} a_{ij}\right)^{\frac{1}{n}}}{\sum_{i=1}^{n} \left(\prod_{j=1}^{n} a_{ij}\right)^{\frac{1}{n}}}, i = 1,2,\cdots,n \tag{6}$$

This section details the characteristics of logistics majors in China and the problems they face, and also analyzes the advantages of using multimedia teaching in the context of double carbon, and finally evaluates the effect of using multimedia teaching. To make the whole study more rigorous, we make a theoretical analysis of the teaching effect of the system. The content of this section lays the foundation for the subsequent implementation of education for logistics students in higher education institutions using multimedia technology.

3. RESULTS AND DISCUSSION

This study uses multimedia virtual technology to analyze the teaching process of logistics students in higher education institutions under the background of double carbon, taking the management of a logistics warehouse as the research object, the study selects a sophomore student of a higher education institution, whose age is between 19 and 21 years old, and after the course, to verify the teaching effect of multimedia virtual technology, a web-based questionnaire is used for higher education

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.237-251

students To verify the teaching effect of multimedia virtual technology, a web-based questionnaire was used to evaluate and analyze the teaching effect. The number of students studied in the paper is 90, but the valid data collected is 69.

3.1. LEARNING ABOUT WAREHOUSE MANAGEMENT

The process includes several specific processes, such as warehousing planning, warehousing acceptance, warehouse storage area planning, etc. The teaching objectives are summarized as follows. The process requires students to master the basic process of warehousing operations, master the basic operational steps and methods of goods acceptance, and understand the various documents involved in the process of goods warehousing, and at the same time, according to the supplier's notice of warehousing, the preparation of warehousing operations plan, according to the nature of goods receiving inspection, according to the goods to plan the storage location and warehouse area, but also must have the ability to deal with the receiving process The ability to handle abnormal situations in the receiving process. This study uses virtual technology that can realize multiple scenes, full process, and full view in the real environment to carry out the inbound operation process teaching, which is conducive to deepening the learners' perception and understanding. The space provided by the multimedia environment enhances the students' spatial sense, satisfies their needs for multiple and repeated trials, improves their ability to plan the storage area, and achieves the set teaching objectives. The warehousing operation mainly includes the following activities: making warehousing plans, preparing for warehousing, receiving and transporting goods, reviewing documents, preliminary acceptance, handing over goods, accepting goods, handling goods for warehousing, and assigning cargo space. Among these activities, preparation for warehousing, review of documents, and handling of goods in the warehouse are declarative knowledge, which can be taught through pictures, videos, and other auxiliary means, or the resources provided by the multimedia environment. Inbound planning, goods receiving, preliminary acceptance, goods acceptance, and cargo space allocation belong to procedural knowledge, and it is more conducive to students' thinking, understanding, and mastery to complete teaching through the multimedia environment. According to the data collected at the end of the course, students' basic learning of warehouse management is shown in Table 1 and Figure 1. In this study, the examination of student's mastery of warehouse management is mainly carried out by understanding students' cognition of knowledge points and their familiarity with warehouse management processes.

Table 1. Survey of Students' Mastery of warehouse management

Options	Subtotal	Proportion
Master all	16	23.2%
Basic mastery	45	65.2%
General mastery	7	10.1%
Not available	1	1.45%

https://doi.org/10.17993/3ctecno.2023.v12n2e44.237-251

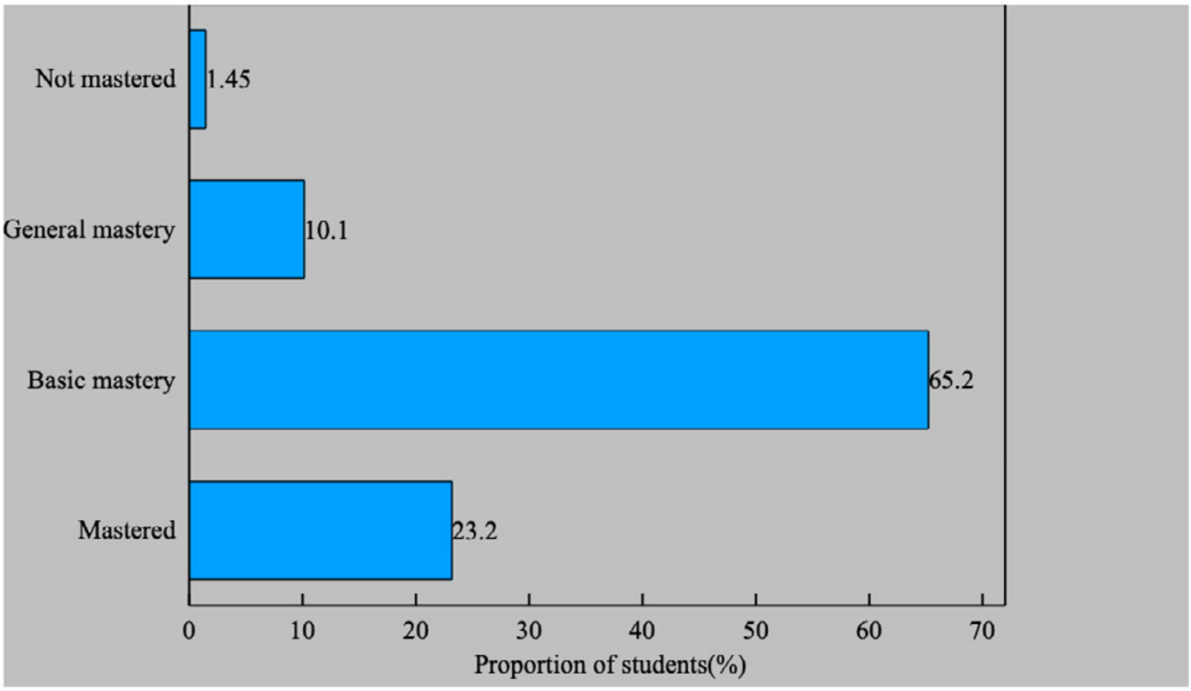


Figure 1. Students' mastery of the warehouse

As can be seen from Table 1 and Figure 1, 23.2% of the students can master the warehouse management process and various operations, 65.2% of the students can master, 10.14% of the general mastery, while only 1.45% did not master, 88.4% can have a good grasp of the teaching knowledge points, the overall effect is good. This shows that the use of multimedia virtual technology for warehouse management is an effective teaching method.

3.2. IMPROVEMENT OF STUDENTS' ABILITY

Cultivating students' independent learning ability and guiding students' good learning habits are more important. For students in higher education institutions, most schools currently adopt the traditional bundled education model for teaching logistics majors, as a student needs to learn dozens of courses, it seems that they have learned everything, but in fact, they feel that they have not learned anything, mainly because they have no deep understanding of the knowledge points. Many logistics students in higher education institutions find that the knowledge they have learned for the actual work can be used is not much, coupled with the lack of in-depth mastery of knowledge during school, thus causing the rapid forgetting of knowledge points. In the face of the competitive society, as logistics students, it is necessary to improve their learning ability and learn the knowledge they need by combining their actual situation and the demand of the social market, so the cultivation of students' learning ability is a necessary choice in the teaching process of higher education institutions. And this study also analyzed the students' independent learning ability, the results are shown in Table 2 and Figure 2.

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.237-251

Table 2. Improvement of Students' independent learning ability

Options	Subtotal	Proportion
Very obvious	12	17.39%
Obviously	40	57.97%
General	16	23.19%
Not obvious	1	1.45%

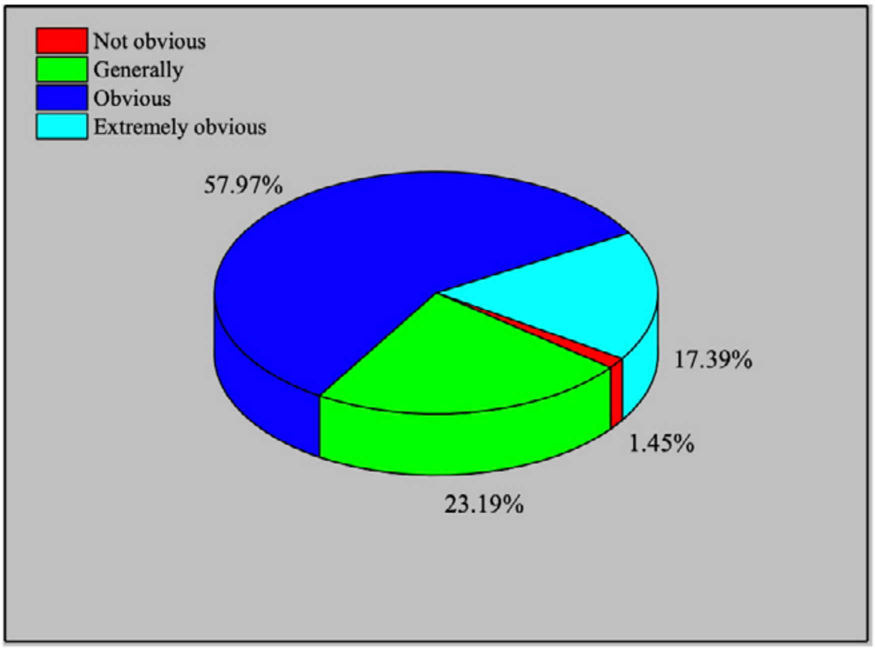


Figure 2. Degree of improvement of students' independent learning ability

The survey analysis of the improvement of student's independent learning ability was done, and the results are shown in Table 2 and Figure 2, from which it can be seen that 17.39% of students think their learning ability is improved very obviously, 57.97% think it is improved, 21.39% think it is improved in general, and 1.45% think it is not improved, in general, the students who think their independent learning ability is improved greatly Students account for 75.36% of the overall number, which is relatively high. The results show that the use of multimedia technology can provide good educational measures and methods for logistics professional education in higher vocational institutions. Compared with the teaching effect without the use of multimedia teaching, the study found that students who use multimedia technology to teach have better cognition and understanding of knowledge.

3.3. IMPROVEMENT OF LEARNING INTEREST

This study is fundamentally different from the traditional teaching model. According to the teaching content, through multimedia simulation technology, students are allowed to simulate field practice, which enables students to be in the situation

https://doi.org/10.17993/3ctecno.2023.v12n2e44.237-251

designed by the teacher, increases communication and exchange between teachers and students, strengthens students' understanding of logistics business, enhances students' practical problem-solving ability, and enables students to apply what they have learned flexibly. Meanwhile, in the context of certain practical cases, practical tasks are assigned as the main line, using the Task-driven method, students, carry out activities around different process tasks in the warehouse management process, through the active application of learning resources to complete a task or decision, and at the same time, in the process of task implementation, students can also creatively design multiple solutions and ways to complete the task, and make choices. Students often have a strong sense of satisfaction and pride after completing the task, and the teacher's motivation will make students have a strong interest in the profession or course, which lays a solid foundation for better learning. At the same time, this survey found that 65% of the students showed obvious interest in logistics majors and were willing to continue their in-depth study, as shown in Figure 3.

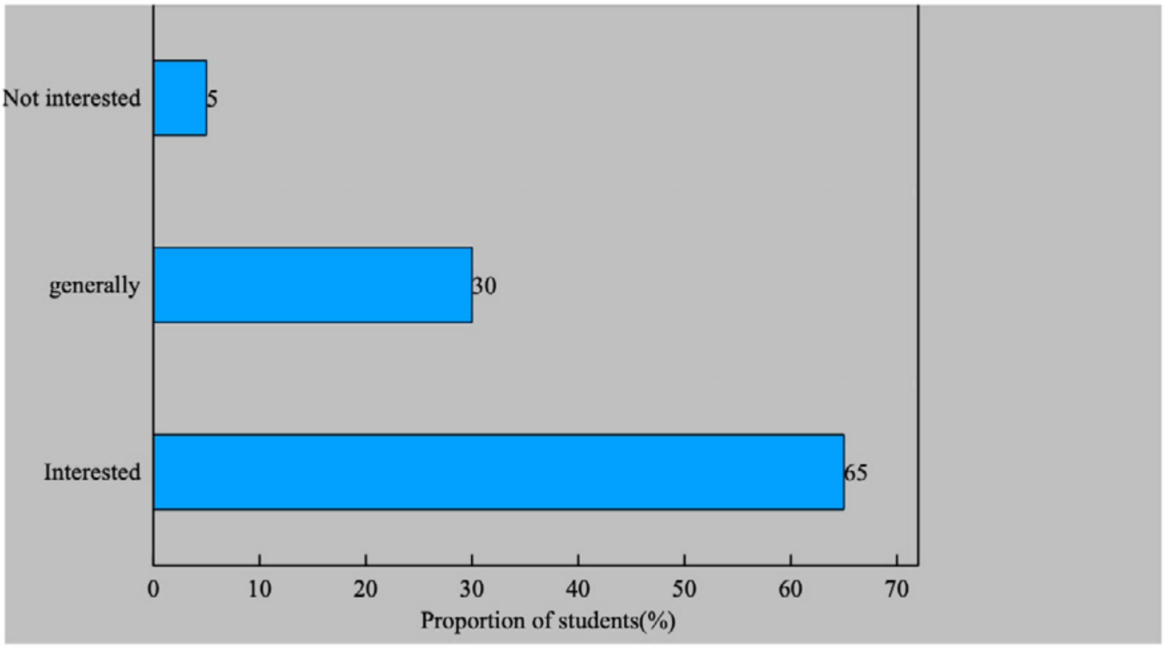


Figure 3. Students' interest in learning

4. CONCLUSION

Under the background of double carbon, with the advent of the big data era and the dramatic increase of the logistics business, the demand for high-end talents specialized in logistics management in China is increasing day by day. In the supply of logistics talents, higher education institutions are important educational institutions, especially for the cultivation of practical and compound talents. The unprecedented speed of development of China's logistics industry and the spurt trend of enterprises' demand for talents are the subjective and objective factors that make higher vocational colleges and universities face unprecedented pressure and challenges in the training of logistics talents. Therefore, how to improve the practical ability of higher

https://doi.org/10.17993/3ctecno.2023.v12n2e44.237-251

vocational logistics students has become an important issue of concern for higher vocational colleges and universities. The multimedia teaching can improve the comprehensive quality of students, and enable them to learn more advanced and low-carbon and environmentally friendly logistics operations, transport high-quality logistics professionals to the society, and indirectly contribute to the society's carbon emissions. To this end, this paper takes logistics teaching in higher vocational institutions as the research object, verifies the application of multimedia technology in logistics teaching, and also verifies the usability of the logistics teaching design model in a multimedia environment, and completes the teaching design of warehouse management operation based on this model. The post-class teaching effect survey showed that compared with the traditional teaching model, students had a better grasp of the key contents of warehouse management such as inbound process and warehouse area planning, and their independent learning ability was improved. The specific work of this study is as follows.

1. By analyzing the characteristics of logistics majors and the problems students may encounter in the learning process, this study uses multimedia virtual technology as the teaching method. The logistics teaching design model in a multimedia environment is based on the classical teaching design model, summarizes the common elements in the classical teaching design model, and combines it with multimedia technology. The survey results show that 23.2% of the students can master the warehouse management process and various operations, 65.2% of the students can master them, and the overall number of students who can master the teaching knowledge points better is 88.4%.

2. Multimedia technology can conform to situational cognitive learning theory, constructivist learning theory, and tower of experience theory, and can enhance the application of teaching theory. Secondly, 75.36% of the learners feel that their independent learning ability has been greatly improved by the practical test of teaching in the storage course.

3. In this teaching of multimedia virtual technology, students' knowledge mastery of the whole process of related operations, their ability to learn independently, and their practical skills have been significantly improved, while also expanding the scope of teaching, breaking through time and space limitations, allowing learners to access more advanced logistics technology and equipment, and finally fully stimulating students' interest in learning, the study results show that more than 65% of students look forward to continuing to use multimedia technology for teaching and learning, and also want to use the method in other courses as well.

REFERENCES

(1) Gao, J., Yang, Y., Gao, F., et al. (2021). Optimization of Electric Vehicles Based on Frank-Copula-GlueCVaR Combined Wind and Photovoltaic Output Scheduling Research. Energies, 14.

(2) Liu, L., Jiang, P., Qian, H., et al. (2022). CO2-negative biomass conversion: An economic route with co-production of green hydrogen and highly porous carbon. Applied Energy, 311, 118685-.

(3) Zhang, R., Tai, H., Cheng, K., et al. (2022). Carbon Emission Efficiency Network: Evolutionary Game and Sensitivity Analysis between Differentiated Efficiency Groups and Local Governments. Sustainability, 14.

(4) Zhao, M. (2020). The Application of Cloud Computing in the Practice Teaching of Business English Major in Higher Vocational Colleges. Journal of Physics Conference Series, 1634, 012009.

(5) Salomone, L. S., Garcia-Inza, M., Carbonetto, S., et al. (2022). Numerical modeling of radiation-induced charge neutralization in MOS devices. Radiation Measurements, 153, 106745-.

(6) Wu, P., Guo, F., Cai, B., et al. (2021). Co-benefits of peaking carbon dioxide emissions on air quality and health, a case of Guangzhou, China. Journal of Environmental Management, 282(4), 111796.

(7) Su, Y., Liu, X., Ji, J., et al. (2020). Role of economic structural change in the peaking of China's CO2 emissions: An input–output optimization model. Science of The Total Environment, 761, 143306.

(8) Wen, Y. A., Zm, A., Mz, A., et al. (2020). Neutralization reaction in synthesis of carbon materials for supercapacitors. Chemical Engineering Journal, 381, 122547-.

(9) Tamersit, S., Bouhidel, K. E. (2020). Treatment of tannery unhairing wastewater using carbon dioxide and zinc cations for greenhouse gas capture, pollution removal and water recycling. Journal of Water Process Engineering, 34, 101120.

(10) Yuan, Y., Duan, H., Tsvetanov, T. G. (2020). Synergizing China's energy and carbon mitigation goals: General equilibrium modeling and policy assessment. Energy Economics, 104787.

(11) Chen, L. (2020). Practice Teaching Reform of Tourism Management Major in Higher Vocational Education under the Background of New Industry Form. Journal of Physics Conference Series, 1549, 042100.

(12) Chen, M., Ma, M., Lin, Y., et al. (2022). Carbon Kuznets curve in China's building operations: Retrospective and prospective trajectories. Science of The Total Environment, 803, 150104.

(13) Cui, X. Q., Wang, K., Fu, S., et al. (2017). Global carbon budget and emissions pathway of 2°C and 1.5°C target. Zhongguo Huanjing Kexue/China Environmental Science, 37(11), 4353-4362.

(14) Singaravelu, G. . (2021). Multimedia assisted teaching in pedagogical technique. The Journal of Educational Research.

(15) Walker, S. , & Sellers, T. . (2021). Teaching appropriate feedback reception skills using computer-based instruction: a systematic replication. Journal of organizational behavior manag ement(3), 41.

(16) Justice, B. (2018). Democracy's schools: the rise of public education in America. Journal of American History.

(17) Dong, & Lin. (2017). Teaching communication and media studies: pedagogy and practice. Technical Communication.

(18) Wu, Y., Zhang, J., Shen, T. (2022). A logical network approximation to optimal control on continuous domain and its application to HEV control. Science China Information Sciences.

(19) Wang, J., Jiang, K., Wu, Y. (2022). On congestion games with player-specific costs and resource failures. Automatica, 142, 110367.

(20) Yao, S., Li, D., Yohannes, A., et al. (2021). Exploration for network distance teaching and resource sharing system for higher education in epidemic situation of COVID-19. Procedia Computer Science, 183, 807-813.

(21) Wood, R., & Shirazi, S. (2020). A systematic review of audience response systems for teaching and learning in higher education: The student experience. Computers & Education, 153, 103896.

(22) Bozzelli, G., Raia, A., Ricciardi, S., et al. (2019). An integrated VR/AR framework for user-centric interactive experience of cultural heritage: The ArkaeVision project. Digital Applications in Archaeology and Cultural Heritage, 15, e124.

(23) Wang, Y., Sun, Q., & Bie, R. (2022). Blockchain-Based Secure Sharing Mechanism of Online Education Data. Procedia Computer Science, 202, 283-288.

(24) Arndt, T., & Guercio, A. (2017). From Multimedia Micro-University to Macro University and beyond. Journal of Visual Languages & Computing, 38, 38-46.

(25) Wuang, Y., Chiu, Y., Chen, Y. J., et al. (2018). Game-Based Auxiliary Training System for improving visual perceptual dysfunction in children with developmental disabilities: A proposed design and evaluation. Computers & Education, 124, 27-36.

(26) Yang, J., Li, Y., Calic, G., et al. (2020). How multimedia shape crowdfunding outcomes: The overshadowing effect of images and videos on text in campaign information. Journal of Business Research, 117, 6-18.

(27) Wu, Y. J., Wu, T., & Li, Y. (2019). Impact of using classroom response systems on students' entrepreneurship learning experience. Computers in Human Behavior, 92, 634-645.

(28) Turkan, Y., Radkowski, R., Karabulut-Ilgu, A., et al. (2017). Mobile augmented reality for teaching structural analysis. Advanced Engineering Informatics, 34, 90-100.

(29) Różewski, P., Łobacz, K., & Malinowska, M. (2021). Multi-dimensional support for development of visual literacy in engineering education. Procedia Computer Science, 192, 4810-4819.

(30) Li, Zhengjian, & Li, Lifeng. (2021). Mathematical statistics algorithm in the bending performance test of corroded reinforced concrete beams under fatigue load. Applied Mathematics and Nonlinear Sciences. doi:10.2478/AMNS.2021.2.00142.

(31) Kong, X. T. R., Chen, G. W., Huang, G. Q., et al. (2017). Ubiquitous auction learning system with TELD (Teaching by Examples and Learning by Doing) approach: A quasi-experimental study. Computers & Education, 111, 144-157.

(32) Orona, G. A., Li, Q., McPartlan, P., et al. (2022). What predicts the use of interaction-oriented pedagogies? The role of self-efficacy, motivation, and employment stability. Computers & Education, 184, 104498.

/15/

RESEARCH ON INTERACTIVE FOOD PACKAGING DESIGN BASED ON USER EXPERIENCE UNDER THE BACKGROUND OF DUAL CARBON

Yanjun Zhao*

Department of Finance and Economics, University of Chinese Academy of Social Sciences, Beijing, 100102, China.

17801567001@163.com

Reception: 17/04/2023 **Acceptance**: 11/06/2023 **Publication**: 29/06/2023

Suggested citation:

Zhao, Y. (2023). **Research on interactive food packaging design based on user experience under the background of dual carbon** . *3C Tecnología. Glosas de innovación aplicada a la pyme, 12(2)*, 253-267. https://doi.org/10.17993/3ctecno.2023.v12n2e44.253-267

ABSTRACT

In recent years, the environmental degradation caused by carbon emissions has become more and more serious. It is particularly important to achieve the dual carbon goals of "carbon peaking" and "carbon neutral". The food packaging process accounts for a large portion of carbon emissions in the food industry and is an important concern for carbon reduction. While the task of carbon reduction is particularly important, it is also important to design food packaging with the user's experience in mind. This is the reason why interactive packaging design, which focuses on two-way communication and user experience, is used in the design of this paper. To corroborate the design scheme, the carbon footprint analysis of three packaging methods for 200g cooked peanuts was conducted in this paper. The final carbon footprints of vacuum, air, and modified atmosphere packaging methods were 36.18, 54.78, and 218.86 gCO_2eq respectively. Subsequently, the sensitivity of different packaging methods is analyzed. It is found that vacuum packaging is more sensitive to changes in emission factors. The final carbon footprint value is changed by 16.31% under the direct influence of emission factors, while the final carbon footprint values in air and modified atmosphere packaging are 4.88% and 0.78% respectively, which are less affected by the change of factors.

KEYWORDS

Dual Carbon; Based on user experience; Food; Interactive; Packaging Design

INDEX

https://doi.org/10.17993/3ctecno.2023.v12n2e44.253-267

1. INTRODUCTION

In 2021, the Chinese government officially included the goals of "carbon peaking" and "carbon neutrality" in the government's work report. To achieve this goal, a timeline was set for carbon emissions to reach a peak by 2030 and carbon neutrality by 2060. In response to the government's call, various industries have developed policies and strategies for energy conservation and emission reduction to achieve the "carbon neutrality" goal. In response to the government's call, the application of green packaging to food and beverage has become a major trend. Packaging has always been an important part of food products and plays an important role in ensuring the quality of food. Survey results show that in the worldwide packaging services industry, the food packaging segment accounts for 60% of the entire market and the industrial scale is a trend of expansion in recent years. In the huge industry chain, the global food system emissions of greenhouse gases accounted for about 26% of the total global emissions. Under the dual impetus of the growing food packaging industry and the implementation of carbon reduction policies, it is a huge problem to design low-carbon packaging that meets the requirements.

Scholars from different countries have different studies on how to design food packaging. Ilicic J studied a product shaking effect [1]. Consumers can moderate the anxiety effect induced by the package design by shaking the product. Anxiety-inducing product package designs with shaking product interactions were introduced and can be used as an anti-emotional eating strategy. It can also be used as an effective measure to prevent obesity. Khan A identified inefficient collaboration between design and management as a factor in the increase of packaging waste [2]. The food packaging design process and the impact of team design on packaging design were studied in his research. He categorized and analyzed the end-of-life issues of food packaging design and explored emerging opportunities. In the end, necessary design, as well as research strategies, are also proposed, which in turn promote end-of-life considerations in food packaging. Yokokawa N argued that packaging design should also try to integrate with factors such as consumers' consumption preferences and the influence of the low environment [3]. And he believes that packaging design can also be used to further influence the purchasing preferences of a particular consumer by using a particular combination of packaging or features for a particular product. In his research project, the environmental impact factors and potential consumer preference effects of over 18 design options with different packaging and functional requirements were systematically evaluated. Subsequently, he has examined quantitatively the influence relationships that exist between the options. Ma X argues that packaging waste is a major issue for both business and society [4]. However, the perception of sustainable packaging efforts in practice is less clear. To address this issue, seven interviews were conducted with providers of sustainable materials and the results were analyzed. The study by Nevala H aimed to model a reusable food packaging service using customer-centered design thinking [5]. The study was conducted using a qualitative research approach, using interviews with 11 study participants. After results such as their packaging preferences were collected, they were placed into the

https://doi.org/10.17993/3ctecno.2023.v12n2e44.253-267

established model as elements of the value proposition. In this way, possible, new and reusable food packaging services were explored. Yu D et al. studied the application of computer graphic design color language in food packaging design at a time of rapid Internet development [6]. The study reported that the unique importance of color treatment as an integral part of the packaging design process is unquestionable. Color not only reflects people's consumption emotions but also drives consumers' psychological associations. For this reason, it is particularly important to investigate the practicality and significance of the application of computer graphic design color language in food packaging design.

From the above studies, it is easy to find that the research on food packaging design concepts and solutions is very in-depth. However, there is relatively little research on food packaging design based on the concept of carbon reduction. In addition, the integration of carbon reduction elements into interactive packaging design based on user experience is also a less studied point. Interactive packaging design integrates cultural and scientific factors into one and also applies various knowledge systems such as information media, consumer psychology, and economics. It not only meets the aesthetic requirements of contemporary people but also takes into account the dissemination of the concept of carbon reduction. One of its advantages is that it focuses more on the user's experience. How to combine the concept of carbon reduction with interactive food packaging design that focuses on user experience is the focus of this paper.

2. INTERACTIVE FOOD PACKAGING DESIGN AND USER EXPERIENCE

2.1. THE CONCEPT OF INTERACTIVE FOOD PACKAGING DESIGN

Interactive print and packaging design technology is a comprehensive applied design engineering discipline that integrates design business, culture, science, art, materials, and printing, including information media, ergonomics, economics, consumer psychology, usability engineering research, and other aspects [7-9]. The leading idea of interactive packaging design is to take digital packaging products and their supporting product systems as the carrier, a new period of two-way communication and bridge established between people and things system, to gradually enhance the effective interactive information exchange between people and things. The interactive design of food packaging places more emphasis on the interaction between packaging and consumers, with the user as the center, to meet the needs of users.

Truly excellent interactive packaging design will not only give everyone visual enjoyment but will also allow all users to experience the entire interactive process of the packaging and better understand the product characteristics and brand

https://doi.org/10.17993/3ctecno.2023.v12n2e44.253-267

information. The process of designing various interactions in food packaging can also be dynamic and can be repeatedly changed, including the interaction designer's design logic and reasoning, accurate prediction, and grasp of the interactive use of the product and product positioning. Focusing on the user's visual experience is the correct guideline for the process of excellent interactive food packaging design. Experience psychology includes basic mental processes such as sensation, perception, feeling, thinking, and cognitive process. The experience design of interactive food packaging design is mainly based on the interaction designer's thinking about many issues such as user information and experience mode, emotional experience building structure, user behavior testing, and the way of their feedback. Food packaging design must not only focus on a variety of external product images such as product graphics, color, material texture, etc. but also first solve the problems of external visual image communication and environmental protection material use and soon.

2.2. USER EXPERIENCE

The American psychologist Maslow proposed a hierarchical model of human needs that divided the basic needs of each person into the following seven levels of needs: physiological needs, security needs, belonging and love needs, respect needs, cognitive needs, aesthetic needs, and self-actualization needs. People's needs are gradually shifting from good use needs to better levels of emotional needs. From self-worth to be recognized, and then to achieve personal social value. People began to have some higher-level design requirements for the product design and service mode of packaging design. In food packaging and design activities, designers should usually focus on the long-term usability of the product itself, and consider whether the product packaging design can fully meet the needs of its target users.

User interaction experience is concerned with the real interaction needs of users and interaction experience, and food packaging design needs to adhere to the main starting point of serving users and the center of the final design. After collecting user feedback and feedback analysis reports, we carefully check all the details in the process of product interaction to give users a comfortable and pleasant interaction experience. Think about the user's feelings when using the product, and finally get the user's consistent love and willingness to accept the interaction of the product.

As shown in Figure 1, three important aspects of user experience design in the overall food and packaging innovation design work include.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.253-267

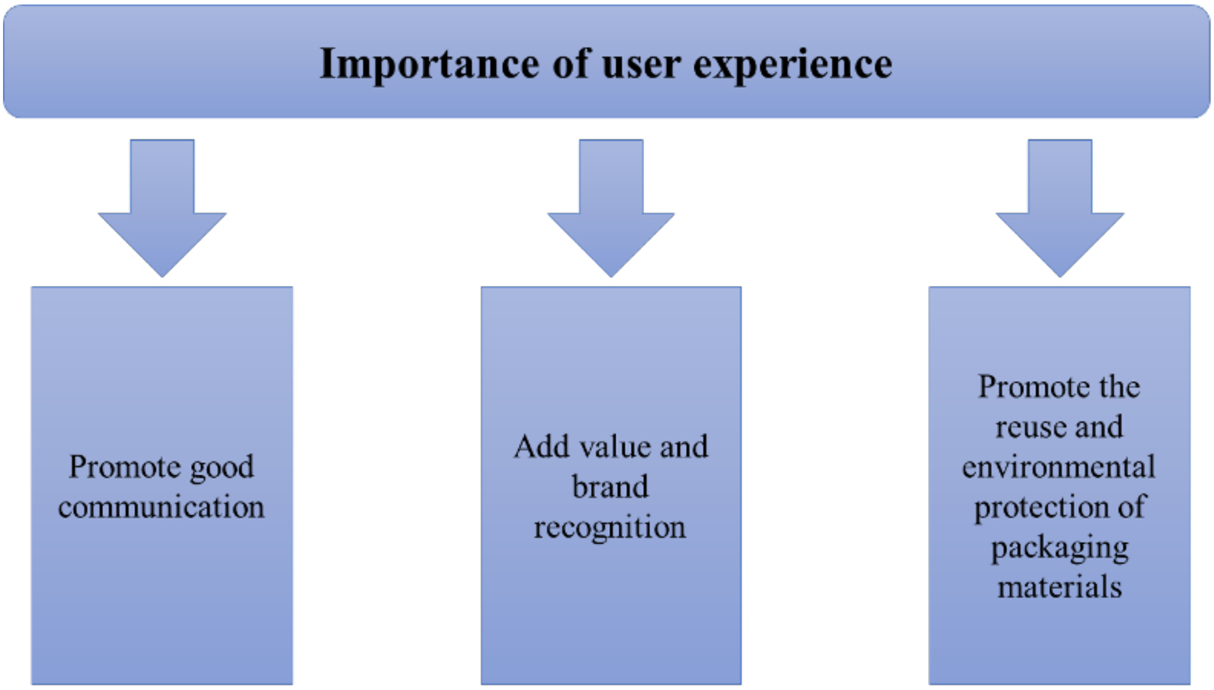


Figure 1. The importance of user experience in food packaging design

1. It often promotes better communication between users and other food manufacturers and product packaging suppliers. User experience-based food packaging design can ensure that all users can accurately receive the relevant information conveyed by the product packaging, making the use of the product clearer, simpler, and more convenient, and achieving two-way communication between the product itself and the target user group.

2. It can likewise further enhance the value and brand awareness of food production operators. Good commodity packaging and design style can ensure a good product image to the majority of user consumers. The interactive contact process between customers and food products will make the user a good and pleasant psychological experience, thus strengthening people's emotional trust, loyalty, and secondary purchase desire for their products, forming the product's word-of-mouth image and brand reputation.

3. It can actively promote the economical use of waste food packaging materials and green environmental protection.

Under the requirement of the ecological background environment of double carbon, designers should further fully consider the final use experience effect of commodity packaging products in the process of designing and manufacturing, and define the reasonable reuse process of packaging resources to increase the user's experience, which can effectively maintain the balance of the whole ecological environment.

The distinctive feature of interactive packaging design is that the interaction between the package and the user is predesigned by the designer. Before completing the package design, the package designer must anticipate the visual image of the

https://doi.org/10.17993/3ctecno.2023.v12n2e44.253-267

package, the opening method of packaging, the using method of packaging, and the secondary use the package will bring to the user's experience.

One of the most significant technical features of interactive packaging design technology is that the designer can design in advance to control the interaction between the user and the product packaging. Before the overall package design is completed, visual designers can anticipate the overall visual image of the package, the way the package will be opened, the way the package will be used, and the experience the user will have when the package is used again.

3. COMPARISON OF THE IMPACT OF CARBON FOOTPRINT IN DIFFERENT FOOD INTERACTIVE PACKAGING METHODS

General food packaging methods are vacuum packaging, air packaging, and modified atmosphere packaging. Among them, vacuum packaging is widely used, research shows that modified atmosphere packaging has the advantage of improving the quality of food storage and extending the shelf life [10-12]. Therefore, this paper firstly takes cooked peanut bags as an example, and per 200g of cooked peanuts, three different packaging and transportation methods, such as vacuum packaging, air packaging, and air-regulated packaging, are used to study the impact of carbon footprint brought by different packaging methods.

3.1. DEFINITION AND SCOPE OF OBJECTIVES

This study is based on the Life Cycle Assessment (LCA) methodology, which is consistent with the methodology described in PAS 2050[13-15]. Calculate the carbon footprint of different packaging methods in the packaging process and assess the impact of the packaging method on the product's carbon footprint [16,17]. The experimental objective of this study was to compare the potential carbon footprint in vacuum, air, and modified atmosphere packaging. The packaging unit process analysis method was used to calculate the potential carbon footprint in cooked peanut packaging. The project uses the vacuum cooling method to reduce the center temperature of the cooked peanut package to less than 10℃, and the cooked peanuts obtained after cooling will be packaged in different kinds of packaging methods, such as vacuum, air, and modified atmosphere packaging. The functional unit reflects the consumption behavior pattern of the end-consumer and can be regarded as a meaningful quantity of a specific product function at the same time. One of the primary objectives of this experimental design is to study the calculation of the overall carbon emissions of the product during the actual operation of the packaging storage and transportation unit. In other words, the experimental study does not cover the entire production, transportation, storage, and consumption of the product packaging [18-20]. One of the functional units in this study is a cooked peanut with a packaging mass of 200g. Determined system boundary To facilitate quantitative calculations and

https://doi.org/10.17993/3ctecno.2023.v12n2e44.253-267

determine the carbon footprint in the production process of specific research products, the system boundary was determined to clarify the objectives of quantitative evaluation and research, to specify the scope of the experimental research process, and to clarify the carbon input and output sources in the quantitative experiment[21-23]. To further investigate the carbon emissions of cooked peanuts during packaging and processing, the scope of this study included the preparation of cooked peanuts, control equipment, and cooling and packaging processes [24-26].

The study scope process is shown in Figure 2, where the green area is the area delineated by the system boundary.

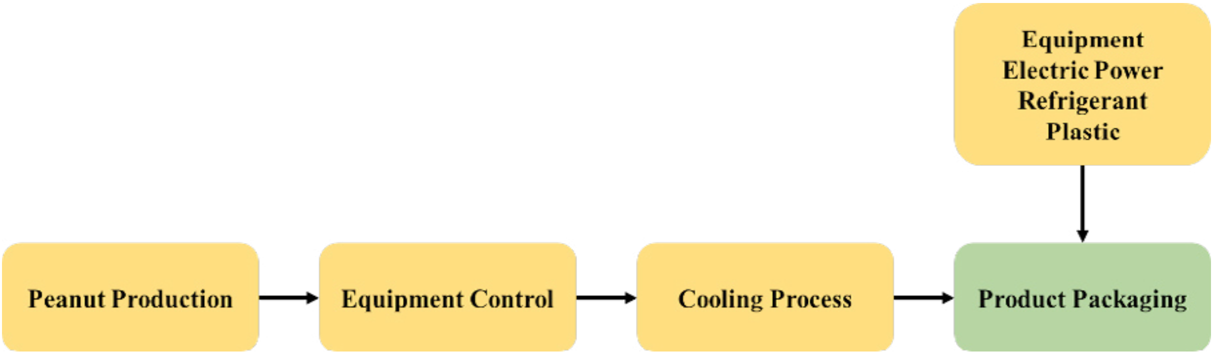


Figure 2. Experimental flow chart

3.2. INVENTORY ANALYSIS

For the inventory analysis step of the entire LCA process, sufficiently detailed input and output data about the product's carbon footprint and processes need to be collected and disaggregated [27,28]. The long phase of inventory analysis is data collection, and the accuracy and validity of the data collected have a significant impact on the accuracy of the carbon emissions calculation, which is the key to the four main steps of the carbon emissions calculation. Data sources for life cycle evaluation can be published data sources, experimental data, or even hypotheses [29-31]. There are two methods of data collection, direct and indirect. Direct collection refers to the collection of primary materials through experiments or interviews with experimenters, while indirect collection refers to the recording of carbon emissions from a process through reading literature, expert interviews, and the use of supporting software.

According to the international standard ISO 14040, the manufacture, maintenance, and disassembly of stationary equipment during the packaging process should be included in the system boundaries. In this test, the inputs used for the vacuum packaging of cooked peanuts, air packaging, and modified atmosphere packaging include equipment, electricity, gases (indirect and direct emissions), and plastic products. The equations for calculating the product carbon footprint of the packaging process are shown in Equation (1) and Equation (2).

$$EF_i = \frac{GHG_i}{t_i} \quad (1)$$

https://doi.org/10.17993/3ctecno.2023.v12n2e44.253-267

$$CF = \sum_{i=1}^{n} \left(Q_i \times EF_i\right) \tag{2}$$

In the above equation, CF is the final carbon footprint, gCO_2eq; EF_i is the i-th input carbon emission factor, gCO_2eq/min; GHG_i is the life cycle carbon emissions for the i-th input, gCO_2eq; t_i is life cycle of the i-th input, min; Q_i is the processing time of samples, min.

Multiply each input emission factor by each input to obtain the input life-cycle GHG emission data. In estimating equipment lifecycle GHG emissions data, 110 $kg/million$ yuan will be used as the equipment emission factor, i.e., the equipment emission factor multiplied by the selling price of each piece of equipment to arrive at the lifecycle GHG emissions per piece of equipment. The service life of vacuum packaging machines, tabletop gasifiers, air compressors, gas mixers, gas cylinders, and buffer tanks is provided by the equipment manufacturer and distributor. In addition to the equipment, other materials should be used in the packaging process. The electricity emission factor is 1.03 $kgCO_2/kW\dot{h}$, 2.0 $kgCO_2eq$ per kg of plastic. As the emission factor of plastic products, the GaBi database of GaBi5 version, a professional carbon footprint calculation software developed by Hangzhou Green Blue Environmental Technology Co. Calculating the carbon dioxide equivalent emissions to the atmosphere for the production of 1 kg of O_2, N_2 and 1 kg of liquid CO_2 in the U.S. yields gas emission factors of 0.15 $kgCO_2eq/kg$, 0.088 $kgCO_2/kg$ and 0.45 $kgCO_2eq/kg$ for the production of O_2, N_2 and CO_2, respectively.

3.3. DATA ANALYSIS

This study investigated the life-cycle carbon emissions in the packaging process of cooked peanuts. It also investigates the three mainstream packaging methods based on the dietary style preferences of users. A 100-year time horizon global warming potential value was used for the calculation according to the Intergovernmental Panel on Climate Change (IGC). The experimental data were statistically analyzed using SPSS software, and the variance of the mean of each sample was analyzed using Tukey's method. The experimental data should be expressed as mean ± standard deviation; Origin 8.5 software was used for the drawing of pictures.

4. RESULTS AND ANALYSIS

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.253-267

4.1. CARBON FOOTPRINT ANALYSIS OF DIFFERENT PACKAGING METHODS

For different user preferences, three packaging methods were studied: vacuum packaging (VP), air packaging (AP), and modified atmosphere packaging (MAP). The final carbon footprint of the packaging process of 200 g of ripe peanuts was also investigated. The calculations can be done using equations (1) and (2). The inputs of the packaging process include equipment (vacuum packaging machine, tabletop gas conditioning machine, air compressor, gas mixer, gas cylinder, buffer tank), electricity energy consumption, gases (CO_2, O_2, N_2), plastic products for packaging, etc. Inputs in the packaging process are respectively: equipment (vacuum packaging machine, tabletop gas conditioning machine, air compressor, gas mixer, gas cylinders, and buffer tanks), electricity consumption, gas (CO_2, O_2 , N_2) plastic products for packaging, etc.

Figure 3 shows the final carbon footprint of 200g of cooked peanuts packed in different packaging methods.

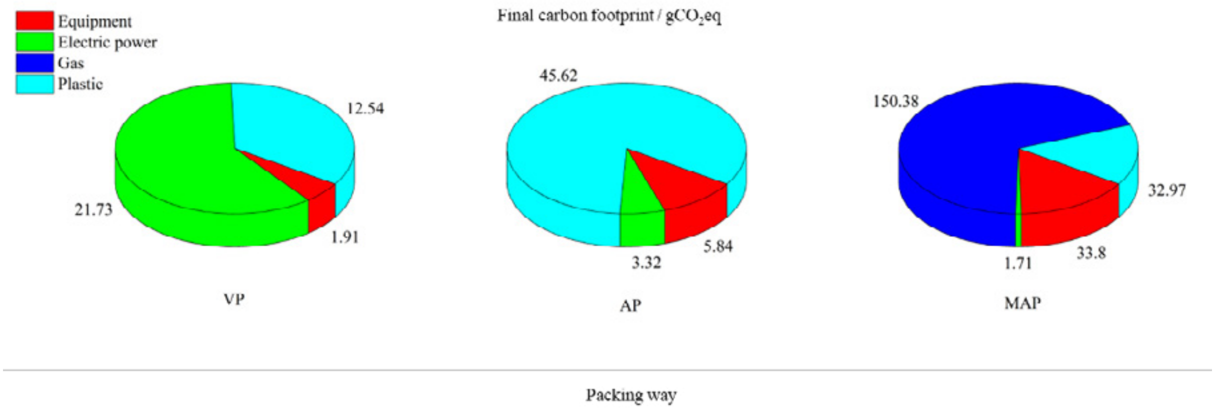


Figure 3. Final carbon footprint of 200g of cooked peanuts packed in different packaging methods

It can be seen from Figure 3 that the final carbon footprint difference under the three packaging methods is relatively large. Overall, the final carbon footprints of vacuum, air, and modified atmosphere packaging are 36.18 , 54.78 and 218.86 respectively. The final carbon footprint of the MAP is the largest, followed by the AP, and the final carbon footprint of VP is the smallest. The size of the carbon footprint is linked to the amount of CO_2 emissions. The final carbon footprint of MAP is 6 times higher than that of VP and 4 times higher than that of AP, reflecting the significant carbon footprint of using MAP as a packaging method. MAP is a method developed to preserve the freshness of cooked food for a long time. The main working principle is to evacuate the air inside the box and fill it with a certain ratio of mixed air to achieve the effect of freshness. This is why in Figure 3(c), gas preparation accounts for 64% of the final carbon footprint. In addition, due to the complexity of the process, the amount of equipment required for MAP is also relatively large, so this part of the carbon footprint accounted for 17%. VP and AP do not require gas preparation for filling, the

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.253-267

impact on the final carbon footprint is negligible. Since AP is simply compressed air for packaging, the impact on the final carbon footprint is mainly on the consumption of plastic products. As can be seen from Figure 3(b), this component accounts for 81%. Finally, VP requires vacuum preparation, so its equipment power consumption accounts for a large part of the final carbon footprint. It can be seen in Figure 3(a) as 60%. From the above description, we can find that the main influencing factors of the final carbon footprint are different due to the different processes of the three. However, since plastic packaging is used in all of them, the influence of plastic products on the final carbon footprint value accounts for a relatively high percentage in all three ways. In the three methods of VP, AP, and MAP, the percentage of this part is 34%, 81%, and 13% respectively. At a time when the concept of carbon reduction is deeply rooted in people's minds, the MAP which consumes so much carbon, should be replaced by two other methods. However, the use of MAP of goods is mostly fresh food. This packaging method allows consumers to visually observe the real appearance of the goods and find points of attraction, thus creating a desire to buy. This interactive experience between humans and food is something that the other two food packaging methods can hardly provide. Therefore, it is important to apply the interactive experience in the gas packaging method to the other two packaging methods in the subsequent research. This will reduce the carbon footprint without disrupting the user experience.

4.2. SENSITIVITY ANALYSIS OF DIFFERENT PACKAGING METHODS

Sensitivity analysis is an important component of LCA and can change the results of LCA. Therefore, this section analyzes important influencing factors that have not been considered in the previous section to consider whether changes in these factors can significantly change the carbon footprint of the packaging process. Due to the limitation of space, this section will focus on the carbon emission factors of the equipment in the carbon footprint sensitivity analysis.

In the results of this experimental study, the mass emission factor of the experimental equipment was used to simulate again the final carbon footprint of the packaging-making process. Setting the emission factor of the equipment for the second time to $3.54\ kgCO_2eq/kg$, it is expected that $2.0\ kgCO_2eq$ is generated per kilogram of plastic product. The carbon emission factors for each test equipment were multiplied by the weight of each experimental equipment itself to facilitate further data on the full life-cycle GHG mass and emissions generated by each experimental equipment itself. The final carbon footprint and emissions packaging data before and after the change in equipment emission factors can also be calculated directly from Equations 1 and 2, the results are represented in Figure 4.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.253-267

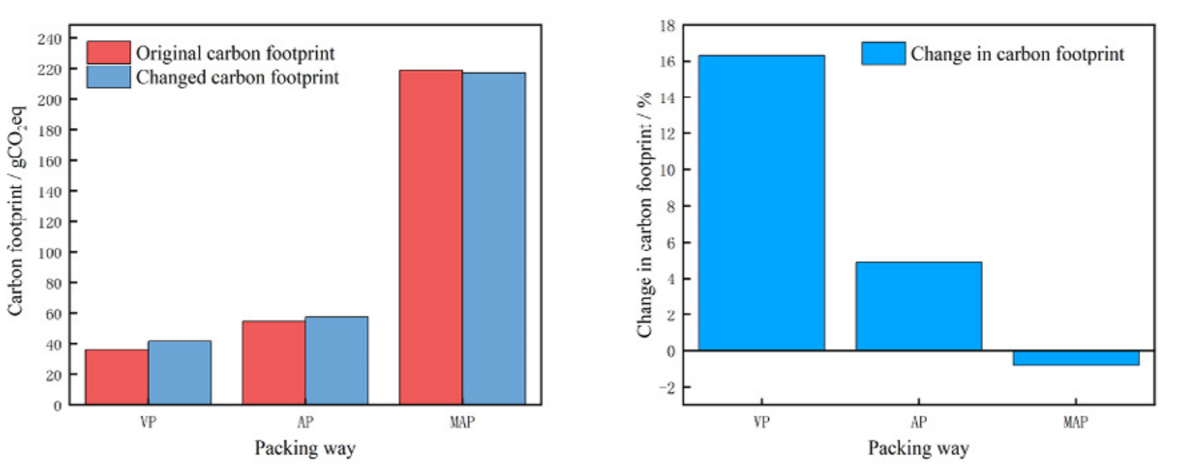


Figure 4. Comparative sensitivity analysis of equipment carbon emission factors

As can be seen in Figure 4(a), the carbon footprints of the three initial VP, AP, and MAP methods of packaging are $36.18\ gCO_2eq$, $54.78\ gCO_2eq$, and $218.86\ gCO_2eq$, respectively. After the emission factor correction calculation, the final carbon footprint was reduced to $217.63\ gCO_2eq$ under the AP transportation method, while the final carbon footprint increases to $42.26\ gCO_2eq$ and $57.45\ gCO_2eq$ for VP and MAP methods, respectively. This is due to the high price of MAP equipment and the small quality of the equipment when the emission factors of the equipment change. The final carbon footprint of the VP and AP will increase, probably due to the larger equipment and excessive plastic usage.

From Figure 4(b), it can be seen that the carbon emissions generated in the VP process changed by 16.31% after the change of emission factors of the equipment. This is partly because the final carbon footprint of the VP production process is extremely sensitive to the influence of the carbon emission factor of the equipment. Therefore, when the influence of this factor changes significantly, the carbon footprint value of the final product tends to change dramatically as well. While the change in the final carbon emissions of AP and MAP equipment is not much different, only 4.88% and 0.78% respectively. This is because the final carbon footprint changes of AP equipment and MAP systems have better stability for the emissions of the equipment. In the subsequent selection of the packaging method, the sensitivity of the emission factor can be a more important factor to consider. Choosing a packaging method with low sensitivity to emission factors for carbon footprint analysis and improvement measures can reduce the fluctuations caused by changes. Such an improvement method can avoid the generation of errors in the investigation of carbon emission factors to a greater extent.

5. DISCUSSION

In the current context of carbon reduction, the burden of carbon reduction for the food industry is huge. As a major part of carbon emission in the food industry, it is a challenging task to make effective methodological improvements and system adjustments. When designing food packaging with the task of carbon reduction, it is

https://doi.org/10.17993/3ctecno.2023.v12n2e44.253-267

important to retain the user's interactive experience and retain or even enhance the attractiveness of the product to consumers while achieving carbon reduction. The design of green, interactive packaging based on user experience should be human-centered and take into account the individual aesthetic needs of users as the main starting point for the product design concept. The task of carbon reduction should be taken into account when providing a better product experience to users and should be reflected. While users can enjoy the experience of food packaging, they can also appreciate the urgency of the task of carbon reduction. A good carbon reduction food packaging design should also absorb more factors of the times in order not to be easily eliminated.

6. CONCLUSION

In this paper, the final carbon footprint results of three different packaging methods were obtained by studying the carbon emission impact factors of 200g cooked peanuts. Subsequently, a sensitivity study of different packaging methods was conducted to explore the high sensitivity of the three methods to the emission factors. The specific findings are as follows.

1. Among the three completely different packaging processes, the final carbon footprint of the MAP process was the largest, at $218.86\ gCO_2eq$. This was followed by the AP process, with a size of $54.78\ gCO_2eq$, and the smallest final carbon footprint of VP, with a value of $36.18\ gCO_2eq$.

2. Among the factors influencing the final carbon footprint of the three methods, the main energy consumption of VP is the consumption of electricity, accounting for 60%. The factor affecting the size of the final carbon footprint of AP is the consumption of plastic products, accounting for 81%. In MAP, gas preparation has the largest impact on the final carbon footprint, accounting for 64%. In all three ways, the impact of plastic products on the final carbon footprint value accounted for a large part of the. For the three methods of VP, AP, and MAP, this part of the impact accounted for 34%, 81%, and 13%, respectively.

3. For the sensitivity of the emission factors, VP is the most affected. Its final carbon footprint changed by 16.31% compared to the previous one. AP and MAP are less affected, with 4.88% and 0.78% respectively.

REFERENCES

(1) Iličić, J., & Brennan, S. M. (2022). Shake it off and eat less: anxiety-inducing product packaging design influences food product interaction and eating. European Journal of Marketing.

(2) Khan, A., & Tandon, P. (2018). Realizing the End-of-life Considerations in the Design of Food Packaging. Journal of Packaging Technology and Research, 2(3), 251-263.

(3) Yokokawa, N., Amasawa, E., & Hirao, M. (2021). Design assessment framework for food packaging integrating consumer preferences and environmental impact. Sustainable Production and Consumption, 27, 1514-1525.

(4) Ma, X., & Moultrie, J. (2018). Understand sustainable packaging design in practice. In DS 92: Proceedings of the DESIGN 2018 15th International Design Conference (pp. 2693-2704).

(5) Nevala, H. (2022). The renaissance of reusable food packaging: design thinking as basis for creating sustainable service models in Tampere.

(6) Yu, D., Liu, X., & Ren, G. (2019). Application of the Computer Graphic Design Color Language in the Food Packaging Design. In International Conference on Frontier Computing (pp. 1677-1682). Springer, Singapore.

(7) Shan, S., Ma, Y., Tang, C., et al. (2018). Folding cartons: Interactive manipulation of cartons from 2D layouts. Computer Aided Geometric Design, 62, 228-238.

(8) Barrientos-Gutiérrez, I., Islam, F., Cho, Y. J., et al. (2021). Assessing cigarette packaging and labelling policy effects on early adolescents: results from a discrete choice experiment. Tobacco Control, 30(5), 505-514.

(9) Zhu, L., Xie, B., Zhang, Y. J., et al. (2019). Cartonist: Automatic Synthesis and Interactive Exploration of Nonstandard Carton Design. Computer-Aided Design, 114, 215-223.

(10) Dias, R. R., Deprá, M. C., Zepka, L. Q., et al. (2022). Roadmap to net-zero carbon emissions in commercial microalgae-based products: environmental sustainability and carbon offset costs. Journal of Applied Phycology, 34(3), 1255-1268.

(11) Fady, B., Davi, H., Martin-StPaul, N., et al. (2021). Caution needed with the EU forest plantation strategy for offsetting carbon emissions. New Forests, 52(5), 733-735.

(12) Han, Y., & Liu, Y. (2018). Study on Influencing Factors of Industrial Carbon Emission in Jiangsu Province Based on LMDI Model. Environmental Science & Technology.

(13) Puettmann, ME, & Milota. (2017). Life-cycle assessment for wood-fired boilers used in the wood products industry. FOREST PROD J.

(14) Florent, Querini, Enrico, & Benetto.(2017). Combining agent-based modeling and life cycle assessment for the evaluation of mobility policies. Environmental Science & Technology..

(15) Kühnen, Michael, & Hahn, Rüdiger. (2017). Indicators in social life cycle assessment: a review of frameworks, theories, and empirical experience. Journal of Industrial Ecology.

(16) Phouratsamay, S. L., & Cheng, T. C. E. (2019). The single-item lot-sizing problem with two production modes, inventory bounds, and periodic carbon emissions capacity. Operations Research Letters, 47(5), 339-343.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.253-267

(17) Xu, X., Wang, Q., Ran, C., et al. (2021). Is burden responsibility more effective? A value-added method for tracing worldwide carbon emissions.

(18) Marland, G., Oda, T., & Boden, T. A. (2019). Per capita carbon emissions must fall to 1955 levels. Nature, 565(7737), 567-568.

(19) Ma, M., & Cai, W. (2019). Do commercial building sector-derived carbon emissions decouple from the economic growth in Tertiary Industry? A case study of four municipalities in China. Science of the Total Environment, 650, 822-834.

(20) Tang, Z., Yu, H., & Zou, J. (2022). How does production substitution affect China's embodied carbon emissions in exports? Renewable and Sustainable Energy Reviews, 156, 111957.

(21) Sommer, M. , & Kratena, K.. (2017). The carbon footprint of European households and income distribution. Ecological Economics, 136(JUN.), 62-72.

(22) Skudder, H. , Druckman, A. , Cole, J. , Mcinnes, A. , Ian Brunton-Smith, & Ansaloni G. P. . (2017). Addressing the carbon-crime blind spot: a carbon footprint approach. Journal of Industrial Ecology, 2 1(4).

(23) Zheng, H. , Fang, Q. , Wang, C. , Wang, H. , & Ren, R. . (2017). China's carbon footprint based on input-output table series: 1992–2020. Sustainability, 9(3), 387.

(24) Wang, S., Tang, Y., Du, Z., et al. (2020). Export trade, embodied carbon emissions, and environmental pollution: An empirical analysis of China's high- and new-technology industries. Journal of Environmental Management, 276, 111371.

(25) Zhang, W., Li, G., & Guo, F. (2022). Does carbon emissions trading promote green technology innovation in China? Applied Energy, 315, 119012.

(26) Zhu, B., & Zhang, T. (2021). The impact of cross-region industrial structure optimization on economy, carbon emissions, and energy consumption: A case of the Yangtze River Delta. Science of The Total Environment, 778, 146089.

(27) Li, Jing. (2021). Evolutionary game research on the psychological choice of online shopping of fresh agricultural products based on the dynamic simulation model. Applied Mathematics and Nonlinear Sciences. doi:10.2478/AMNS.2021.2.00145.

(28) Zhou, N., Zhang, J., Khanna, N., et al. (2019). Intertwined impacts of water, energy development, and carbon emissions in China. Applied Energy, 238, 78-91.

(29) Li, B., Han, S., Wang, Y., et al. (2020). Feasibility assessment of the carbon emissions peak in China's construction industry: factor decomposition and peak forecast. Science of the Total Environment, 706, 135716.

(30) Wu, P., Guo, F., Cai, B., et al. (2021). Co-benefits of peaking carbon dioxide emissions on air quality and health, a case of Guangzhou, China. Journal of Environmental Management, 282, 111796.

(31) Ma, X., Wang, C., Dong, B., et al. (2019). Carbon emissions from energy consumption in China: its measurement and driving factors. Science of the total environment, 648, 1411-1420.

/16/

THE APPLICATION OF BIG DATA TECHNOLOGY IN ONLINE SUBJECT EDUCATION INNOVATION RESEARCH

Chengyi Huang*

College of Teacher Education, Chongqing Three Gorges University, Chongqing, 404100, China.

lovens2018@163.com

Wengxi Tan

College of Teacher Education, Chongqing Three Gorges University, Chongqing, 404100, China.

Xin Yan

College of Teacher Education, Chongqing Three Gorges University, Chongqing, 404100, China.

Yun Tan

College of Teacher Education, Chongqing Three Gorges University, Chongqing, 404100, China.

Heyue Wan

College of Teacher Education, Chongqing Three Gorges University, Chongqing, 404100, China.

Reception: 13/04/2023 **Acceptance**: 16/06/2023 **Publication**: 03/07/2023

Suggested citation:

Huang, C., Tan, W., Yan, X., Tan, Y. and Wan, H. (2023). **The application of big data technology in online subject education innovation research.** *3C Tecnología. Glosas de innovación aplicada a la pyme, 12(2)*, 269-282. https://doi.org/10.17993/3ctecno.2023.v12n2e44.269-282

ABSTRACT

This paper applies big data technology to promote the innovative development of online subject education and improve students' self-learning efficiency to promote innovative management interaction in the education industry. In the design process, big data technology is used to mine and analyze massive educational data, combine the learning needs of online subjects, and provide technical support for six application levels of the online subject education system. Document transformation of education data is performed through the DCF mechanism, and the synchronization time slot is divided into a safe time slot and a reservation time slot. Then, the adaptive recommendation function is used to extract valuable information from behavioral data for personalized learning resource pushing. To verify the practical application effect of big data technology in the online subject education innovation system, the simulation analysis results show that after applying big data technology, the recommended resources preference of the education system is above 86%, the subject coverage rate is 90.48%, and the performance of test scores is improved by 17.5% relative to Class C. This shows that big data technology optimizes the application mode of online subject education and can provide students with better-quality educational resources.

KEYWORDS

Big data technology; online subject education; DCF mechanism; adaptive recommendation function; subject coverage

INDEX

https://doi.org/10.17993/3ctecno.2023.v12n2e44.269-282

1. INTRODUCTION

Online subject education is an Internet-mediated way of teaching and learning, which crosses the time and space limitations of teaching and learning. Compared with traditional education, online education is characterized by low threshold, high efficiency, and abundant teaching resources [1]. Online education adopts diversified teaching forms, delivers resource information through multimedia network technology, combines the real world offline with the virtual world online, and enables learners to grasp learning content better and faster, playing a unique role with its unique concepts and methods [2-4]. In this context, the concept of big data and corresponding technologies can enable the identification of educational data and the mining of its implied information value to achieve a two-way balance between online educational services and learners' needs [5].

With the development of big data technology, the education industry has increasingly shown a trend of technology integration. For example, the literature [6] constructed an online education evaluation model by analyzing the application of current scientific paradigms in the field of education, which promoted the development of a new paradigm for the study of big data online education technology. By applying this paradigm, a series of educational evaluation models have been constructed at macro and micro levels, which play an active role in the practice and evaluation of education. The literature [7] used the Asia-Pacific Network for Health Professions Education Reform to assess students in five Asian countries on their attitudes and willingness to work in rural areas. The pretested anonymous questionnaire consisted of four parts, including demographic data, attitudes toward working in rural areas, location of work after graduation, and perceptions of the respondent's competence. The findings showed that about 60% of the students in Bangladesh and Thailand had positive attitudes towards working in rural areas, compared to 50% in both China and India and only 33% in Vietnam. The literature [8] developed a theoretical model to identify the factors influencing BDA in higher education by combining the technology organization environment and innovation diffusion. In the development process, the moderating effects of university size and university age were added to the developed model using the technological factors in BDA. Structural equation modeling was used to test the research model and 195 data samples were collected from campus administrators of virtual universities in Pakistan using an online questionnaire to demonstrate the relative merits of the theoretical model in educational management. The literature [9] innovated the management of university online educational records in the context of big data and designed a model for evaluating the construction of university online records to further promote digital records services in universities. The calculation and survey research methods of this model play an important influential role in the process of developing and utilizing archival information resources in colleges and universities. The literature [10] constructed a personalized dynamic evaluation model based on artificial intelligence big data technology to make evaluation the center of online education and teaching efforts. To verify the performance of the designed model, the article conducted model analysis through a

https://doi.org/10.17993/3ctecno.2023.v12n2e44.269-282

practical teaching method. The results of the study showed that the model it constructed had good performance and improved the effectiveness of online education quality management. Based on the big data cloud computing platform and the application scenario of online education, the literature [11] redivided the functional modules of the system and briefly designed the system according to the functional requirements of users for the system. The core functional modules of the innovative system include an online experiment module, online classroom module, video course module, online examination module, and basic function module, which effectively improve the comprehensive management of online education. To sum up, the educational business module after using big data technology innovation, although briefly satisfying the thematic needs of users, lacks the technical motivation for long-term development, and does not fully reflect the market application value and educational teaching value.

Based on this, in the process of application, this paper firstly uses big data technology to perform predictable mining analysis on massive education data and provides a simple and highly fault-tolerant architecture for massively parallel processing of massive data. Secondly, the DCF mechanism is used to transform education data documents, which effectively avoids the problem of large errors in the collection process of online education data, and the synchronization time slot is divided into a safe time slot and a reservation time slot in the channel reservation scheme based on the DCF mechanism. Again, the big data interaction window is used to realize the adaptive function of the online education system, to provide learning strategies and guidance to learners by using evaluation feedback, and to establish an adaptive question bank. Finally, the application of big data technology in online subject education system is simulated and analyzed, and its application effect is judged by the evaluation results of educational resources recommendation effect, students' test results, and educational fitting indexes to provide a path reference for the innovative application of online subject education.

2. ADVANTAGES OF BIG DATA TECHNOLOGY

Big data technology is a cutting-edge technology for data analysis, which can quickly obtain valuable information from multiple types of data and access massive, high growth rates and diverse information assets to provide stronger decision-making power and process optimization for online subject education with new processing models. The innovative advantages of big data technology applied to online subject education are shown in Table 1.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.269-282

Table 1. Advantages of Big Data Technology in Online Education

Features	Content
Large Volume	Storage is big and growing fast. Large amounts of data are generated in real time and have now jumped from the TB level to the PB level.
Many Types	Many formats, including unstructured and structured data, data analysis challenges the traditional data analysis processing capabilities.
Value Density	The value of data is large, but the value density is low. Analysis of massive data mining, predictable analysis of future trends and patterns, deep and complex analysis.
Speed	Fast processing and analysis will provide real-time insight into market changes, rapid response measures and decision-making support for enterprises to grasp market opportunities.

As can be seen from Table 1, traditional education management cannot accurately predict the number and type of resources needed for teaching activities, which often results in too many or too few educational resources for a certain teaching activity, not only causing serious waste or lack of educational resources but also making educational resources a rope limiting the smooth development of teaching activities. Big data technology can store a large amount of online learning data, and the storage capacity of data can even reach the level of petabytes, which can be processed in seconds for massive data. Big data technology can be used to analyze the future trends of online education and provide the education industry with real-time insight into the market changes and take corresponding measures quickly. This enables the optimal allocation of educational resources so that each educational resource can be used to the maximum extent.

3. APPLICATION OF BIG DATA TECHNOLOGY IN THE ONLINE EDUCATION SYSTEM

3.1. EDUCATIONAL SYSTEM APPLICATION OF BIG DATA

With the support of big data technology, combined with the learning needs of online subject education, big data technology can provide technical updates for six levels of the online education system:

1. User service layer. The users of online subject education platforms contain teachers and learners, for whom big data technology can provide four types of services: online teaching content, teaching management, communication and interaction, and learning management. The teaching service of big data technology will reconstruct the information resources according to the user's demand and provide personalized service resources for the user. The user does not need to know the resource integration process of the background data, which is completely done by the data resource processing layer of the system. For example: For teachers, the system will provide real-time feedback on the analysis of learners, especially learning styles and preferences, and

https://doi.org/10.17993/3ctecno.2023.v12n2e44.269-282

conduct intelligent analysis of students' behavior and learning records on the platform. For learners, the system will constitute a learning mode that integrates learning, question and answer, assessment, and interaction, so that learners can fully enjoy an autonomous learning atmosphere and multi-modal online interactive learning services.

2. Client. Big data technology will create online education platform users through computers and smart mobile terminal devices to complete the interface and user interaction.

3. Basic application layer. Big data technology can support the online subject education system and enable cloud service sharing if users access to the platform.

4. Data storage layer. The data layer is the core of the architecture, which is divided into three parts. The lower layer is the database, the middle layer is the data mining and analysis integration, and the upper layer is the standardized processing. In the face of rapidly increasing complex data, big data technology will use cloud computing and big data technology for modern data management of online subject education systems, storing all types of data persistently in cloud storage data centers and keeping data updated in real-time to lay the foundation for subsequent data sharing and analysis and enhanced data value.

When online education data is analyzed and mined, the raw data will be scattered in different data sources. The target-driven function of big data technology will read the education data through the application program interface that comes with the cloud storage, pre-process it using a mapping reduction algorithm, and the resulting file can be applied by various data analysis techniques. System mapping is used to map a set of key-value pairs into a new set of key-value pairs, specifying concurrent simplification functions that are used to ensure that all mapped key-value pairs have a shared set of identical keys [12]. This process can be iterated until the information is sufficiently simplified, the essence of which is to use big data technology to refine massive amounts of data to provide high-density value for data mining and intelligence analysis, and to provide a simple and highly fault-tolerant architecture for massively parallel processing of massive amounts of data [13].

5. Management platform layer. The main task of big data technology at the management level is to realize the normal operation of the online education system and improve the reliability and security of the system.

6. Infrastructure layer. The use of big data technology can solve the problem of hardware silos in the operation of the system, and the centralized management of hardware resources can improve the reliability and availability of the system. The use of virtualization technology can enable hardware resources to be realized, and the use of physical server virtual machines to isolate storage resources can improve the integrated use of storage resources. Hardware

https://doi.org/10.17993/3ctecno.2023.v12n2e44.269-282

resources such as servers are integrated to form a dynamic resource allocation that is dynamically assigned to each application system on demand. During peak periods of application systems, Big Data technology dynamically allocates more hardware resources as a way to get through peak periods and automatically reclaims excess resources to be dispatched to other application services or automatically shut down to extend hardware life.

3.2. TRANSFORMING DOCUMENT DATA

Online subject education requires that the data collected be relevant, reliable, and timely. Applying big data technology to the data transformation process of online subject education by using padding for document transformation can avoid the problem of large errors in the data collection process [14-15]. Based on the DCF mechanism (discounted free cash method), the designed data channel reservation framework is shown in Figure 1.

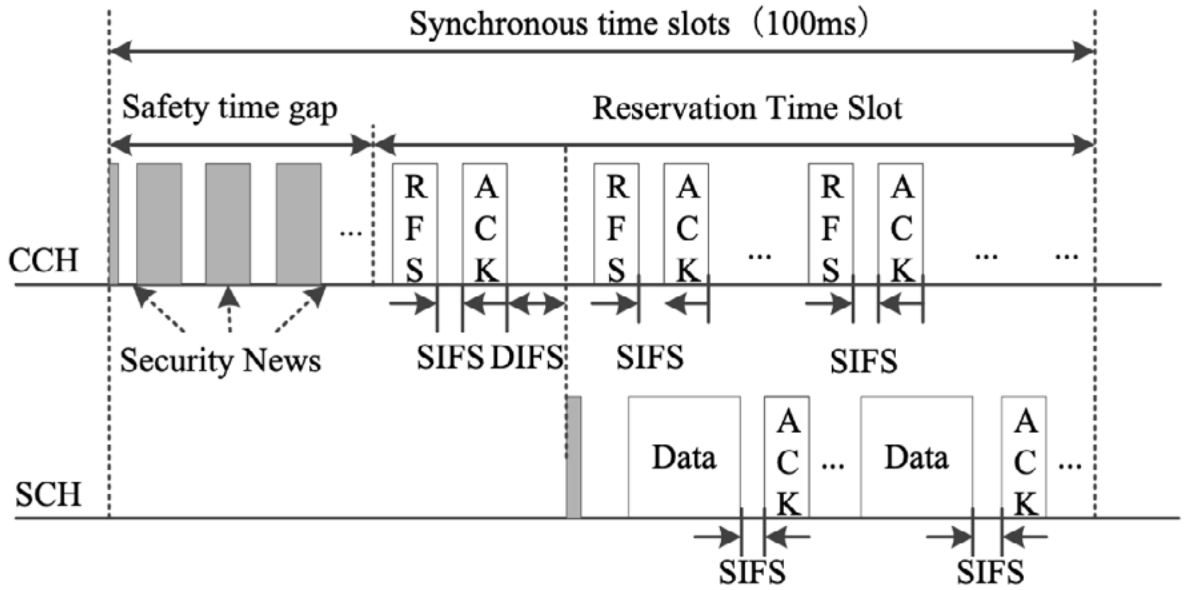


Figure 1. Data channel reservation framework

As can be seen from Figure 2, in the DCF mechanism-based data channel reservation scheme, the synchronization time slot is divided into a secure time slot and a reservation time slot. In the secure time slot, the PCF mechanism in IEEE802.11 wireless LAN is used. The system application within its communication area sends its security-related message after receiving the polling message from the system. Sending security messages within the security time slot is a contention-free transmission, and this approach meets the requirements for low latency in online subject education systems while ensuring the transmission of security messages.

Within the reservation time slot, the big data nodes are reserved on the CCH using the basic access method of the DCF mechanism, and the specific reservation process is as follows:

https://doi.org/10.17993/3ctecno.2023.v12n2e44.269-282

Step 1: Users who need to reserve SCH for uploading or downloading data services need to send RFS packets at the CCH node with the DCF mechanism.

Step 2: After the OBU node successfully transmits the RFS packet, if there is a free SCH in the system, the RSU will allocate an SCH channel to the desired OBU and send an ID containing the allocation to the OBU. If there is no free SCH in the system, the RSU will send a NAK to the OBU, and the OBU will enter the backoff process and double the contention window.

Step 3: Upon receiving an ACK from RSU response, OBU immediately switches to the assigned SCH and transmits the data file on the SCH within the specified time.

3.3. ADAPTIVE APPLICATION OF BIG DATA TECHNOLOGY

The adaptive function of big data technology can create different learning contexts for online education systems and tailor learning strategies and paths for learners to realize the educational means of tailoring education to meet the needs of personalized learning [16], as shown in Figure 2.

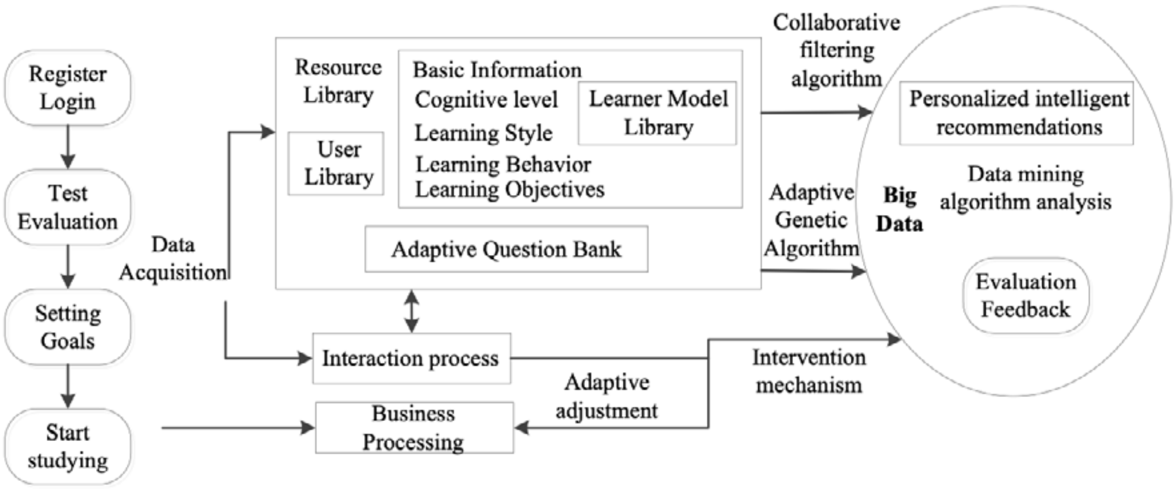


Figure 2. Adaptive personalized recommendation process of the online education system

As can be seen from Figure 2, in the adaptive personalized recommendation process, learners will generate learning behavior data after ability assessment and big data technology will combine with data mining technology to extract valuable information from the behavior data. Using big data technology to analyze learners' personal characteristics and build a learner model library, personalized learning resources are pushed using collaborative filtering recommendation algorithms.

In the process of learning personalized resources, the big data interaction window can be used to achieve the adaptive function of the online education system [17]. During the interaction process, big data technology collects learner interaction data, matches it with the knowledge base as the basis, and digs out the learning behavior implied behind the interaction behavior. Through the analysis engine, the learner's

https://doi.org/10.17993/3ctecno.2023.v12n2e44.269-282

knowledge system is analyzed comprehensively to plan learning strategies in a targeted manner, and different analysis tools are invoked according to different analysis purposes by combining the learner's learning behaviors and interaction data. Personalized test assessment through an adaptive question bank to establish data to correlate with student behavior. Combine multidisciplinary techniques to predict learners' learning behaviors and results, provide learning strategies and guidance to learners using evaluation feedback or manual intervention, and build a library of adaptive questions.

4. ONLINE DISCIPLINE EDUCATION INNOVATION RESEARCH RESULTS

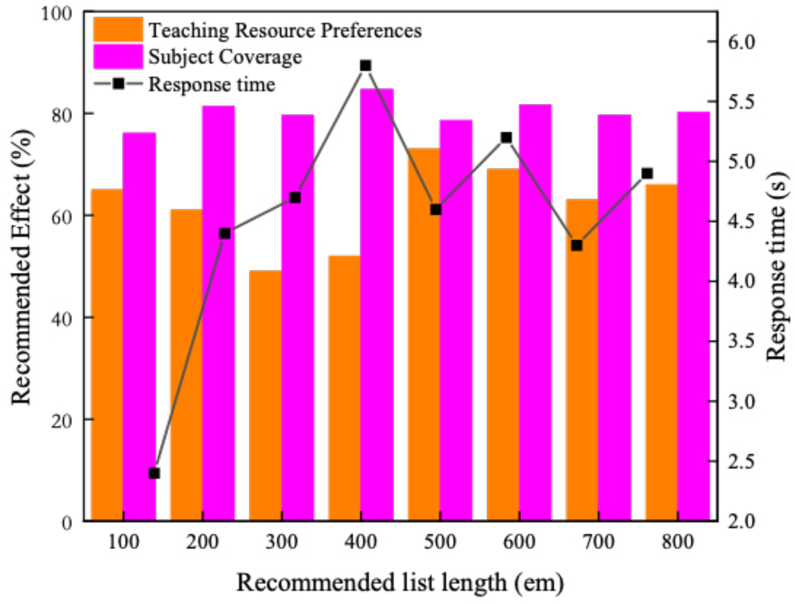
In this paper, big data technology is applied to an innovative system for online subject education to optimize the teaching process of online subject education. To verify the feasibility of this application, this paper analyzes the effect of educational resources recommendation, education fitting index evaluation results, and test performance regression results to determine the practical application of big data technology in online subject education.

4.1. EFFECTIVENESS OF EDUCATIONAL RESOURCES RECOMMENDATION

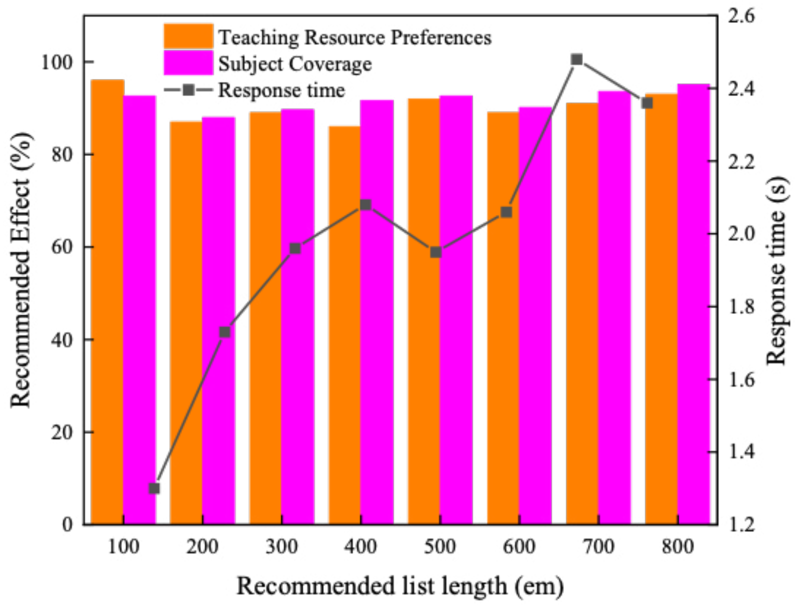
The evaluation metrics in this section are Educational resource preference, server response time, and subject coverage metrics. Educational resource preference refers to the degree of adaptation of the system to recommend content for users when they search for resources. Server response time refers to the average recommendation speed of the system. Coverage is an important metric used to evaluate the recommendation system's recommendation capability, indicating the proportion of items predicted by the algorithm to all items.

The recommendation effect of online subject education resources with big data technology is compared with the recommendation effect of resources based on graph embedding. The recommendation effect of big data technology is based on the weighted calculation of the number of user clicks and user favorites, and the more clicks and favorites a knowledge point has, the more popular the knowledge point is. The graph-embedded resource recommendation system is based on the number of clicks by users. The results of this experiment are shown in Figure 3, where the recommendation lists of length 100em-800emem are compared.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.269-282



(a) Resource recommendation based on graph embedding



(b) Resource recommendation for big data technology

Figure 3. Comparison of the effect of educational resources recommendation

From Figure 3(a), it can be seen that the average response time of the server is 4.1s when the graph-embedded resource recommendation system recommends subject educational resources for users. In terms of the degree of preference for educational resources, the average preference of recommended resources of the graph-embedded resource recommendation system is around 0.56. The average coverage rate of the tested subjects is 80.44% of all subjects, which indicates that the accuracy of this educational resource recommendation is relatively average and cannot meet the long-term development goal of online subject education.

From Figure 3(b), it can be seen that the server response time is short when Big Data technology recommends subject educational resources for users of online

https://doi.org/10.17993/3ctecno.2023.v12n2e44.269-282

subject education systems, with the average response time being 1.77s and the shortest being only 1.3s. In terms of the preference degree of educational resources, the preference degree of resource recommendation of the online subject education system with Big Data technology is above 0.86, and the coverage rate of the tested subjects in all subjects is on average the average coverage rate of all subjects tested was 90.48%. It can be seen that when applying big data technology to the resource recommendation of the subject education system, big data technology can automatically filter the resources that do not meet the requirements and add more running conditions to the recommendation process, which makes the server response time shorter and the user preference higher, thus achieving good recommendation of subject education resources. In summary, this paper applies big data technology to the online subject education system, which can shorten the response time of the system server, improve the coverage of search subjects and provide more accurate recommendation services for users based on fully satisfying user preferences.

4.2. EVALUATION RESULTS OF EDUCATION FITTING INDICATORS

In this paper, two main aspects, teaching quality and student evaluation, are considered in the evaluation of the fitted indicators for the effectiveness of online subject education. In terms of teaching quality, influencing factors such as teaching level and course content are mainly considered. In terms of student evaluation, influencing factors such as system performance and course acceptance are mainly considered. This experiment required the test students to make a comprehensive evaluation of the online subject education system after the application of big data technology on a 5-point scale, and the results are shown in Figure 4.

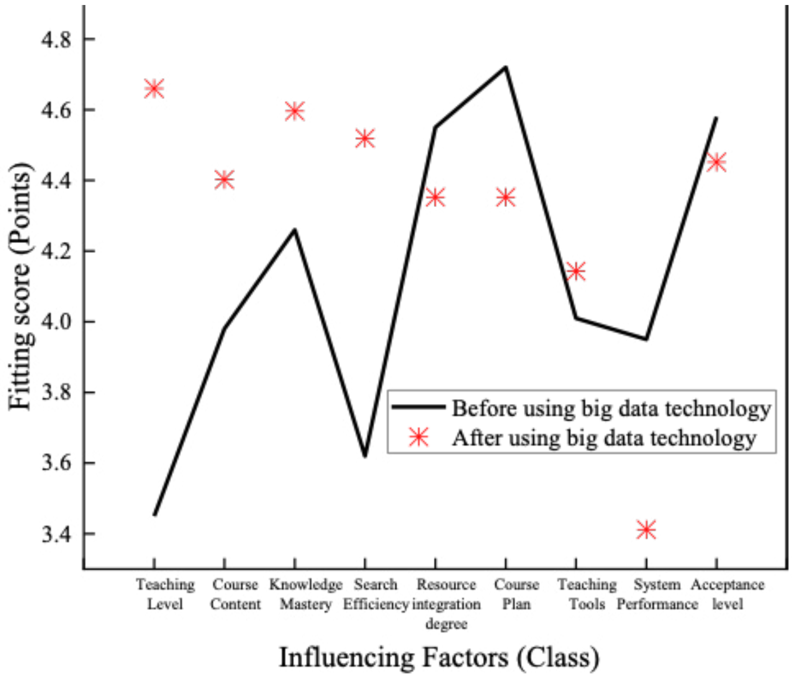


Figure 4. Evaluation results of education fitting indicators of the online education system

https://doi.org/10.17993/3ctecno.2023.v12n2e44.269-282

As can be seen from Figure 5, after the application of big data technology to the online subject education system, students' overall evaluation of teaching quality reached 4.81 points, of which teaching level rating reached 4.95 points, course content reached 4.789 points, students' knowledge mastery reached 4.91 points, lesson plan design efficiency reached 4.758 points, and teaching means optimization efficiency reached 4.627 points The efficiency of lesson plan design was 4.758, and the efficiency of teaching method optimization was 4.627. In terms of student evaluation, students rated the system's resource search efficiency at 4.862, resource integration at 4.758, overall evaluation of system performance at 4.842, and educational satisfaction at 4.82, all achieving an excellent evaluation level of 4.75. It shows that the application of big data technology to the online subject education innovation system can ensure the high-quality education level of online subject education to a large extent, and strongly stimulate the students' learning initiative and interest.

4.3. REGRESSION ANALYSIS OF TEST SCORES

In this paper, two classes of the same major in college A were selected as the experimental samples, and a semester-long educational experiment was conducted on them. There were 117 students in the two classes, including 57 students in class B as the experimental sample and 60 students in class C as the control sample, and the experimental variables were the educational system application of big data technology. The pre- and post-test scores of students in the two classes were examined using regression test analysis, and the comparison results are shown in Table 2.

Table 2. Achievement Test Results

Models	C Variable		B Variables	t	Sig.
	B	Standard Error			
Constants	49.368	1.469		37.625	1
Self-directed Study Time	1.629	1.069	7.45	6.9415	1
Degree of Exclusivity	3.655	1.1165	7.959	4.32	1
Interest	2.658	659	5.954	3.95	1
Achievements	78.6	0.79	95.36	3.214	2

As can be seen from Table 2, the performance test Sig values of the regression coefficients for all samples, with a maximum of Sig = 0.002 < 0.05 and a minimum of Sig = 0.001 < 0.05, reached a significant level of 0.05. This indicates that all reference samples in this experiment were significantly different. Class B students reached 7.45 h of independent learning time after using big data technology for the online subject education system, which is nearly 4.58 times higher relative to the control sample.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.269-282

The degree of exclusivity and interest dimensions for the subject reached 7.959 and 5.954, respectively, a basic increase of 220%. Moreover, the mean test score performance of students in Class B was 95.36, which was significantly higher than that of Class C at 78.6, indicating positive changes in students' cognitive abilities in the subject after participation in the experiment in Class B. The data from this test indicates that big data technology can have a positive and significant impact on student's performance, starting from the interesting and relevant knowledge of the subject.

5. 5. CONCLUSION

Guided by big data technology, this paper optimizes the design of an innovative application for online subject education in the context of big data technology, starting from transforming data documents and designing an adaptive resource recommendation process, and verifies the practical effect of the application in simulation tests. The test conclusions are as follows:

1. In terms of educational resource recommendation, the average response time of the resource recommendation server of big data technology is 1.77s, the preference of the recommended resources is above 0.86, and the coverage rate of the tested subjects is 90.48% of all subjects on average. It is known that applying big data technology to the online subject education innovation system can provide more accurate education resource recommendation services for users.

2. After using big data technology, the overall level of online subject education reached more than 4.62 points at the level of teaching quality and more than 4.75 points at the level of student evaluation. This indicates that big data technology has ensured the high-quality education level of online subject education to a greater extent and stimulated students' learning initiatives.

3. The results of the achievement test showed that Class B, after using big data technology for online subject education learning, had a mean performance value of 95.36 in test scores and 7.45h of independent learning time, which was nearly 4.58 times higher relative to Class C. And the degree of exclusivity and interest dimensions of the subject matter increased by 220%. The test data illustrates the significant performance-enhancing effect of big data technology on online subject education.

REFERENCES

(1) Wang, Z., Wan, Y., & Liang, H. (2022). The Impact of Cloud Computing-Based Big Data Platform on IE Education. Wireless Communications and Mobile Computing, 2022(JAN), 1-13.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.269-282

(2) Hussain, A., & Cambria, E. (2017). Semi-Supervised Learning for Big Social Data Analysis. Neurocomputing, 275.

(3) Xu, H. (2020). Intelligent system for university legal education. Journal of Intelligent and Fuzzy Systems, 40(4), 1-12.

(4) Neal, D., Dreamson. (2017). Online Collaboration in Design Education: an Experiment in Real-Time Manipulation of Prototypes and Communication. International Journal of Art & Design Education, 36(2), 188-199.

(5) Wink, D., Ruland, et al. (2016). Multiagency Online Preceptor Education: Design, Implementation, and Outcomes. Nurse educator, 41(5), 270-273.

(6) Zhang, R., Zhao, W., & Wang, Y. (2020). Big data analytics for intelligent online education. Journal of Intelligent and Fuzzy Systems, 40(7), 1-11.

(7) Chuenkongkaew, W. L., Negandhi, H., Lumbiganon, P., et al. (2016). Attitude towards working in rural areas and self-assessment of competencies in last year medical students: A survey of five countries in Asia. Bmc Medical Education, 16(1), 238.

(8) Baig, M. I., Shuib, L., & Yadegaridehkordi, E. (2021). A Model for Decision-Makers' Adoption of Big Data in the Education Sector. Sustainability, 13(24), 13995.

(9) Hong, Y., & Chen, Y. (2021). University online education file management under the background of big data. Journal of Intelligent and Fuzzy Systems, 2021(1), 1-7.

(10) Bai, X., & Li, J. (2021). Personalized dynamic evaluation technology of online education quality management based on artificial intelligence big data. Journal of Intelligent and Fuzzy Systems, 2021(3), 1-10.

(11) Wang, J., & Zhao, B. (2020). Intelligent system for interactive online education based on cloud big data analytics. Journal of Intelligent and Fuzzy Systems, 40(1), 1-11.

(12) Simsekler, M., Can, et al. (2018). Evaluation of system mapping approaches in identifying patient safety risks. INTERNATIONAL JOURNAL FOR QUALITY IN HEALTH CARE, 30(3), 227-233.

(13) Muhammad, S., Norma, F., Li, D., et al. (2017). An Open Source-Based Real-Time Data Processing Architecture Framework for Manufacturing Sustainability. Sustainability, 9(11), 2139.

(14) Domont, G., Cavaglieri, et al. (2017). 7-Ketocholesterol overcomes drug resistance in chronic myeloid leukemia cell lines beyond MDRI mechanism. Journal of proteomics, 151, 12-23.

(15) Jieyun, S., Qian, et al. (2018). Dendritic Cell Factor 1-Knockout Results in Visual Deficit Through the GABA System in Mouse Primary Visual Cortex. Neuroscience Bulletin, 34(3), 465-475.

(16) Tabuenca, B., Kalz, M., Ternier, S., et al. (2016). Mobile authoring of open educational resources for authentic learning scenarios. Universal Access in the Information Society, 15(3), 329-343.

(17) Niu, L., & Durakoglu, A. (2021). Sports Science Teaching of Athletics Based on Nonlinear Mathematical Equation. Applied Mathematics and Nonlinear Sciences.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.269-282

/17/

INDUSTRIAL RESTRUCTURING AND OPTIMIZATION FOR SUSTAINABLE DEVELOPMENT OF RESOURCE CITIES BASED ON DYNAMIC SIMULATION PERSPECTIVE

Chen Peng*

University of Leicester, University Rd, Leicester LE1 7RH, UK

cc_academy@163.com

Wanlu Ji

University of Lancaster, Bailrigg, Lancaster LA1 4YW, UK

Reception: 01/05/2023 **Acceptance**: 18/06/2023 **Publication**: 08/07/2023

Suggested citation:

Peng, C. and Ji, W. (2023). **Industrial restructuring and optimization for sustainable development of resource cities based on dynamic simulation perspective**. *3C Tecnología. Glosas de innovación aplicada a la pyme, 12(2)*, 284-304. https://doi.org/10.17993/3ctecno.2023.v12n2e44.284-304

ABSTRACT

Resource cities are highly dependent on resource industries and have a single industrial structure, so how to adjust and optimize the industrial structure is of practical significance to the sustainable development of resource cities. This paper combines the principle of data envelopment analysis (DEA) and the principle of industrial layout optimization to evaluate and position the current situation of industrial structure in resource cities. Based on this study, the simulation dynamic simulation of the path optimization of sustainable industrial development is conducted through the study of the dynamics principle, and the realism and validity of the model are tested by combining it with the actual data to realize the prediction of sustainable industrial path development. The results show that: In the simulation dynamic simulation prediction, the scale of the resource industry in resource cities decreases by about 6%-8% in 2020, and its simulation prediction data and real data have high consistency, which verifies the effectiveness of industrial structure adjustment and optimization strategy. This paper studies the optimization and upgrading of industrial structure to promote the sustainable development of a resource-based city economy, narrow the gap between the economic development of east and west regions, promote urbanization, and improve inter- and intra-regional development imbalance.

KEYWORDS

Resource city; industrial structure; sustainable development; data envelopment analysis; dynamic simulation

INDEX

https://doi.org/10.17993/3ctecno.2023.v12n2e44.284-304

INTRODUCTION

Resource-based cities refer to those cities that gradually grow and emerge from the large-scale exploitation of natural resources, and their growth and development are inseparable from the exploitation of natural resources, and the basic characteristic of these cities is that the industrial structure is relatively homogeneous, and the resource industry is "one and only" [1-3]. With the exploitation of resources, some mineral resources are close to depletion, and the development process of "construction - prosperity - decline - extinction or transformation" is inevitably in front of single-type resource-based cities [4-5]. Therefore, the research on the development of resource-based cities is still a worldwide problem that has received much attention from scholars at home and abroad [6].

For the study of the industrial structure of resource-based cities, based on the degree of mineral resources processing and utilization in the regional context, the literature [7] proposed a five-stage theory of mining town development. The literature [8] then pioneered the study of resource-based cities, which focused on the demographic characteristics of resource-based cities, psychosocial issues, and architectural planning of towns. In a comprehensive analysis of resource industries and economics, literature [9] found that: labor salary differences trigger the phenomenon of shifting industrial focus, and the output value of each industry will influence the composition of employment. The literature [10] establishes a measure of economic development and industrialization through a study of the relationship between the growth rates of several industries in the manufacturing sector, which in turn enables the division of the industrialization process into four stages.

The energy crisis has promoted foreign scholars to conduct a lot of research and practice on industrial transformation and sustainable development of resource-based cities [11-13]. The literature [14] proposed a development model of LDC exploitation of mineral resources, i.e., the long-distance commuting model, and analyzed in some detail how regional and social development is affected by this model. The literature [15] studied the relationship between economic growth and natural resources positively, and the main variables they selected included economic system, investment, market openness, and natural resource abundance as indicators. The

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.284-304

literature [16] studied the impact of industrial transformation on the quality of life of a region in a resource city subject to sustainable development.

This paper firstly constructs the resource city resilience, economic resilience evaluation index system, urban economic resilience evaluation index system, comprehensive urban vulnerability index system, and sustainable development evaluation index system. Combined with the principle of data envelopment analysis (DEA) and the principle of industrial layout optimization to evaluate and position the current situation of industrial structure in resource cities. Secondly, through the study of the dynamics principle, the simulation and dynamic simulation of the path optimization of industrial sustainable development is carried out, and the realism and validity of the model are tested by combining it with actual data to realize the prediction of industrial sustainable path development. Finally, by comparing and analyzing the same and different characteristics of development among four resource-based cities with different natures, we propose targeted countermeasures and suggestions to improve the economic resilience of cities according to the characteristics of different cities.

1. ECONOMIC RESILIENCE ASSESSMENT SYSTEM AND MEASUREMENT METHOD FOR RESOURCE-BASED CITIES

1.1. CONSTRUCTION OF ECONOMIC RESILIENCE EVALUATION INDEX SYSTEM FOR RESOURCE CITIES

This paper collects relevant urban economic resilience evaluation indexes based on conceptual and theoretical mechanism research. Through a large amount of literature on urban resilience, economic resilience evaluation index system, urban economic resilience evaluation index system, comprehensive urban vulnerability index system, sustainable development evaluation index system, and other related research. Then, combined with the resources of resource-based cities, the characteristics of economic development conditions, etc., a comprehensive index system and assessment model of economic toughness evaluation of resource-based cities are established based on data availability, and the economic toughness of the four major coal cities are analyzed empirically, and the dynamic development characteristics and laws of the analysis results are summarized.

The city is a complex whole, and the system is affected by a variety of factors its economic system is also affected by the government's financial status, economic structure, innovation capacity, and other multi-purpose factors. Given this, based on the above index system and concerning the existing literature, a four-level comprehensive evaluation index system of urban economic resilience of the four major coal cities in Heilongjiang Province is constructed as shown in Table 1. The

https://doi.org/10.17993/3ctecno.2023.v12n2e44.284-304

system level is characterized by six subsystems: revenue and expenditure capacity, innovation environment, development vitality, stability, diversity, and openness system.

Table 1. Evaluation index system of economic resilience of resource-based cities

<table>
<tr><th>System layer</th><th>Evaluation Factor Layer</th><th>Evaluation Indicator Layer</th><th>Notes</th></tr>
<tr><td rowspan="4">A1 Income and Expenditure Capability System System</td><td rowspan="2">B1 Personal revenue and expenditure capacity</td><td>C1 GDP per capita Characterizing the urban economy</td><td rowspan="4">Indicates the city's economic strength and financial accumulation capacity</td></tr>
<tr><td>C2 Disposable income per capita and fiscal burden</td></tr>
<tr><td rowspan="2">B2 Government revenue and expenditure capacity</td><td>C3 Local public revenue to GDP ratio</td></tr>
<tr><td>C4 Fiscal self-sufficiency rate</td></tr>
<tr><td rowspan="4">A2 Innovation Environmental Systems System</td><td rowspan="2">B3 Science and technology innovation capacity</td><td>C5 Number of patent applications per 10,000 people</td><td rowspan="4">Reflecting the level of science and education, innovation capacity and economic development momentum</td></tr>
<tr><td>C6 Science and technology expenditures/fiscal expenditures</td></tr>
<tr><td rowspan="2">B4 Social infrastructure environment</td><td>C7 Education expenditure/fiscal expenditure</td></tr>
<tr><td>C8 Number of doctors per 10,000 people</td></tr>
<tr><td rowspan="4">A3 Development Vitality System</td><td rowspan="2">B5 Social Development Vitality</td><td>C9 Rate of increase in employed persons</td><td rowspan="4">Characterize the overall urban development trends</td></tr>
<tr><td>C10 Rate of increase in total retail sales of consumer goods</td></tr>
<tr><td rowspan="2">B6 Ecological development vitality</td><td>C11 GDP growth rate</td></tr>
<tr><td>C12 Greening coverage rate of built-up areas</td></tr>
</table>

1. Income and Expenditure Capacity System

Government public finance revenue and expenditure can effectively regulate the allocation of resources. Fiscal work is one of the important means to realize the macroeconomic control of each country and plays an important role in achieving the goals of economic development and the rational and optimal allocation of resources. The increase in fiscal strength can effectively regulate the internal contradictions of the people, and social distribution relations, maintain the stable development of the market mechanism and achieve social equity.

2. Innovative Environmental Systems

https://doi.org/10.17993/3ctecno.2023.v12n2e44.284-304

Innovation has a great impact on China's economy, which is reflected in promoting consumption, enhancing the competitiveness of foreign trade, and changing the mode of economic growth. A city or region with a strong innovation capacity can promote the high-quality development of the city or region. Vigorously promoting innovation capacity is conducive to the progress of science and technology and improving the vitality of urban economic development.

3. Development of a vitality system

The Vitality System is a system that characterizes the general trend of urban development. In addition, it can also be used to predict future fluctuations and development trends, so that we can prepare and make decisions in advance to face the crises and risks of urban development.

4. Stability System

The stability system is mainly reflected in harmonious and stable social and sustainable economic development, which is important for cities or regions to maintain stable development and absorb learning when they suffer from unknown risks and great disturbances. The increase in urbanization level, the improvement of the living environment, and the increase of people's life security level can promote the stable development of society.

5. Diversity System

Many regions and cities have thus experienced periods of economic recession, and in the face of periodic financial crises and risks, the economic development of resource-based cities has slowed down and their development levels have declined, the reason for this recession being an over-reliance on natural resources leading to a more homogeneous industrial structure.

6. Open System

The level of openness of a country or region is also the ability of foreign trade is one of the important factors in promoting economic development. The faster or slower economic growth and the ability of foreign trade both have a very close relationship, the stronger the level of foreign trade, the more developed the economy, the greater the influence, and the higher the level of economic resilience of the city.

The industrial development of small and medium-sized resource cities, especially small and medium-sized dependent resource cities, provides good reference, and the sustainable development route of 6 major systems in resource cities is shown in Figure 1.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.284-304

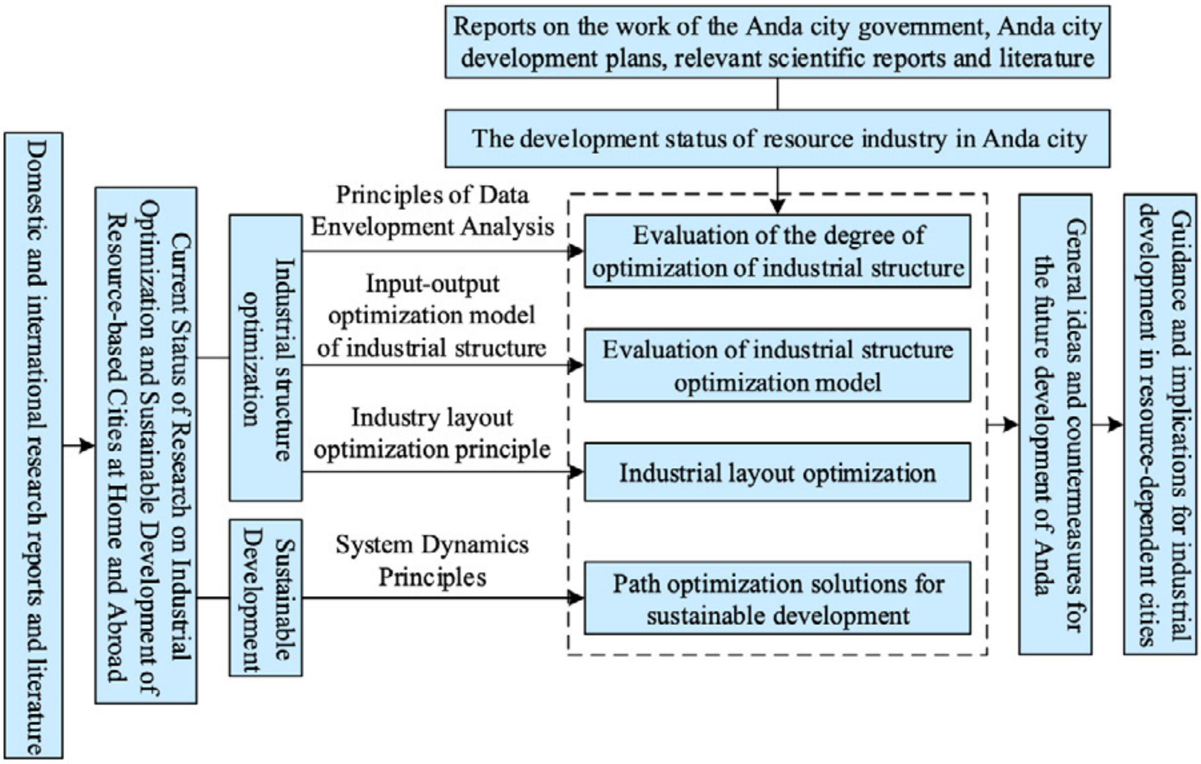


Figure 1. Industrial structure optimization and sustainable development road map

1.2. ECONOMIC RESILIENCE MEASUREMENT METHODS

1.2.1. SHANNON INDEX METHOD

Let the number of employees in a city be A, divided into n types of industries, and the number of employees in each type of industry be $A_i(1,2,3\ldots n)$, then we have:

$$\sum_{i=1}^{n} A_i = A \tag{1}$$

The ratio of the number of employees in each type of industry can be obtained as:

$$H = -\sum_{i=1}^{n} P_i \ln P_i = -\sum_{i=1}^{n} \left(A_i / \sum_{i=1}^{n} A^2 \right) \ln \left(A_i / \sum_{i=1}^{n} A_i \right) \tag{2}$$

The information entropy of the industrial structure can be defined by the Shannon entropy formula:

$$P_i = A_i/A = A_i/\sum_{i=1}^{n} A_i, \sum_{i=1}^{n} P_i = 1 \tag{3}$$

https://doi.org/10.17993/3ctecno.2023.v12n2e44.284-304

Where: H is the industrial diversity index, P_i is the ratio of the number of industrial employees, A_i is the number of industrial employees, and A is the total number of employees.

1.2.2. ENTROPY METHOD

The entropy value method to determine the index weights mainly analyzes the degree of variation of the index. It is generally believed that the higher the entropy value, the smaller the degree of variation, the slower the change tends to be balanced, and vice versa. Therefore, this paper selects the entropy method to determine the weights, which can eliminate the influence of subjective assignments and reflect the information objectively, and the results are more scientific. The main steps are as follows:

1. The dimensionless treatment of indicators.

Eliminate the influence of indicators with positive and negative directions, enhance the comparability between different indicators, and eliminate the influence of outliers to some extent. The specific calculation formula and operation steps are:

Positive indicators:

$$X'_{ij} = \frac{X_{ij} - \min\left(X_{ij}\right)}{\max\left(X_{ij}\right) - \min\left(X_{ij}\right)} \tag{4}$$

Negative indicators :

$$X'_{ij} = \frac{\max\left(X_{ij}\right) - X_{ij}}{\max\left(X_{ij}\right) - \min\left(X_{ij}\right)} \tag{5}$$

Where: X_{ij} is the index data. $min(X_{ij})$ is the minimum value of the assessed index, $max(X_{ij})$ is the maximum value of the assessed index.

2. Calculate the entropy value of the index.

According to the information entropy theory, the entropy value of the index can be expressed as:

$$e_j = -k\sum_{i=1}^{m} y_{ij}\ln\left(y_{ij}\right) \tag{6}$$

Of these, $k = \dfrac{1}{\ln m}$, there are $0 \leq e_j \leq 1$.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.284-304

3. Finally, the weights of each indicator are calculated:

$$W_j = \frac{1 - e_j}{\sum_{i=1}^{n} 1 - e_j} \tag{7}$$

1.2.3. MULTI-OBJECTIVE WEIGHTING FUNCTION METHOD

The level of urban economic resilience is the result of the combined effect of various indicators of each system, and the degree of urban economic resilience varies from system to system. The system is first quantified and finally, the urban economic resilience index is calculated. In this study, we use this method to calculate the urban economic resilience level of four major coal cities, first calculate the urban economic resilience index of each system, and then calculate the comprehensive urban economic resilience index. The calculation formula is as follows:

$$t = \sum_{i=1}^{m} ai \cdot \omega i, i = 1, \ldots, m \tag{8}$$

Where: t is the system resilience index, m is the number of indicators, a_i is the standard value of the i indicator in the factor layer, and i is the weight of the i indicator.

The city economic resilience index is calculated by the formula:

$$T = \sum_{j=1}^{n} t_j \cdot W_j, j = 1, \ldots, n \tag{9}$$

Where: T is the economic resilience index, t_j is the j system economic resilience index, and W_j is the j system weight of the system layer.

1.3. MULTI-OBJECTIVE LINEAR PATH PLANNING

Based on the inter-regional input-output table of province H in 2017, an optimization model is established, which should specifically contain a multi-objective optimization model using resource-output and economic objectives, since both objectives cannot be optimal at the same time. Therefore a satisfactory compromise between the two objectives can be solved using multi-objective linear programming. The dimensionless treatment should be carried out for different objective functions, while converting the multi-objective planning into single-objective planning, i.e., assigning a weight factor of 0.5 to the two objectives.

1. Objective function

https://doi.org/10.17993/3ctecno.2023.v12n2e44.284-304

Objective function 1: The overall gain along the yellow area is the largest, that is, the sum of the value added of each industry in each city along the yellow area is the largest, the formula is as follows:

$$\max \sum_{r=1}^{m} = \sum_{i=1}^{n} v_i^r X_i^r \tag{10}$$

Where m is the number of cities, n is the number of industries in the city, v_i^r is the rate of value added in the r city i sector, X_i^r indicates the output of the r city i sector, in this paper $m = 8, n = 8$.

Objective function 2: The overall minimum water consumption along the yellow area, i.e., the minimum water consumption of each industry in each city along the yellow area, is given by the following formula:

$$\min \sum_{r=1}^{m} = \sum_{i=1}^{n} w_i^r X_i^r \tag{11}$$

Where w_i^r is the direct water use coefficient for the r city i sector and X_i^r indicates the output of the -city sector.

2. Binding Conditions

Constraint 1:Constraints on input-output models. The inter-municipal input-output model also provides a framework for describing the industrial relationships between different cities. The specific equations are as follows:

$$X_i^r = \sum_{s}^{m} \sum_{j}^{n} x_{ij}^{rs} + \sum_{s}^{m} y_i^{rs} \tag{12}$$

n is the number of industrial sectors, m is the number of cities, X_i^r is the output of sector i of city r, x_{ij}^{rs} represents the amount of intermediate inputs from sector i of city s to sector j of city r, and y_i^{rs} represents the final demand of sector i of city s. The above equation can be rewritten by introducing direct coefficients, which are structured as follows:

$$X_i^r = \sum_{s}^{m} \sum_{j}^{n} a_{ij}^{rs} x_j^r + \sum_{s}^{m} y_i^{rs} \tag{13}$$

where the direct coefficient a_{ij}^{rs} is expressed as the amount of input from the s city i sector needed to increase the unit output of the r city j sector, and X_j^r is the output of the r city j sector.

In the optimization model, it is ensured that the demand from the product in each department does not exceed the output, i.e. the constraints are as follows:

https://doi.org/10.17993/3ctecno.2023.v12n2e44.284-304

$$\sum_{s}^{m}\sum_{j}^{n} a_{ij}^{rs} = x_j^r + \sum_{s}^{m} y_i^{rs} \le X_i^r \tag{14}$$

Constraint 2:Industrial structure constraint. To achieve the objective function while ensuring that the optimal output value of the high water use sector in the city is not 0, to meet the actual situation of the city, therefore, according to the previous study, a range of variation will be set for the output of the production and supply industry and the wholesale, retail and residential food industry. The formula is as follows:

$$X_i^r / \sum_{i=1}^{n} X_i^r \le \bar{L}_i^r \tag{15}$$

Where X_i^r is the output of the r City i sector and $\overrightarrow{L}_i$ is the actual output ratio of the r City i sector.

Constraint 4:Baseline of agricultural production. From the analysis of water resources efficiency in the fourth sector, it can be seen that high water intensity in agriculture, i.e. the more water resources, the lower the economic efficiency, so there is a strong tendency for optimal agricultural production in the model to converge to zero. And Henan is a large grain province, which must take food security as a hard constraint. According to the change in agricultural output value in the past five years, the upper and lower limits of agricultural output in each city are determined, denoted as :

$$\underline{X}_i^r \le X_i^r \le \bar{X}_i^r \tag{16}$$

$\underline{X}^r$ is the lower bound of the output of the r city i sector and $\bar{X}_i^r$ is the upper ratio of the output

Constraint 5: Water use restrictions. To ensure that the water consumption for optimal production does not exceed the actual water consumption, the total actual water consumption is taken as the basis, specifically:

$$\sum_{i=1}^{n} w_i^r X_i^r \le W^r \tag{17}$$

2. INDUSTRIAL RESTRUCTURING AND OPTIMIZATION OF RESOURCE CITIES

2.1. BUILDING CIRCULAR ECONOMY AND INDUSTRIAL CHAIN STRATEGY

Traditional value chains focus on value addition and profit, without much consideration for resource conservation. In the case of individual enterprises, there is

https://doi.org/10.17993/3ctecno.2023.v12n2e44.284-304

an interaction with the external environment from the development of their products to their final consumption. In the case of an industry, i.e. a sector, its development is not only constrained by the local resources and environment but also has an impact on the surrounding environment.

Therefore, to realize the coordination of industrial development with resources and environment. To achieve sustainable urban economic development, the circular economy strategy for industrial and even enterprise development should be studied from a strategic perspective. In terms of the relationship between individual enterprises and the environment, and thus from the aspect of clean production. As for the interrelationship between the industrial value chain composed of multiple enterprises and the natural environment, it should be studied from the perspective of system theory, how to be between enterprises. For example, between upstream and downstream enterprises in the industry, a large number of subsystems with resource conservation and ecological harmony are constructed, and each subsystem plays its function through the whole because it is in the same system. As an economic system as a whole, the purpose is to promote the rational and efficient allocation of resources, and this effective input and output is still sustainable, playing the maximum economic benefits of resources while minimizing damage to the environment, and even has the function of restoring the environment. The material flow cycle within the resource-based industry is shown in Figure 2.

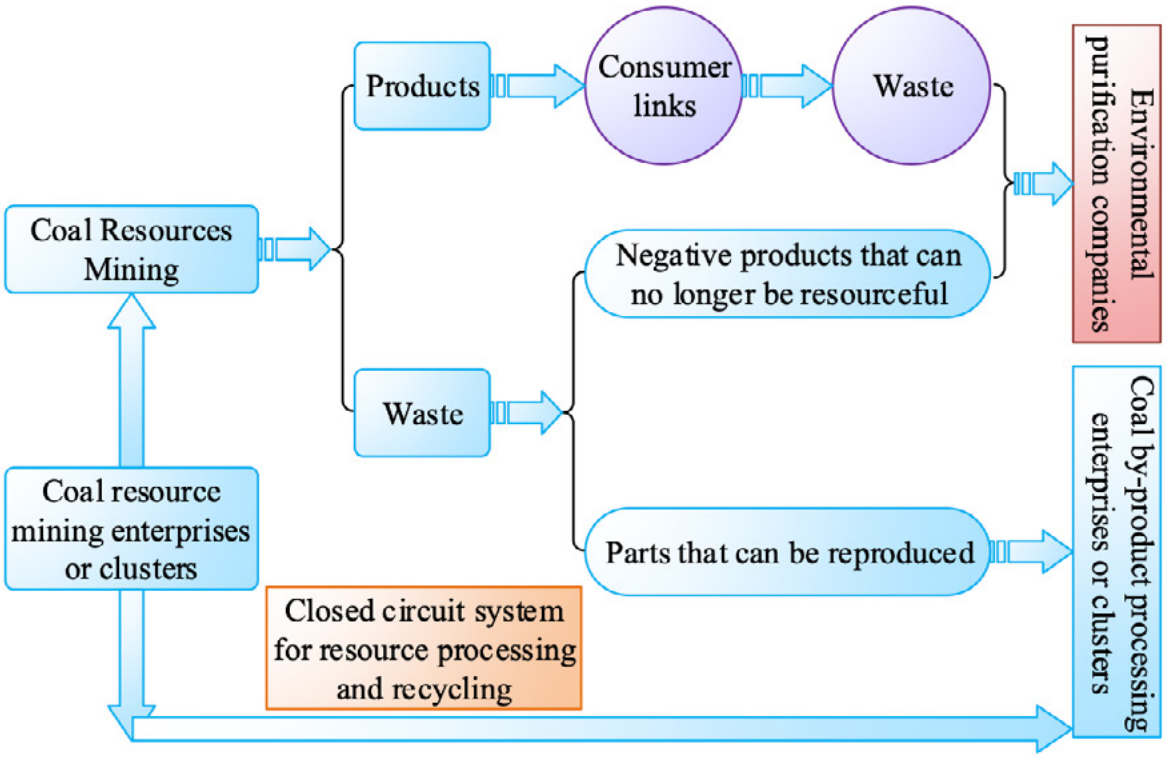


Figure 2. Roadmap for industrial structure optimization and sustainable development

To put the ecological and environmental elements, a scarce resource, into the industrial chain formed between upstream and downstream enterprises for allocation,

https://doi.org/10.17993/3ctecno.2023.v12n2e44.284-304

so that the union of upstream and downstream enterprises into a circular production model. In other words, the waste produced by one enterprise becomes the raw material or resource input for another enterprise. In this way, different enterprises maintain their unique core competencies, and the industrial chain alliance formed between enterprises as a whole can realize the efficient allocation of resources and circular production, and achieve the most optimal economic benefits.

2.2. ADVANCED INDUSTRIAL STRUCTURE UNDER THE CONSTRAINTS OF MULTIPLE FACTORS

Demand structure, supply structure, and science and technology level are the key factors that dominate industrial upgrading. Demand and scientific and technological progress factors promote the development of advanced industrial structures, and the supply structure constitutes a rigid factor that restricts industrial upgrading within a certain period. At the same time, industrial policies and mechanisms in a certain period will have an impact on industrial upgrading.

Demand structure restricts the direction of industrial structure upgrading while promoting the development of advanced industrial structures. Demand factors bring the birth of new industries, the restructuring and upgrading of existing industries, and the elimination of some backward industries. The scale of demand brings the impetus for the development and expansion of the demanded industries, and promotes the process of industrial advancement, the specific driving process is shown in Figure 3.

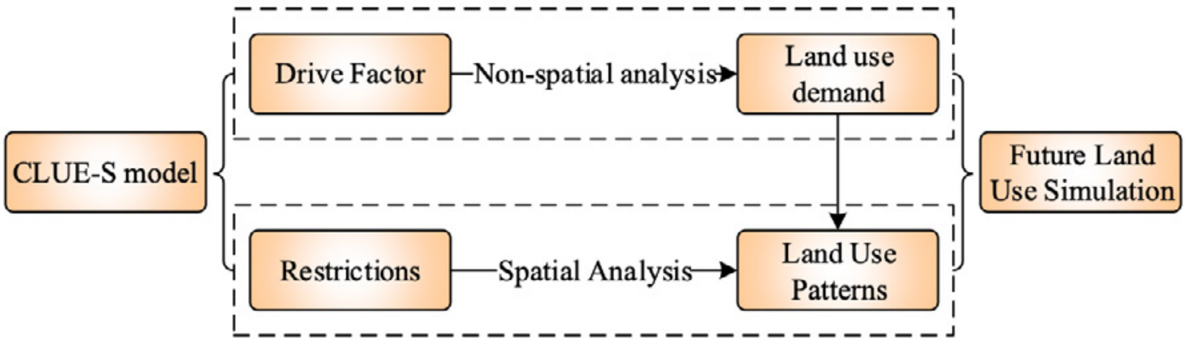


Figure 3. Industrial advanced CLUE-S cycle drive principle

Supply structure is a rigidifying factor for industrial development in a certain period and is a limiting factor for industrial upgrading. The supply structure of labor and resource-rich regions has the advantage of developing resource-based industries and labor-intensive industries. Once the industrial development forms a certain scale, it gradually becomes the leading industry of the region and dominates the development of urban industrialization and industrial upgrading will influence rigidification factors. If capital accumulation is insufficient or the human resources and technology level of the region is low and the introduction of capital and technology is difficult, even with the strong thrust of the demand factor, the development of new industries and the advanced industrial structure will be difficult.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.284-304

2.3. INDUSTRIAL CLUSTER DEVELOPMENT UNDER AGGLOMERATION ECONOMY

An agglomeration economy is a gathering of diverse manufacturers, residents, and related organizational units in a certain spatial area such as a city. And to obtain economies of scale, external economic effects, and other effects of an economic model, agglomeration economic effect to promote the expansion and development of the scale of the industry. The agglomeration economic effect promotes the scale expansion and development of industries and makes them enjoy the external economic effect and the improvement of science and technology and management level brought by the agglomeration economic effect, and the agglomeration of industries promotes the acceleration of urbanization process and the expansion of city scale.

An industry cluster is a group of companies and institutions that are geographically close to each other and belong to the same industry and are interconnected with each other. For example, a group of competing and cooperating firms, specialized suppliers, service providers, financial institutions, manufacturers of related industries, and other related institutions in a given region, which are geographically concentrated and interrelated. A highly developed industrial cluster can improve the productivity and competitiveness of the overall industry and drive innovation through synergies in research and technology, complementary industries, and knowledge and human capital. This leads to increased competitiveness and economic wealth creation.

There is an inextricable link between industrial clusters and industrialization. Industrial clusters drive the population to cities, thus the proportion of the non-farm population increases and drives urbanization. The industrial cluster model points out that the transformation of industrial structure drives the industrialization process as shown in Figure 4.

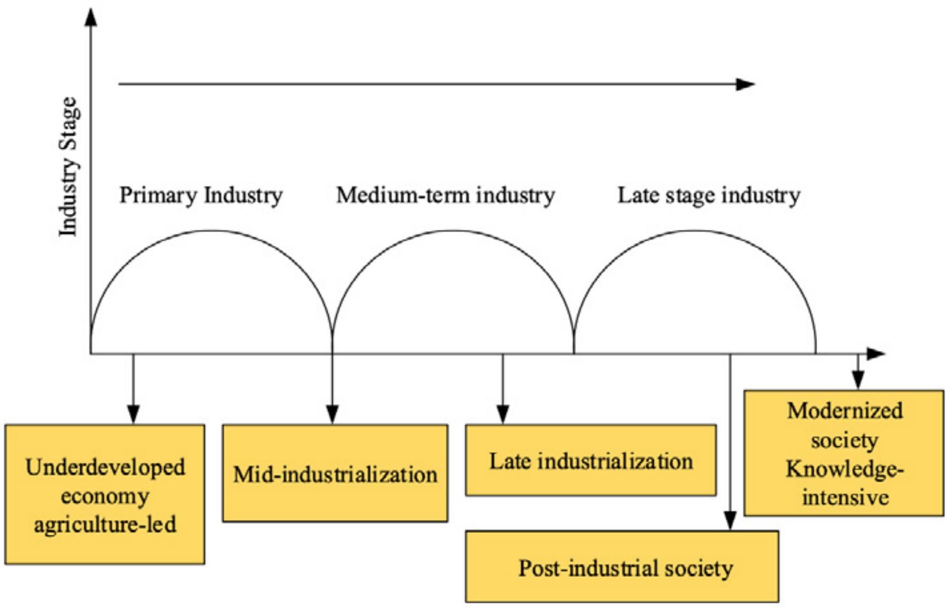


Figure 4. Structural transformation of industrial clusters drives industrialization

https://doi.org/10.17993/3ctecno.2023.v12n2e44.284-304

Industrial agglomeration is also a reasonable way for resource-based cities to realize industrial scale and brand development, promote industrial structure adjustment, and achieve efficient resource allocation and optimal urban development. Resource-based cities can rely on their own mineral resources and labor production factors and other resource advantages to develop large leading enterprises in line with regional characteristics. The formation of the production chain as a link to the internal division of labor refinement of enterprise clusters, to improve the internal production efficiency of the industry, gathering capital factors, labor factors, and science and technology, information, and talent factors to promote the development of industrial branding.

3. SIMULATION RESULTS AND ANALYSIS OF SUSTAINABLE ECONOMIC DEVELOPMENT DYNAMICS IN RESOURCE CITIES

3.1. ANALYSIS OF OVERALL DYNAMIC SIMULATION RESULTS OF ECONOMIC RESILIENCE IN RESOURCE CITIES

Unlike traditional linear prediction methods such as trend extrapolation and gray prediction, the multi-objective weighting function method has greater advantages for solving nonlinear system problems. In terms of accuracy, the multi-objective weighting function method continuously adjusts the weights by backpropagation and thus minimizes the error. The data in this paper are autoregressive and consistent with time series analysis, so the dynamic simulation model of the nonlinear multi-objective weighting function method is selected to more accurately reveal the development trend of economic resilience of the four major coal cities.

The overall error and deviation results of economic resilience of the four cities for 2018-2022 are calculated as shown in Table 2, and the deviation of each subsystem and the total system is small, and the subsystem error results are less than 0.12%, and the total system error is below 0.5%. The results pass the test and the calculation results can be used for the prediction and analysis of the economic toughness of the four major coal cities in Heilongjiang Province.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.284-304

Table 2. MAE (%) values and deviations of economic toughness for each system and total system

City	Jixi City	Hegang City	Shuangyashan City	Qitaihe City
Income and Expenditure Capacity System	2	2	0.02	80
Deviation	124	102	4	7
Innovation Environment System	2	4	0.07	8
Deviation	0.02	0.02	0.05	1
Development Dynamics System	1	3	0.03	4
Deviation	6	5	403	8
Stability System	1	12	4	182
Deviation	0.01	90	2	0.01
Diversity System	9	90	1	5
Deviation	0.1	0.01	0.04	1
Open System	7	0.02	1	0.01
Deviation	0.07	0.03	17	0.03
Total System	9	0.12	0.12	0.05
Degree of deviation	0.11	0.0004	2	143

In general, the four major coal cities 2018-2022 city economic resilience index Jixi and Qitaihe cities generally show a decreasing trend, and Hegang and Shuangyashan cities generally increase, but to a small extent. From the mean value of the change in economic resilience index of the four cities from 2018-2022, the mean value of Jixi city is the largest at 0.513, followed by Hegang city with a mean economic resilience index of 0.397, Shuangyashan city is the third at 0.134, and the smallest mean economic resilience index is Qitaihe city at 0.395.

Overall the average value of economic toughness of the four cities from 2018-2022 is presented as Jixi City > Hegang City > Shuangyashan City > Qitaihe City. It can be seen that the economic toughness level of the four major coal cities in the next five years Jixi City is still in the highest position, Qitaihe City has the lowest economic toughness level, Hegang City and Shuangyashan City will be in the middle level of economic toughness 0. From the fluctuation of the dynamic simulation of the four major coal cities' economic toughness index in 2018-2022, Qitaihe City has the largest decline in the next five years and is more volatile in each year, 2019 the predicted value is 0.325 in 2019 and 0.319 in 2022, a decline of 0.007. Jixi City declines only after Qitaihe City, and the economic toughness value will decline by

https://doi.org/10.17993/3ctecno.2023.v12n2e44.284-304

0.005 in the next five years. this paper simulates and verifies the household population and gross product of the four major resource cities as shown in Figures 5 and 6. From the simulation results, the simulated data and the real data have a high degree of consistency and meet the extrapolation requirements.

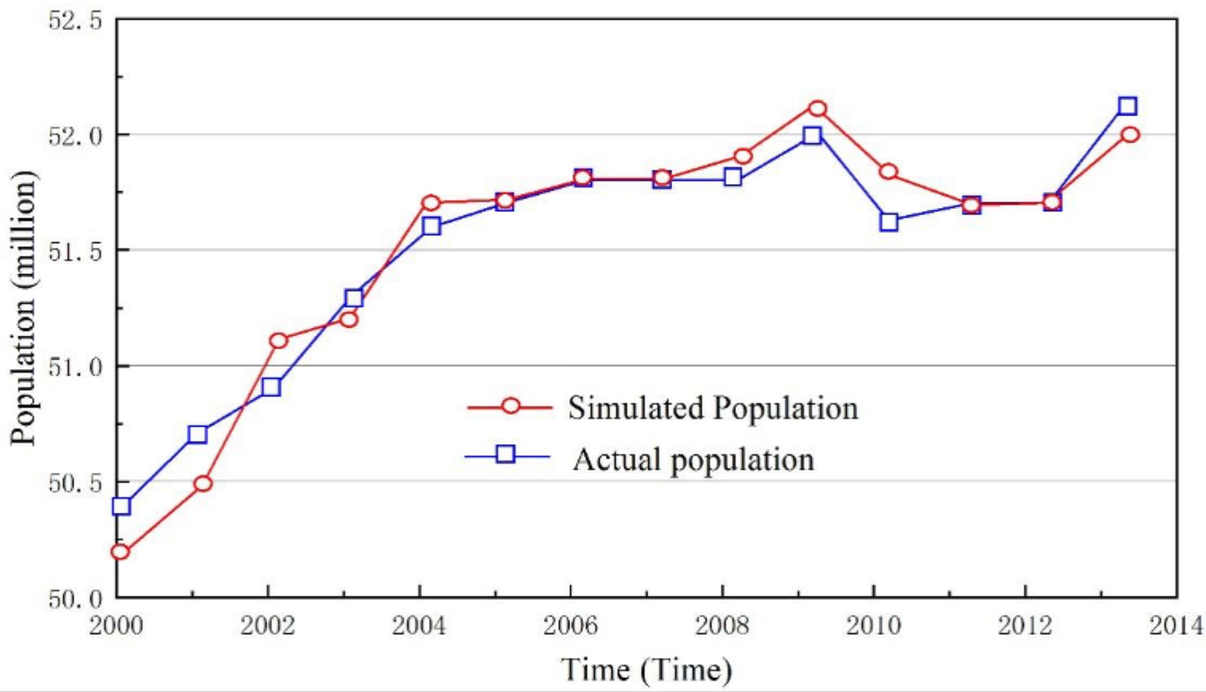


Figure 5. Simulated and actual values of household population, 2000-2013

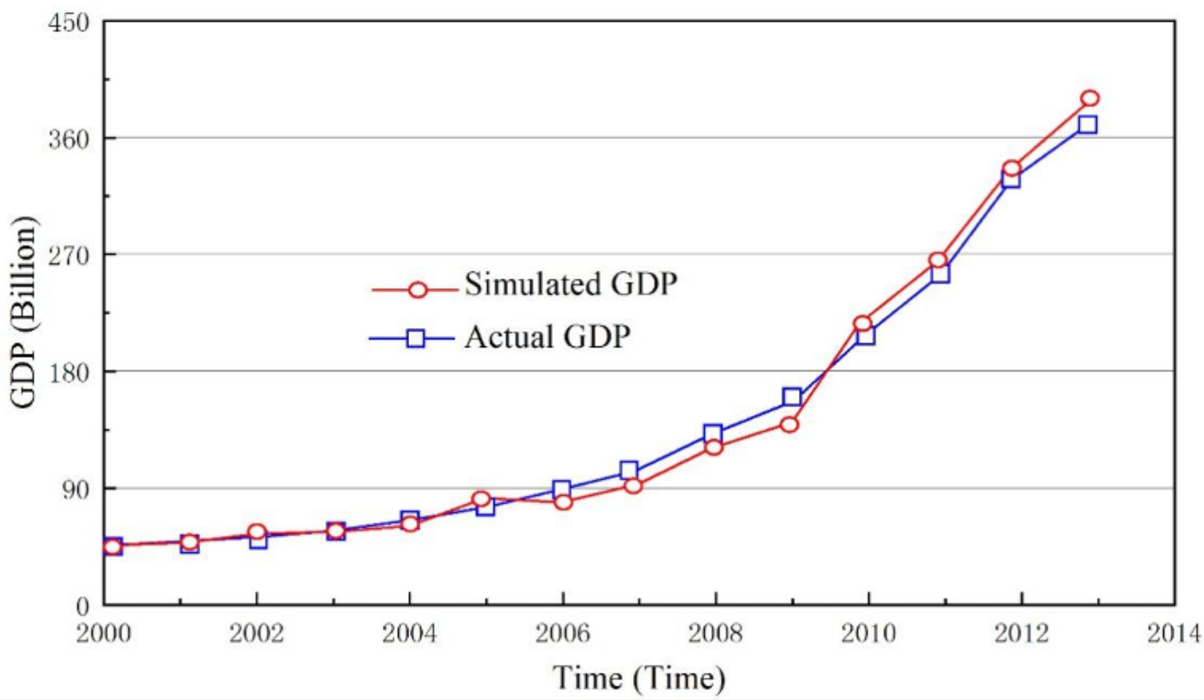


Figure 6. Simulated and Actual GDP for Resource Cities, 2000-2013

The economic resilience values of Hegang City and Shuangyashan City have increased, but the magnitude is small, and the overall Hegang City will only increase

https://doi.org/10.17993/3ctecno.2023.v12n2e44.284-304

by 0.001, and the overall ups and downs in each year are not significant. Overall, the economic resilience of Jixi is still stronger than the other three cities in the next five years, but the development of various subsystems in Jixi is not coordinated, and the level of economic resilience decreases. The economic resilience value of Qitaihe is still the smallest among the four cities, and the economic resilience level also continues to decline. There is no significant change in Hegang and Qitaihe, which shows that the macro-control role and policy initiatives of the governments of the four cities are not significantly effective in the next five years. The depletion of resources, single economic structure, difficulties in industrial transformation, and large population outflow are still the shortcomings of the four cities' development.

3.2. COMPARATIVE ANALYSIS OF DYNAMIC SIMULATION RESULTS OF ECONOMIC RESILIENCE OF RESOURCE CITY SUBSYSTEMS

Table 3 shows the dynamic simulation comparison analysis of the six system economic resilience indices of the four major resource coal cities from 2019-2023. it can be seen that the overall trend of the four cities' income and expenditure capacity systems in the next five years shows both fluctuating upward and fluctuating downward trends. The average value of economic resilience of the revenue and expenditure capacity system is Jixi > Shuangyashan > Qitaihe > Hegang. It means that compared with the other three cities Jixi city has a better development level of economic toughness of income and expenditure capacity system. Overall, the degree of economic resilience of the income and expenditure capacity system in Jixi and Shuangyashan is better than in the other two cities in the future, but the level of income and expenditure capacity in Jixi and Hegang decreases in the next five years, and the level of their own income and expenditure capacity in Shuangyashan and Qitaihe improves.

Table 3. Comparison of dynamic simulations of economic resilience indices for the six systems

City	Income and Expenditure Capacity System	Innovation Environment System	Development Vitality System	Stability System	Diversity System	Openness System
Jixi	198	163	156	453	414	205
Hegang	106	203	136	143	142	263
Shuangyashan	192	263	264	264	113	165
Qitaihe	536	135	193	263	419	231
Average value	192	169	179	96	429	189

https://doi.org/10.17993/3ctecno.2023.v12n2e44.284-304

The mean value of economic resilience of the development vitality system is 0.096 in Jixi and 0.053 in Hegang, with the highest value and the lowest value in Shuangyashan. The overall mean value is Jixi City > Shuangyashan City > Qitaihe City > Hegang City. Overall, the economic resilience of the development vitality system in Jixi and Shuangyashan is high in the next five years, but the level of development vitality decreases. Hegang and Qitaihe are relatively low, but the development vitality level will have a good development trend in the next five years.

Both Jixi City and Shuangyashan City increased by 0.003, and Qitaihe City increased by a smaller amount. In terms of the mean value of economic resilience of the open system, it shows Jixi City> Hegang City> Qitaihe City> Shuangyashan City. In general, the economic toughness of the open system in Jixi and Hegang is higher in the next five years, but the level of the open system in Hegang is weakened.

4. CONCLUSION

In response to the problems of sustainable development and low and unreasonable industrial structure faced by resource-based cities. This paper combines the principles of data envelopment analysis (DEA) and industrial layout optimization to evaluate and position the current industrial structure of resource cities. The comprehensive economic resilience system of the city is divided into six systems: city economic revenue and expenditure capacity, innovation environment, development vitality, stability, diversity, and openness. This paper proposes effective countermeasures for the development planning and industrial development of resource cities. At the same time, it provides a good reference for the industrial restructuring and sustainable development of a large number of other domestic cities with dependent resources, and the specific conclusions are recognized as follows:

1. In terms of the average weights of the overall economic resilience subsystems of the four major coal cities, the main factors affecting economic resilience are the revenue and expenditure capacity, development vitality, and innovation environment systems. The diversity system has the least degree of influence. In terms of the weights of the influencing factors in the four cities, the main factors affecting Jixi city are openness, revenue and expenditure capacity, and stability system: Hegang city is mainly influenced by the stability system, innovation capacity system, and openness system. Shuangyashan City is influenced by a development vitality system, innovation environment system, and income and expenditure capacity system. The main factors affecting the economic resilience of Qitaihe City are income and expenditure capacity, openness, and development vitality system.

2. In terms of the weights of the influence factors of each system layer of the city, the income and expenditure capacity system mainly affects Qitaihe City, and the innovation environment system and the development vitality system affect Shuangyashan City. The stability system of Hegang is most influenced by it,

https://doi.org/10.17993/3ctecno.2023.v12n2e44.284-304

and both the diversity system and the openness system are most influenced by Jixi city.

REFERENCES

(1) Yu, X., Shan, L., & Wu, Y. (2021). Land Use Optimization in a Resource-Exhausted City Based on Simulation of the F-E-W Nexus. Land, 10.

(2) Li, J. (2020). Resource optimization scheduling and allocation for hierarchical distributed cloud service system in smart city. Future generation computer systems, 107(Jun.), 247-256.

(3) Pardo-Garcia, N., Simoes, S. G., Dias, L., et al. (2019). Sustainable and Resource Efficient Cities Platform – SureCity holistic simulation and optimization for smart cities. Journal of Cleaner Production, 215(APR.1), 701-711.

(4) Shu, M., Wu, S., Wu, T., et al. (2020). Efficient energy consumption system using heuristic renewable demand energy optimization in smart city. Computational Intelligence.

(5) Xia, Q. (2019). Research on the Eco-environment and Industrial Structure Optimization of Coal Resource City. China Ancient City.

(6) You, G., Pan, Q. (2011). Probe into Lupanshui City Frame Adjustment and Optimization of Coal Resource Exploitation and Utilization. Coal Geology of China.

(7) Li, S., Zhao, Y., Xiao, W., et al. (2021). Optimizing ecological security pattern in the coal resource-based city: A case study in Shuozhou City, China. Ecological Indicators, 130, 108026.

(8) Oldenhuizing, J., Kraker, J. D., Valkering, P. (2013). Design of a Quality-of-Life monitor to promote learning in a multi-actor network for sustainable urban development. Journal of Cleaner Production, 49(jun.), 74-84.

(9) Santos, T. M., Zaratan, M. L. (2017). Mineral resources accounting a technique for monitoring the Philippine mining industry for sustainable development. Journal of Asian Earth Science, 12(5), 142-158.

(10) David, P., & G. Wright. (2019). Increasing returns and the genesis of American resource abundance. Industrial and Corporate Change, 6, 203-245.

(11) Kaleka, A. (2012). Resources and capabilities driving competitive advantage in export markets: Guidelines for industrial exporters. Industrial Marketing Management, 31, 273-283.

(12) Grander, J. A., & Scott, M. (2018). The Simple Economics of Easter Island: A Ricardo Malthus Model of Renewable Resource Use. The American Economic Review, 88, 119-138.

(13) Carlaw, K. I., & Lipsey, R. G. (2012). Externalities, technological complementarities and sustained economic growth. Research Policy, 31, 1305-1315.

(14) Martin, R. (2018). Regional Economic Resilience, Hysteresis and Recessionary Shocks. Journal of Economic Geography, 12(1), 1-32.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.284-304

(15) Zhong, Y., Ruan, G., Abozinadah, E., & Jiang, J. (2021). Least-squares method and deep learning in the identification and analysis of name-plates of power equipment. Applied Mathematics and Nonlinear Sciences.

(16) Martin, R. (2018). Regional economic resilience, hysteresis and recessionary shocks. Journal of Economic Geography, 12(12), 1-32.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.284-304

/18/

THE IMPACT OF LOW-CARBON EMISSION POLICIES ON RURAL SOCIAL GOVERNANCE UNDER THE CONCEPT OF GREEN LIFE

Jingjing Shan*

College of Finance and Taxation, Jiangsu College of Finance & Accounting, Lianyungang, Jiangsu, 222061, China.

cadybao@163.com

Reception: 30/04/2023 **Acceptance**: 23/06/2023 **Publication**: 18/07/2023

Suggested citation:

Shan, J. (2023). **The impact of low-carbon emission policies on rural social governance under the concept of green life**. *3C Tecnología. Glosas de innovación aplicada a la pyme, 12(2)*, 306-329. https://doi.org/10.17993/3ctecno.2023.v12n2e44.306-329

https://doi.org/10.17993/3ctecno.2023.v12n2e44.306-329

ABSTRACT

As one of the important contents of the new development concept, the green development concept is an important guideline for the national development strategy. To promote social and economic stability in rural areas, realize low-carbon development in rural areas, and build a harmonious society between society and ecology. Based on the concept of green life, through SWOT analysis to explore the advantages and disadvantages of rural social governance, from the four aspects of economic development, social development, carbon emissions, and ecological environment, to construct an evaluation system for the impact of low-carbon emission policies on rural social governance. The hierarchical progressive relationship between the indicators, the weight of each indicator is calculated by the analytic hierarchy process, and the comprehensive evaluation value of the social governance effect of the research target in the past five years and the evaluation value of the secondary indicators are obtained. The obtained evaluation results show that the comprehensive evaluation value and the positive index values have increased by 0.056, 0.032, 0.0039, and 0.043, respectively, while the negative index value of the study area has decreased by 0.32. Development, carbon emissions, and the ecological environment have a greater positive promotion and positive impact.

KEYWORDS

Green life concept; Low carbon emission policy; Rural social governance; SWOT analysis; Analytic hierarchy process

INDEX

https://doi.org/10.17993/3ctecno.2023.v12n2e44.306-329

1. INTRODUCTION

Climate change is a common challenge faced by human society in the 21st century, and every country has an inescapable responsibility for controlling carbon dioxide emissions [1-2]. As a result, policies such as mandatory carbon emissions, carbon taxes, carbon trading, and carbon offsets have emerged and become the main measures to control carbon dioxide emissions [3-6]. The purpose of a low-carbon emission policy is that the construction and development of the social and economic system can achieve low-carbon emissions [7-8]. Low carbon emissions can be defined in different ways. One is to realize the common vision of human society, that is, to achieve the emission level under the global low-temperature target. Greenhouse gas emissions to achieve lower greenhouse gas emissions pathways [9-10]. The concept of low-carbon emissions proposed in the world refers to achieving lower greenhouse gas emissions at a certain time [11].

The low-carbon emission policy of the agricultural society is to avoid the use of pesticides, fertilizers, etc. to offset the emissions of livestock enteric fermentation, rice fields, biomass burning, and manure treatment, and reduce greenhouse gas emissions; characteristics of energy flow to avoid nitrous oxide and biogas emissions in cultivated or dry peatlands [12-15].

Rural social governance under the concept of green life is an innovative model, and its basic characteristics are overall development, interaction and high efficiency between industries, and comfortable and harmonious development of the social environment, to promote the sustainable development of rural society [16-19]. Its core is not to sacrifice agriculture and food, not to damage the ecology and the environment [20]. Taking farmers' interests as the starting point, realizing the integration of infrastructure and equalization of public services, promoting the steady development of rural society and economy, realizing a well-off life, and building a harmonious society [21-25].

Since the reform and opening up, the exploration of rural social governance has gradually attracted the attention of scholars at home and abroad. Reference [26] conducted in-depth semi-structured interviews with farmers, village cadres, and town managers, taking Sandu town in eastern China as an example. Then, a conceptual framework of integrated factors is proposed to analyze the driving factors and mechanisms of farmers' participation in rural MSW management. The results show that farmers' participation in environmental action is a response to an integrated network of internal and external factors. The inertia of life, the loss of personal interests, and objective conditions are obstacles to the peasants' decision to participate. And found that environmental awareness can improve farmers' internal motivation. The literature [27] guided by the five pillars of eco-design theory and economic development, using a circular urban approach, outlines the concept of urban planning and architectural flagship projects that highlight the image, culture, and heritage of communities, as well as strategies to improve markets. Through decentralized governance and reimagined priorities, Batibo has the opportunity to be

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.306-329

a prototype and a model for a quality future for sustainable rural development in Cameroon. Literature [28] reviewed and synthesized extensive spatial studies of oligotrophic mountain streams in rural southern Appalachian Mountains and concluded that, despite higher forest retention rates, rural land-use activity is driven by altered and predominantly enhanced landscapes - Stream connections significantly reduce water quality. Rural water quality problems can be greatly alleviated through well-known best management practices, which raises the question of socio-ecological governance using best management practices. Reference [29] uses a key multi-level, multi-scale management model to illustrate the entire process. The author's project role involves developing local community management skills while protecting social welfare and environmental health. And process results are analyzed to facilitate local and larger regional impact. Transformative environmental governance solutions actively address potential challenges while fully recognizing feasible thresholds of vulnerability conditions, thereby promoting more comprehensive social engagement and local empowerment. Reference [30] uses the multi-model comparison and regression optimization techniques of spatiotemporal analysis of rural civil bulk coal governance consumption to analyze provincial panel data and examines the time effect and spatial spillover effect of consumption to solve governance problems. The results show that the governance of rural credit cooperatives should adhere to the principle of inter-provincial coordination, determine the governance policy based on the conditions within the province, establish a subsidy mechanism, use resource competition to guide the changes in rural credit cooperatives and coordinate with urbanization. In short, scholars have paid more and more attention to the governance of rural society, and their research has yielded fruitful results. However, the governance of rural society should not only be realized through the above aspects, but requires every villager to be aware of their responsibilities and obligations to nature, reflect on the existing way of life, implement it based on action, and choose a green way of life to promote the harmonious development of human and nature.

The proposal of the concept of green life indicates that we will pay more attention to the issue of green life, adhere to the guidance of the concept of green, and implement it in all aspects of social life. Therefore, according to the SWOT status analysis results of rural social governance under the concept of green life, this paper constructs an evaluation model for the impact of low-carbon emission policies on rural social governance. The impact of emission policies on rural social governance, to actively comply with the realistic trend of rural social governance under the concept of green life, improve and innovate rural social governance methods, strengthen rural residents' green and low-carbon awareness, and upgrade the original single governance of rural society to the level of low-carbon social governance, and constantly improve the rural social governance system.

2. SWOT ANALYSIS OF RURAL SOCIAL GOVERNANCE BASED ON THE CONCEPT OF GREEN LIFE

Table 1. SWOT analysis of rural social governance under the concept of green life

https://doi.org/10.17993/3ctecno.2023.v12n2e44.306-329

Analytical Metrics	Analysis results
Advantage	Economic foundation with low carbon development
	A wide range of low carbon forms and technologies exist
	Energy-saving and emission reduction have relative cost advantages
	Carbon sinks and biomass resources are abundant
Disadvantage	Decentralized operation hinders the promotion of low-carbon technologies
	Lock-in effect of "high carbon" development
	The construction of agricultural and rural environmental protection systems is blank
	Poor quality of agricultural workers
	Lack of funds for low-carbon agricultural development
Opportunities	Politically attached great importance to
	The initial establishment of an international carbon trading market
	The world energy crisis calls for the development of low carbon
	The academic research boom has promoted low carbonization
Threats	The overall technology research and development capacity is limited
	Food security has a major impact
	International pressure to reduce emissions
	An international emission reduction sharing mechanism has not yet been formed

The SWOT analysis method was first proposed by a management professor at the University of San Francisco in the early 1980s. Although some people have mentioned internal strengths and weaknesses, external opportunities and threats, these changing factors, are the contribution of the SWOT method. It lies in the creative use of systems thinking to comprehensively analyze these factors [31]. The so-called SWOT analysis method is to list various main internal strengths and weaknesses, external opportunities, and threats closely related to the research object through investigation and then uses the idea of systematic analysis to match various factors to analyze, this leads to a series of corresponding strategies [32]. It was originally intended to provide a scientific basis for corporate strategic decisions, but due to its simplicity and clarity, the analysis method has been widely used in related research in other fields in recent years [33]. As an important part of developing low-carbon rural areas and the concept of green life, rural social governance under low-carbon emission policies provides an opportunity for rural areas to achieve leapfrog development [34]. Through SWOT analysis, we can clarify the advantages and disadvantages of rural social governance, grasp external opportunities, and actively prevent possible threats and risks, which is conducive to clarifying the strategic direction of rural social governance and formulating scientific, reasonable, and

https://doi.org/10.17993/3ctecno.2023.v12n2e44.306-329

effective governance countermeasures. Taking a rural area as the research target, the SWOT analysis results from the concept of green life are shown in Table 1.

2.1. ADVANTAGES

1. Economic foundation for low-carbon development: the implementation of relevant policies has led to the continuous increase of farmers' income, the steady increase of agricultural comprehensive productivity, the continuous optimization of agricultural internal structure and planting structure, and the continuous improvement of policy support and scientific and technological innovation system. Carbon countryside provides a certain economic foundation.

2. Extensive low-carbon forms and technologies: for the study area, low-carbon agricultural forms and technologies already exist. The main modes are conservation-oriented agriculture; high-efficiency agriculture; pollution-free agriculture; recycling mode of planting and breeding waste; rural clean energy; tourism and leisure agriculture.

3. Energy conservation and emission reduction have relative cost advantages: affected by economic conditions, the low level of investment in productive fixed assets in rural households limits the use of advanced technology and efficient agricultural equipment and aggravates the current situation of high energy consumption and low energy efficiency in rural production and life. This status quo means that its energy utilization has a large room for improvement, the cost of energy conservation and emission reduction is relatively low, and the implementation of low-carbon emission policies and the construction of low-carbon rural areas have certain relative cost advantages.

4. Carbon sinks and biomass resources are abundant: reasonable production behaviors such as returning farmland to forests, afforestation, land erosion control, organic matter remediation, soil fertility restoration, improving feed technology, and improving the production efficiency of pastures in the research area are conducive to the absorption, fixation, and transfer of carbon dioxide, and play a role in "reducing sources and increasing sinks" for agricultural and rural carbon emissions.

2.2. DISADVANTAGES

1. Decentralized operation hinders the promotion of low-carbon emission policies: the decentralized farmers' production and business model is the main reason for the lack of investment in agricultural production in China and the lack of stamina for rural economic development. By 2020, only 46.13% of farmers will participate in industrial operations, and the proportion of dairy cattle and pig breeding will only be 16.47% and 28.43%, which will seriously restrict the development of a low-carbon agricultural society.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.306-329

2. Lock-in effect of "high-carbon" development mode: the natural development of rural society makes the development cognitive lock-in effect obvious, and the acceptance period of new technologies and new ideas in rural areas is long.

3. Environmental protection system construction gap: there is no special rural environmental protection law, although some laws and regulations are involved in low-carbon rural social governance, the operability is poor, the applicability is not strong, and detailed management regulations and environmental protection infrastructure construction are even fewer, and there are only 3 or 5 centralized rural sewage treatment stations and garbage treatment stations.

4. Low quality of agricultural practitioners: the development of agricultural mechanization has released a large number of the rural labor force, and the transfer of rural surplus labor has caused problems such as rural hollowing, agricultural concurrent employment, women's aging, and aging. Among the agricultural technicians in this region, 56.49% have only primary titles, and only 3.8% have a high school or above.

5. Lack of funds for low-carbon agricultural development: in recent years, the proportion of fiscal support to agriculture in total fiscal expenditure has only increased from 6.49% to 10.24%. Under the influence of factors that tend to profit, the idle funds in the vast rural areas have flowed to urban areas with high returns, and farmers' passive investment in agricultural production and financial support for agriculture is limited, resulting in a lack of funds for agricultural development.

2.3. OPPORTUNITIES

1. High attention at the political level: the affirmation of the green role of agriculture by some international organizations has strengthened the emphasis on the implementation of low-carbon emission policies at the rural political level. In the technology and planning for strengthening energy conservation and emission reduction in agriculture and rural areas, it is required that the penetration rate of biogas suitable for farmers and the comprehensive utilization rate of crop stalks should reach 55% and 85% respectively.

2. Preliminary establishment of carbon trading market: the natural carbon sink effect of the agricultural system can offset part of carbon emissions and promote the smooth transition of rural society. In addition, carbon trading will bring more projects to provide technical and financial support for the implementation of low-carbon emission policies.

3. The energy crisis requires the implementation of low-carbon emission policies: agriculture is the only field that produces biomass. Therefore, developing low-carbon emission policies, especially improving the comprehensive utilization

https://doi.org/10.17993/3ctecno.2023.v12n2e44.306-329

rate of rural biomass resources, can alleviate the energy crisis to a certain extent.

4. The academic research boom promotes the development of low-carbon emissions: the establishment of various research institutions and the conduct of seminars are not only conducive to the implementation of rural low-carbon emissions policies but also provide conditions for active participation and introduction of international low-carbon cooperation projects. Corresponding technical and financial support was provided for rural social governance.

2.4. THREATS

1. The overall technology research and development capacity is limited: actions to address climate change will make human society step into a low-carbon society after experiencing an agricultural society, an industrial society, and an information society, and a series of technological innovation activities will also be carried out. The policy will become an important part of comprehensive national strength.

2. The impact of food security is significant: the population pressure in the study area is high and the contradiction between man and land is serious. The traditional concept of food security encourages the development of chemical agriculture to a certain extent and hinders the development of low-carbon agriculture.

3. Great pressure on emission reduction: this region is at the end of the industrial chain in the division of labor system, and the heavy industry using energy as raw materials accounts for a high proportion of the economy. The implementation of low-carbon emission policies will also limit the development of related high-emission industries and restrict the development of the local economy.

4. The emission reduction sharing mechanism has not yet been formed: greenhouse gas emissions are bounded, but the impact of emissions is not bounded. Emission reduction commitments are directly related to their interests, which makes it difficult to form emission reduction opinions.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.306-329

3. THE IMPACT EVALUATION SYSTEM OF LOW-CARBON EMISSION POLICIES ON RURAL SOCIAL GOVERNANCE

3.1. THE FRAMEWORK OF THE EVALUATION INDEX SYSTEM

Table 2 shows the comprehensive evaluation system framework for the impact of low-carbon emission policies on rural social governance.

The specific description of the three-level indicators is as follows:

1. Gross output value of agriculture, forestry, animal husbandry, and fishery: this indicator reflects the total scale and total results of agricultural production within a certain period.

2. The proportion of GDP of the primary industry to the total GDP (%): the ratio of agricultural output value to the three major industries, we can clearly understand the development of agriculture.

3. Farmers' per capita net income (yuan/person): this indicator refers to the annual per capita income of farmers in rural areas. The increase in income increases farmers' low-carbon awareness.

4. Agricultural mechanization level: this indicator is obtained by dividing the total power of rural machinery by the sown area of crops. It is the use of mechanical equipment to replace the labor of farmers, improve planting speed and efficiency, and bring higher economic benefits.

5. Agricultural product production price index: this index shows the price changes of production factors in agricultural production, and prices generally rise with time, so this index can reflect the impact of market price changes on low-carbon agriculture.

6. Agricultural commodity retail price index: this indicator shows the changes in the value of agricultural products and indirectly reflects the planting volume of agricultural products.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.306-329

Table 2. Evaluation index system

First-level indicator	Secondary indicators	Three-level indicator
A comprehensive evaluation of the impact of low carbon emission policies on rural social governance	Rural economic development	The gross output value of agriculture, forestry, animal husbandry and fishery
		The ratio of primary industry GDP to total GDP
		Average net income of rural residents
		Total power of agricultural machinery
		Producer Price Index of Agricultural Products
		Agricultural Commodity Retail Price Index
	Rural social development	Rural population
		The sown area of crops
		Engel's coefficient of rural residents
		The consumption level of rural residents
		Fiscal expenditure on agriculture, forestry and water affairs
		Rural electricity consumption
	Agricultural carbon emissions	Crop farming
		Forestry
		Animal husbandry
		Fishery
	Rural ecological environment	Forest cover rate
		Effective irrigation rate of farmland
		Local government environmental protection expenses
		Rural toilet penetration rate
		Total agricultural water use
		The number of harmless treatment plants

7. Rural population: this indicator refers to the number of permanent residents in the number of rural households. This indicator is mainly based on the household registration statistics of the public security department.

8. Sown area of crops: this indicator refers to the area of crops that are sown or transplanted each year. Crops that can be planted after restoration after a disaster are also included in this indicator.

9. Rural Engel's coefficient (%): this indicator refers to the proportion of farmers' food expenditure in the total consumption expenditure in that year.

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.306-329

10. Consumption level of rural residents (yuan/person): this indicator can reflect the level of rural social development. The higher the level of development, the more low-carbon awareness, and low-carbon investment will be.

11. Fiscal expenditure on agriculture, forestry, and water affairs: to have international competitiveness for agriculture, depends to a large extent on the government's financial support for agriculture.

12. Rural electricity consumption: this indicator refers to the total electricity consumption of all enterprises, institutions, administrative units, and households in rural areas engaged in production and business activities, work, and daily life within the year, which plays an important role in rural social development.

13. Agricultural carbon emission: the carbon emission of the planting industry is mainly the input of agricultural production activities, including agricultural chemical fertilizers, pesticides, agricultural film, agricultural machinery, and diesel consumption. industry carbon emissions, etc.

14. Forestry carbon emission: this indicator specifically includes the carbon sequestration effect of forest land, shrub forest, sparse forest land, unforested afforestation land, slashed land, and nursery; carbon sequestration.

15. Animal husbandry carbon emissions: this indicator mainly selects the year-end slaughtering numbers of rural pigs, cattle, sheep, and poultry as the inspection indicators to represent the carbon emissions of animal husbandry.

16. Fishery carbon emissions: this indicator mainly includes carbon emissions from the use of fish farming materials, fishing boats, and measuring instruments.

17. Forest coverage rate (%): this indicator refers to the percentage of forest area in the total land area.

18. Effective irrigation coefficient of farmland (%): this indicator is calculated by calculating the ratio of the effective irrigation area of farmland to the total sown area.

19. Local government environmental protection expenses: this indicator refers to the expenses that the government takes on units and individuals that pollute, damage, and erode the environment to maintain, control, and protect the natural environment of human society.

20. Rural toilet penetration rate (%): refers to the ratio of the number of farmers using sanitary toilets to the total number of farmers, which plays an important role in improving the rural ecological environment.

21. Agricultural water consumption: this indicator refers to the total amount of water used for irrigation and livestock drinking in rural areas.

22. Number of harmless treatment plants: the number of treatment plants that can make waste no longer pollute the environment and can be used, and turn waste into treasure, will play a good role in the treatment of agricultural waste.

3.2. AHP EMPOWERMENT

Based on the hierarchical progressive relationship between the indicators in the index system and the principle of determining the weight of the indicators according to the AHP method, the weights of the evaluation indicators of each layer in the target object are calculated [35]. The calculation process of index weights at each level is generally divided into the following five basic steps:

1. Build a progressive hierarchical structure model: by sorting out the previous research results, the evaluation index system of the rural social governance effect under the low-carbon emission policy is divided into three layers: A target layer, B criterion layer, and C indicator layer. There is an affiliation relationship between each evaluation index layer.

2. Constructing a pairwise judgment matrix: first, compare the judgment matrix of the evaluation indicators in each level concerning each index in the previous level, and for the indicators of the same level, according to the 1-9 scaling method. By comparing them in pairs, the relative attribute measurement value of the evaluation of rural social governance effects can be obtained [36]. As shown in the following formula:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \quad (1)$$

The comparison matrix $A, A = \{a_{ij}\}$ can be obtained according to the relative attribute measurement value of the index. The conditions that the matrix A should meet are:

$$a_{ij} > 0, a_{ij} = \frac{1}{a_{ji}}, a_{ij} = 1 \quad (2)$$

3. Calculation of weights: calculate the product of each row in the judgment matrix A:

$$M_i = \prod_{j=1}^{n} a_{ij}, i = 1,2,\cdots,n \quad (3)$$

Compute the n-root $\overline{W_i}$ of M_i:

$$\bar{W}_i = \sqrt[n]{M_i}, i = 1,2,\cdots,n \quad (4)$$

https://doi.org/10.17993/3ctecno.2023.v12n2e44.306-329

Where n is the order of the matrix.

Normalize vector group $\left(\overline{W_1}, \overline{W_2}, \cdots, \overline{W_n}\right)^T$:

$$W_i = \bar{W}_i / \sum_{i=1}^{n} \bar{W}_i \tag{5}$$

Then $W = \left(W_1, W_2, \cdots, W_n\right)^T$ is the eigenvector, that is, the weight of the rural social governance indicator under the low-carbon emission policy.

Compute the largest eigenvalue of the judgment matrix :

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^{n} \frac{(AW)_i}{W_i} \tag{6}$$

Through the formal expression and quantitative processing of subjective judgment, AHP can effectively eliminate human subjectivity and objectively describe and evaluate things. The objectivity of AHP evaluation results depends on whether the objective components of the evaluation object are sufficient and reasonable. Given the subjective consciousness of decision-makers and the complexity of the evaluation object itself, the consistency test of the judgment matrix has become a key link. The process is as follows:

4. Extract the consistency index of the judgment matrix:

$$CI = \frac{1}{n-1}\left(\lambda_{\max} - n\right) \tag{7}$$

Among them, $\lambda_{\max}$ is the largest eigenvalue, and n is the order of the matrix.

5. Calculate whether the fuzzy judgment matrices of different orders satisfy the consistency test by adding the average random consistency test index RI. To judge whether the corresponding matrix satisfies the consistency condition, this paper uses the consistency ratio CR to make the corresponding judgment [37].

$$CR = \frac{CI}{RI} \tag{8}$$

When the order of the judgment matrix is $n \geq 3$, if it is $CR < 0.1$, the judgment matrix passes the consistency test; otherwise, if it is $CR \geq 0.1$, the judgment matrix needs to be adjusted to reach $CR < 0.1$. If $CR = 0$, it is completely consistent.

4. RESULTS AND ANALYSIS

Combined with the weights of indicators at all levels, after implementing the low-carbon emission policy under the concept of green life, the comprehensive evaluation

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.306-329

value of the social governance effect of the research target in the past five years and the indicator values of rural economic development, social development, carbon emission, and ecological environment are calculated, such as Figure 1 and Figure 2.

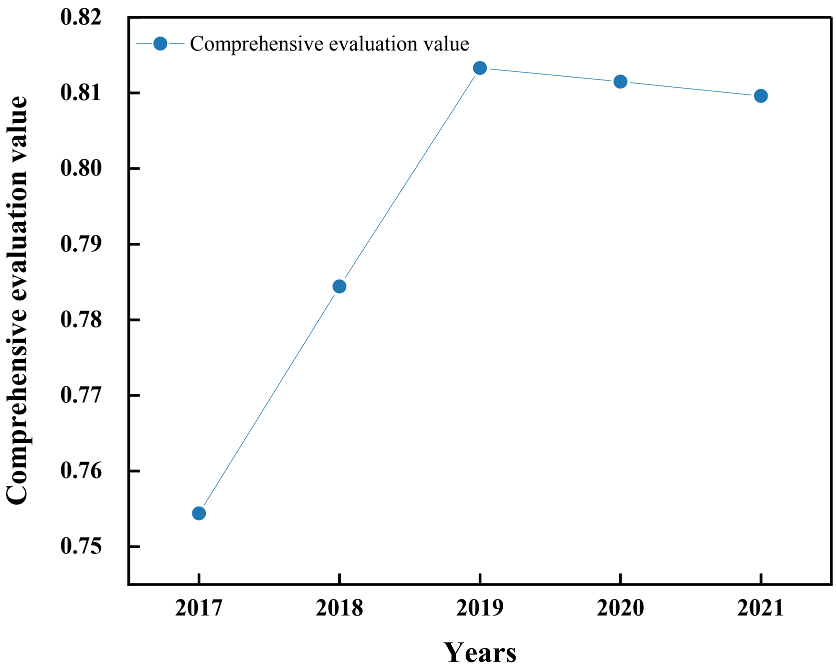


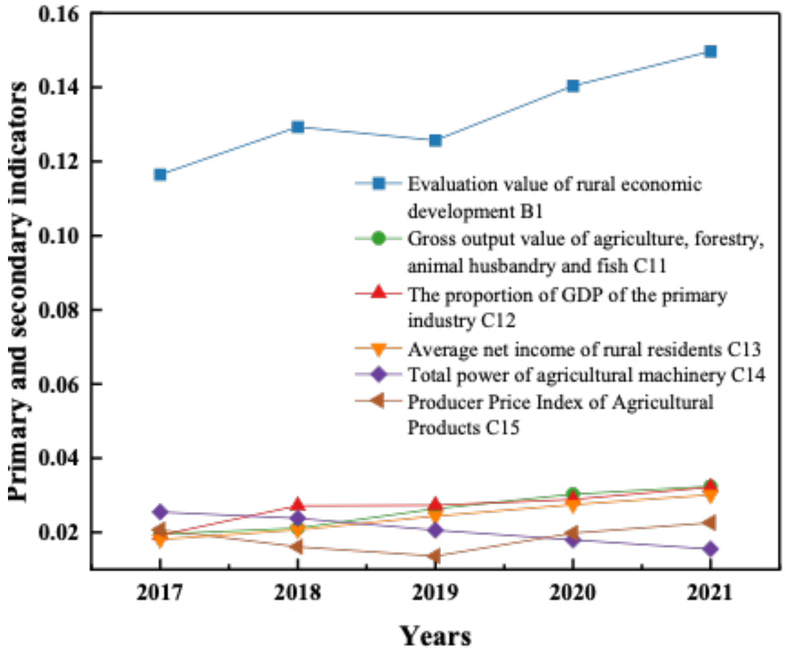
Figure 1. Schematic diagram of the comprehensive evaluation value of social governance effect

According to the comprehensive evaluation value of the rural social governance effect in the study area in Figure 1, it can be found that the evaluation value of the governance effect before 2019 has increased significantly, although the social governance level in the region has shown a downward trend after 2019, but the decline is small, that is to say, although the rural area in order to pursue high-standard economic development, agricultural investment is increasing, resulting in a small increase in carbon emissions, but after the implementation of the low carbon emission policy under the concept of green life, the rural area has adopted the treatment of returning farmland to forest, afforestation and land erosion reasonable production behaviors such as organic matter remediation, soil fertility remediation, improving feed technology, and improving the production efficiency of pastures are conducive to the absorption, fixation and transfer of carbon dioxide, and play a role in "reducing sources and increasing sinks" in agricultural and rural carbon emissions, so that the progress of social governance level effectively controls the degree of carbon emissions in agriculture to a certain extent, so the downward trend of comprehensive evaluation value after 2019 is insignificant compared with the upward trend.

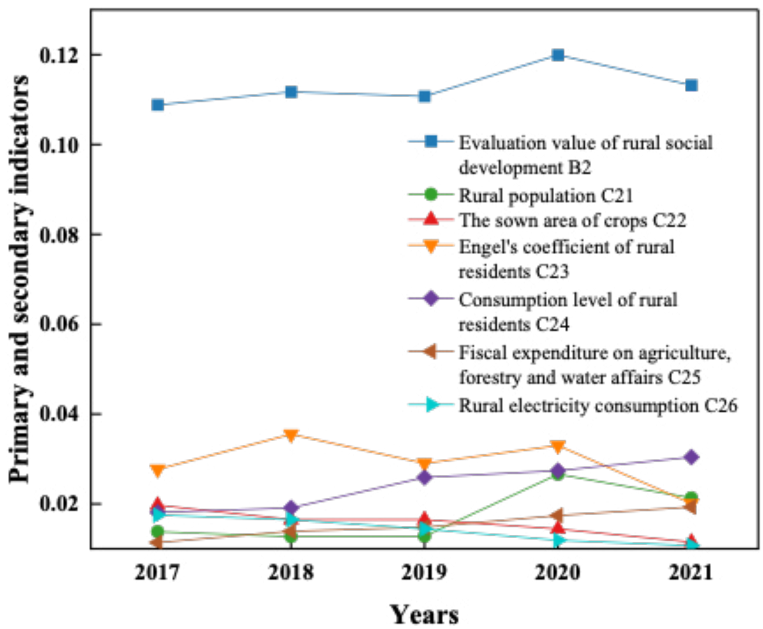
To specifically analyze the problems existing in social governance under the low-carbon emission policy, the evaluation values of social governance effects were calculated for each index of economic development, social development, carbon

https://doi.org/10.17993/3ctecno.2023.v12n2e44.306-329

emission, and ecological environment, respectively. In this way, the influencing factors of low-carbon emission policies on rural social governance can be obtained, so that the most effective governance suggestions can be put forward in the follow-up. The obtained evaluation index values are shown in Figure 2.

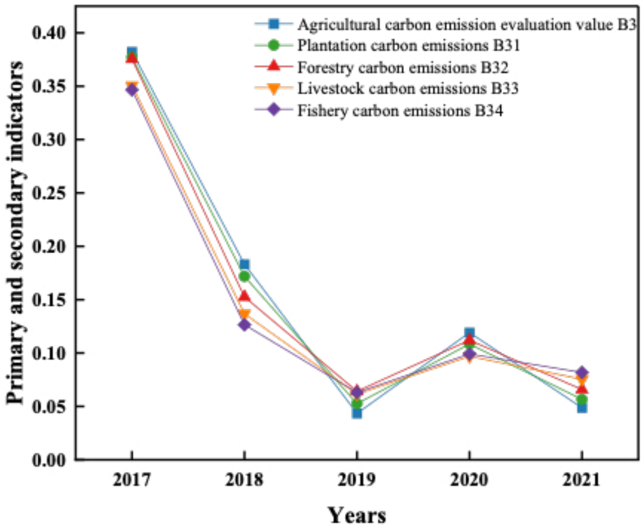


(a) rural economic development index value

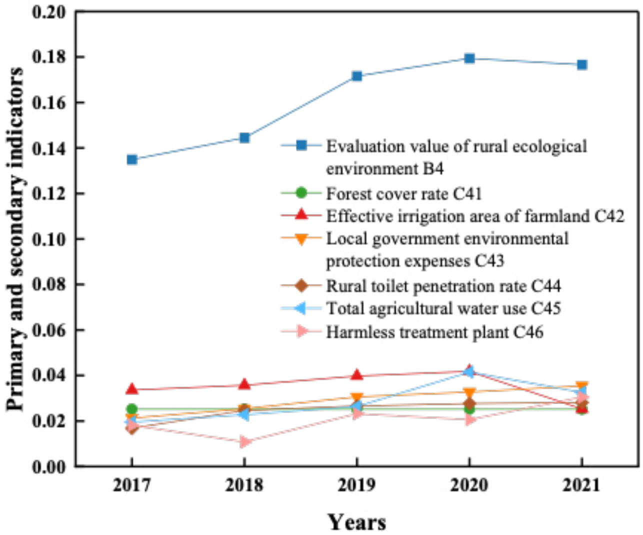


(b) rural social development index value

https://doi.org/10.17993/3ctecno.2023.v12n2e44.306-329



(c) agricultural carbon emission index value



(d) rural ecological environment index value

Figure 2. Evaluation of the effect of rural social governance under low-carbon emission policies

The calculation results of the rural economic development index values in Figure 2(a) show that in terms of economic development in this rural area, the secondary indicators have the highest evaluation values in 2021, mainly because the following three indicators have higher evaluation values: the total output value of agriculture, forestry, animal husbandry and fishery, the proportion of the GDP of the primary industry to the total GDP, and the average net income of rural residents. Among them, the total output value of agriculture, forestry, animal husbandry, and fishery in the countryside is the sum of the output value and the value of by-products. With the

https://doi.org/10.17993/3ctecno.2023.v12n2e44.306-329

vigorous implementation of the low carbon emission policy, with low-carbon concepts and technological transformation and innovation of rural production and lifestyle, through the adoption of increased publicity, the implementation of technological transformation, economic interest guidance and the establishment of supervision mechanisms and other corresponding measures to break the cognitive, technical lock-in effect, under the leadership's attention and macro-level policy support and other related political measures, change the political lock-in effect, improve the requirements of low-carbon rural areas, and promote the governance and development of a low-carbon society, The evaluation value of the total output value of agriculture, forestry, animal husbandry, and fishery has gradually increased from 0.02 in 2017 to 0.0358 in 2021. Although the primary industry in the research area occupies an important weight, the proportion of primary industry GDP to total GDP in 2021 is the highest, as high as 0.0358, which is mainly caused by the slow development of the secondary industry and the tertiary industry in the old industrial base in recent years, and the agricultural development is relatively normal in comparison. With the implementation of the low carbon emission policy, the average net income of the people is increasing, and in 2021 to reach a maximum of 0.0351, the economy continues to develop, and the investment in low-carbon environmental protection will increase, indirectly reducing agricultural carbon emissions, for the rural area is only a microcosm of the increase in national income. The rising trend of rural economic development evaluation values in the past five years shows that low carbon emission policies have a greater role in promoting rural social governance, and through simple technical treatment, the agricultural system returns some wastes and biological resources to agricultural production and life in the form of organic matter and energy. It not only reduces the waste of guanidine hydrochloride, improves soil organic matter, and increases the production of clean energy in rural areas, but also increases farmers' incomes from multiple channels and promotes the sustainable development of a low-carbon economy in agriculture and rural areas. The more developed the rural economy, the more it can drive the development of low-carbon emission policies, and the higher the requirements for rural social governance. The economic development index continued to rise after it was at a low level of development. On the whole, the agricultural economic development index of the study area continued to rise, which was the most favorable factor to promote the level of social governance in the countryside.

Figure 2(b) shows the calculation result of the social development index value of the village. It can be seen that in terms of social development, the evaluation value moves forward in a wave-like manner with the advancement of the low-carbon emission policy, and the evaluation value in 2020 is the highest at 0.121. This is mainly because all aspects of society are constantly developing, and rural society is keeping pace with the times and making continuous progress. Under the low-carbon emission policy, the quality of rural employees has gradually increased, the number of agricultural technicians has gradually increased, and the system of agricultural technology extension stations has been continuously upgraded, all of which have promoted rural social governance and economic development. The high quality of

https://doi.org/10.17993/3ctecno.2023.v12n2e44.306-329

relevant practitioners enables farmers to gradually form a low-carbon awareness, actively participate in low-carbon production and life, and further increase the depth and intensity of rural social governance. Due to the low carbon emission policy to expand the rural capital investment in related aspects, and under the general attention of the academic community, various research institutions have been established, various seminars have been held, and low-carbon cooperation projects have been carried out, which have provided relevant theoretical, technical and financial support for rural social governance, and increased the government's investment and attention to agriculture, forestry and water affairs, and finally, as a result, the consumption level of rural residents increased from 0.178 in 2017 to 0.031 in 2021, so that the evaluation value of the financial expenditure on agriculture, forestry, and water affairs also increased year by year. However, to obtain a higher level of the agricultural economy, the sown area of crops has increased year by year, resulting in a decrease in the evaluation value of the sown area of crops from 2017 to 2021, and agricultural carbon emissions will also increase every year. The evaluation value of rural electricity consumption is declining year by year. Although the low-carbon emission policy has a certain effect on the governance of rural society, social progress has also led to an increase in energy consumption, which increases electricity consumption and carbon emissions.

The calculation result of the agricultural carbon emission index value is shown in Figure 2(c). In terms of agricultural carbon emissions, the evaluation results of this village have different scores for small-scale agriculture. Due to the low carbon emission policy by emphasizing the non-excessive use of machinery, fertilizers, pesticides, and agricultural film, efforts to control carbon emissions in the planting and animal husbandry industries, effectively alleviate the high carbon emission situation, expand the forestry coverage, gradually enhance the carbon sequestration capacity, so that carbon emissions are relatively reduced, and the development of fisheries is encouraged under geographical restrictions, so that the evaluation value of agricultural carbon emission indicators has decreased year by year, and has decreased by 0.32 in the past five years.

Figure 2(d) shows the calculation results of the ecological environment index values in the study area. As can be seen from the trend of the curve in the figure, the ecological environment evaluation value of the rural area is generally increasing year by year, and it will decrease slightly in 2021, indicating that the ecological environment has been paid more and more attention, and the investment has also increased year by year, resulting in a decrease in carbon emissions and low carbon emissions. The level of governance of rural society by emission policies is getting higher and higher. From 2017 to 2021, the evaluation value of the rural ecological environment will first rise and then decline, and the evaluation value will be the largest in 2020. Since the study area is dominated by mountains, the forest coverage has not changed much in the past five years. The low-carbon emission policy enhances the drought resistance of farmland by requiring complete water conservancy facilities, so that it can maximize the use of land under the specified environment, resulting in a higher score for the

https://doi.org/10.17993/3ctecno.2023.v12n2e44.306-329

effective irrigation area of farmland. Various research institutions in academia have been established successively, various seminars have been held successively, and low-carbon cooperation projects have been carried out successively, which has provided good financial support for the increase of local financial environmental protection expenses, so that the trend of its evaluation value in the past five years has been consistent uptrend, rising from 0.0208 to 0.0362. The evaluation values of the two indicators of rural toilet penetration and total agricultural water use are increasing with the promotion of low carbon emission policies, indicating that the research area has turned the advantages of its development into actual economic advantages through the implementation of low-carbon emission policies, and continuously strengthened this positive cycle, to improve the self-development ability of the rural economic system, achieve the leapfrog development of low-carbon rural areas, and continuously improve the level of social governance in the countryside from the perspective of environmental protection. And under the condition of limited R&D capacity, by focusing on the research and development of selected technologies, from the perspective of national strategy, the research and development of low-carbon technologies, to improve the independent innovation capacity of core technologies, and making full use of the natural spillover effects of commercial technology trade and technology to continuously improve scientific research. Therefore, the construction of harmless treatment plants has increased, and the evaluation index value of the number of harmless treatment plants has shown a positive upward trend, reaching a maximum value of 0.0321 in 2021.

5. DISCUSSION

Rural areas are an important part of the economy and society. For a long time, due to the inclination of national policies at the macro level, the rural economy has been impoverished and weak, which has become an obstacle to the further development of the economy and society. Under the background of the concept of green life and low-carbon emission policies, it is of great significance to study how rural areas can get out of the "high-carbon" development dilemma, improve their self-development capabilities, and achieve leapfrog development. The downsides are:

1. Due to the insufficient collection of some data, the relevant data on rural social governance are not fully grasped.

2. The personal understanding of low-carbon emission policies is not deep enough, the research on rural areas is not enough, and the impact of low-carbon emission policies on rural social governance is not deep and comprehensive enough.

3. Due to limited capacity, there are many deficiencies in the understanding of rural social governance issues. The opinions and suggestions are not yet mature and need to be further expanded and supplemented in the next step.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.306-329

6. CONCLUSION

The concept of green life reveals the harmonious symbiosis between man and nature and points out a new path to realizing the coexistence of development and protection of ecology. Rural areas are the basic unit of society. Driven by low-carbon emission policies, rural society has begun to gradually transition to low-carbonization. Therefore, this paper takes the concept of green life as the core and uses SWOT analysis to clarify the advantages and disadvantages of rural social governance. The weight of the evaluation indicators at each level of the evaluation system for the impact of low-carbon emission policies on rural social governance is determined by the method, and through the comprehensive evaluation value of the social governance effect in the past five years and the development trend of the indicator values of rural economic development, social development, carbon emission, and ecological environment. The following conclusions are drawn:

1. By adopting reasonable production behaviors such as returning farmland to forests, afforestation, land erosion control, organic matter restoration, soil fertility restoration, improvement of feed technology, and improvement of pasture production efficiency, it is beneficial to the absorption, fixation, and transfer of carbon dioxide, which is beneficial to agricultural and rural areas. Carbon emissions play the role of "reducing sources and increasing sinks", strengthening the level of social governance to effectively control the degree of agricultural carbon emissions, and increasing the comprehensive evaluation value of rural social governance effects from 0.754 in 2017 to 0.81 in 2021.

2. Use low-carbon concepts and technologies to transform and innovate rural production and lifestyles, and break the cognitive and technical lock-in effects by taking corresponding measures such as increasing publicity, implementing technological transformation, guiding economic interests, establishing supervision mechanisms, etc. Under the leadership's attention and macro-level policy support and other relevant political measures, change the political lock-in effect, improve the low-carbon requirements in rural areas, promote the governance and development of a low-carbon society, and make some waste and biological resources as organic substances and energy. In the form of returning to agricultural production and life, reducing guanidine hydrochloride in waste, improving soil organic matter, and increasing the production of clean energy in rural areas. It also increases farmers' income through multiple channels, promotes the sustainable development of agricultural and rural low-carbon economies, and continuously increases the value of the rural economic development index from 0.118 to 0.15.

3. The low-carbon emission policy has expanded rural investment in related aspects, and under the general attention of the academic community, various research institutions have been established successively, various seminars have been held successively, and low-carbon cooperation projects have been carried out one after another. Social governance provides relevant theoretical,

https://doi.org/10.17993/3ctecno.2023.v12n2e44.306-329

technical, and financial support, increases the government's investment and emphasis on agriculture, forestry, and water affairs, and greatly increases the value of rural social development indicators, reaching the highest value in 2020 at 0.121.

4. By emphasizing that machinery, chemical fertilizers, pesticides, and agricultural films should not be used excessively, efforts should be made to control carbon emissions from planting and animal husbandry, effectively alleviate high carbon emissions, expand forestry coverage, and gradually enhance carbon sequestration capabilities. The emission is relatively reduced, and the development of fishery is encouraged under geographical restrictions, which reduces the evaluation value of the rural carbon emission by 0.32.

5. The low-carbon emission policy requires complete water conservancy facilities, enhances the drought resistance of farmland, maximizes the use of land under the specified environment, and provides good financial support for the increase of local fiscal environmental protection expenses. By turning the advantages of its development into real economic advantages, it can improve the self-development ability of the rural economic system and realize the leap-forward development of low-carbon rural areas. The ecological environment index value of the study area has increased by 0.043 within five years.

REFERENCES

(1) Tan, Yongtao, Ya, Shen, Liyin, & Shuai, et al. (2017). Identifying key impact factors on carbon emission: evidences from panel and time-series data of 125 countries from 1990 to 2011. Applied energy.

(2) Samour, A., Moyo, D., & Tursoy, T. (2022). Renewable energy, banking sector development, and carbon dioxide emissions nexus: A path toward sustainable development in South Africa. Renewable Energy, 193.

(3) Morrell, S. (2022). Helping to reduce mining industry carbon emissions: A step-by-step guide to sizing and selection of energy efficient high pressure grinding rolls circuits. Minerals Engineering, 179, 107431-.

(4) Liu, Z., Lang, L., Hu, B., et al. (2021). Emission Reduction Decision of Agricultural Supply Chain Considering Carbon Tax and Investment Cooperation. Journal of Cleaner Production, 294(12), 126305.

(5) Entezaminia, A., Gharbi, A., & Ouhimmou, M. (2021). A Joint Production and Carbon Trading Policy for Unreliable Manufacturing Systems under Cap-And-Trade Regulation. Journal of Cleaner Production, 293(2), 125973.

(6) Lei, Y. , Yiji, C. , Xiaozhe, Z. , Yongqiang, S. , & Zhiyong, Z. . (2017). A carbon emission evaluation for an integrated logistics system—a case study of the port of shenzhen. Sustainability, 9(3), 462.

(7) Ahmadi, S., Ghasemzadeh, H., & Changizi, F. (2021). Effects of A Low-Carbon Emission Additive on Mechanical Properties of Fine-grained Soil under Freeze-Thaw Cycles. Journal of Cleaner Production, 304(4), 127157.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.306-329

(8) Guo, X., Wang, X., Wu, X., et al. (2022). Carbon Emission Efficiency and Low-Carbon Optimization in Shanxi Province under "Dual Carbon" Background. Energies, 15.

(9) Li, B., & Li, J. (2021). Probabilistic sizing of a low-carbon emission power system considering HVDC transmission and microgrid clusters. Applied Energy, 304, 117760-.

(10) Hao, L. N., Umar, M., Khan, Z., et al. (2021). Green Growth and Low Carbon Emission in G7 Countries: How Critical the Network of Environmental Taxes, Renewable Energy and Human Capital is? Science of The Total Environment, 752, 141853.

(11) Grant, N., Hawkes, A., Mittal, S., et al. (2021). Confronting mitigation deterrence in low-carbon scenarios. Environmental Research Letters, 16(6), 064099 (13pp).

(12) Ma, C., Yang, H., Zhang, W., et al. (2021). Low-carbon consumption with government subsidy under asymmetric carbon emission information. Journal of Cleaner Production.

(13) Hernández-Castellano, C., Piol, J., & Espadaler, X. (2021). Distinct macroinvertebrate soil food webs at one-meter scale in a Mediterranean agroecosystem. Pedobiologia, 87-88(10), 150751.

(14) Zhang, Y., Peng, Y., Song, W., et al. (2021). Contribution of brown carbon to the light absorption and radiative effect of carbonaceous aerosols from biomass burning emissions in Chiang Mai, Thailand. Atmospheric Environment, 623, 118544.

(15) Kreidenweis, U., Breier, J., Herrmann, C., et al. (2020). Greenhouse gas emissions from broiler manure treatment options are lowest in well-managed biogas production. Journal of Cleaner Production.

(16) Brat, Bugaud, Guillermet, et al. (2020). Review of banana green life throughout the food chain: From auto-catalytic induction to the optimization of shipping and storage conditions. SCIENTIA HORTICULTURAE, 262.

(17) Liu, M., & Koivula, A. (2021). Silver Spoon and Green Lifestyle: A National Study of the Association between Childhood Subjective Socioeconomic Status and Adulthood Pro-Environmental Behavior in China. Sustainability, 13.

(18) Brown, D..(2021). Towards a comparative research agenda on in situurbanisation and rural governance transformation. International development planning review (3), 43.

(19) A, A. K. , B, B. B. , C, M. M. , & C, M. N. . (2021). The cultural political economy of rural governance: regional development in hesse (germany) - sciencedirect. Journal of Rural Studies.

(20) Aprea, J. L., & Bolcich, J. C. (2020). The energy transition towards hydrogen utilization for green life and sustainable human development in Patagonia. International Journal of Hydrogen Energy, 45(47).

(21) Pacheco, R., Rajo, R., Hoff, R., et al. (2021). Will farmers seek environmental regularization in the Amazon and how? Insights from the Rural Environmental Registry (CAR) questionnaires. Journal of Environmental Management, 284(1), 112010.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.306-329

(22) Yao, Z., Shen, L., Liu, R., et al. (2020). A Dynamic Predictive Traffic Signal Control Framework in a Cross-Sectional Vehicle Infrastructure Integration Environment. IEEE Transactions on Intelligent Transportation Systems, 21(4), 1455-1466.

(23) Aguilar, L., Juan David González-Ruiz, & Botero, S. (2022). Shareholder Option Valuation in Mezzanine Financing Applied to CO2 Reduction in Sustainable Infrastructure Projects: Application to a Tunnel Road in Medellin, Colombia. Sustainability, 14.

(24) Rico, M., Vergara-Romero, A., Subia, J., et al. (2022). Study of citizen satisfaction and loyalty in the urban area of Guayaquil: Perspective of the quality of public services applying structural equations. PLOS ONE, 17.

(25) Liu, J., Cui, J., Li, Y., et al. (2021). Synergistic Air Pollutants and GHG Reduction Effect of Commercial Vehicle Electrification in Guangdong's Public Service Sector. Sustainability, 13.

(26) Meng, F., Chen, H., Yu, Z., et al. (2022). What Drives Farmers to Participate in Rural Environmental Governance? Evidence from Villages in Sandu Town, Eastern China. Sustainability, 14.

(27) Mbah, M., & Franz, A. (2021). Revitalization and Branding of Rural Communities in Cameroon Using a Circular Approach for Sustainable Development—A Proposal for the Batibo Municipality. Sustainability, 13.

(28) Rhett, J. C., Cecala, K. K., Wenger, S. J., et al. (2021). Distinctive Connectivities of Near-Stream and Watershed-Wide Land Uses Differentially Degrade Rural Aquatic Ecosystems. BioScience, 2(2).

(29) Rivera-Arriaga, E., Williams-Beck, L., LEV Hernández, et al. (2021). Crafting grassroots' socio-environmental governance for a coastal biosphere rural community in Campeche, Mexico. Ocean & Coastal Management, 204(4), 105518.

(30) Han, J., Hou, X., & Zhang, L. (2022). Policy implications of China's rural household coal governance from the perspective of the spillover effect. Energy, 242.

(31) Maximilian, V., & Rastan, A. J. (2021). SWOT analysis of coronary artery bypass surgery by the use of intraoperative epiaortic imaging and functional graft assessment. European Journal of Cardio-Thoracic Surgery, 1.

(32) Bonfante, M. C., Raspini, J. P., Fernandes, I. B., et al. (2021). Achieving Sustainable Development Goals in rare earth magnets production: A review on state of the art and SWOT analysis. Renewable and Sustainable Energy Reviews, 137, 110616.

(33) Hosseini, S. M., Paydar, M. M., & Triki, C. (2021). Implementing sustainable ecotourism in Lafour region, Iran: Applying a clustering method based on SWOT analysis. Journal of Cleaner Production, 329, 129716-.

(34) Jetoo, S., & Lahtinen, V. (2021). The Good, the Bad and the Future: A SWOT Analysis of the Ecosystem Approach to Governance in the Baltic Sea Region. Sustainability, 13.

(35) Karymbalis, E., Andreou, M., Batzakis, D. V., et al. (2021). Integration of GIS-Based Multicriteria Decision Analysis and Analytic Hierarchy Process for Flood-

Hazard Assessment in the Megalo Rema River Catchment (East Attica, Greece). Sustainability, 13.

(36) Su, Jing, Yuan, Sunan, & Joseph, Nympha Rita. (2021). Mathematical simulation experiment based on optimization of heat treatment process of aluminum alloy materials. Applied Mathematics and Nonlinear Sciences.

(37) Amenta, P., Lucadamo, A., & Marcarelli, G. (2020). On the transitivity and consistency approximated thresholds of some consistency indices for pairwise comparison matrices. Information Sciences, 507, 274-287.

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.306-329

/19/

REGIONAL DIFFERENTIATION IN INFLUENCING FACTORS OF CLEAN RENEWABLE ENERGY CONSUMPTION FROM THE PERSPECTIVE OF AIR POLLUTION PREVENTION AND CONTROL

Jin Zhan*

Intelligent Manufacturing College, Shanxi Vocational University of Engineering Science and Technology, Taiyuan, Shanxi, 030004, China.

School of Mechanical Engineering, Taiyuan University of Science and Technology, Taiyuan, Shanxi, 030024, China.

ggh0546@163.com

Reception: 30/04/2023 **Acceptance**: 23/06/2023 **Publication**: 14/07/2023

Suggested citation:

Zhan, J. (2023). **Regional differentiation in influencing factors of clean renewable energy consumption from the perspective of air pollution prevention and control**. *3C Tecnología. Glosas de innovación aplicada a la pyme, 12(2)*, 331-345. https://doi.org/10.17993/3ctecno.2023.v12n2e44.331-345

ABSTRACT

Global economic growth is now increasingly conflicting with the sustainable development strategy. In the context of ecological environmental preservation and air pollution prevention and control, this paper probes into the regional differentiation in the influencing factors of clean renewable energy consumption. First and foremost, a brief analysis of the status quo of clean renewable consumption in China was outputted, grounded on data on the input and output of 30 provinces and cities nationwide from 2010 to 2020. Then, national and regional models are built respectively in virtue of differential GMM, systematic GMM, and bias-corrected LSDV methods. Furthermore, efforts were invested in dissecting the working mechanism of the influencing factors and verifying the previous prediction resulting in applying the Tobit regression method. For every 1% increase in the green finance index, the clean renewable energy consumption rises by 0.882 accordingly, said the regression analysis results. Last but not least, it was concluded that the development level of green finance, internet advance, and technological progress significantly positively affected clean renewable energy consumption. While the industrial structure, the degree of openness, and the level of urbanization represented by the proportion of the secondary industry play hardly-seen impact.

KEYWORDS

Offset correction; Influencing factors; Regression method; Clean renewable energy consumption; Regional differentiation.

INDEX

https://doi.org/10.17993/3ctecno.2023.v12n2e44.331-345

1. INTRODUCTION

The construction of ecological civilization is an important aspect of the long-term development of the Chinese nation and has always been a hot spot of concern for all countries. The report of the 19th National Congress states that we should continuously promote green development, strengthen environmental governance, and increase the protection of ecosystems [1]. However, the current air pollution problem faced by human society is a serious constraint to the construction of ecological civilization [2]. Atmospheric pollution can have catastrophic effects on human economic and social development, such as climate anomalies, extreme weather such as dust storms, sea level rise, and global warming [3]. Ecological and environmental issues are related to the health of the people, the harmony and stability of society, and the healthy and orderly development of the economy [4]. The management of atmospheric pollution has become a hot issue of close concern to all sectors of society [5]. And the use of clean renewable energy has a positive effect on air pollution control as well as ecological environmental protection [6].

Energy consumption is not only an important aspect of national implementation but also, it is related to the strategic overall situation of national energy sustainable development [7]. In the context of sustainable development theory and ecological modernization, people's requirements for living environment and quality of life are increasing with the increase in income level [8]. The type of energy consumption in China is shifting from high pollution to cleanliness [9]. In recent years, the rise of a low-carbon economy has increased under the premise of the sustainable development concept [10]. To deeply strengthen the management of the atmospheric environment, improve the quality of urban and rural air environment, and improve the ecological environment, China has continuously increased the development and use of clean energy [11]. The state has also introduced relevant laws and regulations, and clear requirements for the use of high-pollution fuels in some areas of the province designating a no-burn zone that requires the use of high-pollution fuels in the no-burn zone [12]. They should be removed or switched to natural gas, LPG, electricity, or other clean energy sources promptly. Clean renewable energy resources in China vary from region to region and within regions due to differences in the economic development of each region leading to their consumption [13].

The eastern region of China accounts for 41.56% of the total national consumption in 2020, while western regions account for 38.87% and 19.57%, respectively. The regional differences are large [14]. In terms of energy use consumption, the five provinces with the lowest energy consumption accounted for 16.54% of the country's energy consumption but their combined GDP only accounted for 8.28% of the country's GDP. The five provinces with the highest energy use consumption account for 15.22% of the country's energy consumption but their combined GDP accounts for 26.47% of the country's GDP. There are significant regional differences in energy consumption in China [15]. Therefore, while improving energy use consumption, a correct understanding of the structural characteristics and regional disparities in energy use consumption is significant to effectively promote the work of air pollution prevention and control in China as well as to continuously promote sustainable development strategies [16-17].

https://doi.org/10.17993/3ctecno.2023.v12n2e44.331-345

Clean renewable energy has been studied by many scholars. The literature [18] presents a model used to describe the development. The literature [19] simulates the consumption of natural gas by randomly combining several influences including GDP, population, natural gas imports and exports, and employment while predicting natural gas consumption by selecting the most realistic equation from all simulated equations. Literature [20] and literature [21] investigate the impact of the national economic growth rate through the ARDL method [22-24]. Literature [25] and literature [26] studied the impact of various factors on renewable energy consumption based on a multivariate framework. Literature [27] conducted research using panel data from nearly 35 years and obtained that, from a long-term perspective, natural gas energy consumption has an impact on the GDP growth of GCC countries. Literature [28] proposes a parameter estimation method that eliminates omitted variable bias due to unobserved cross-sectional individual effects by differencing. In addition, the literature [29] used the Granger causality test to obtain the relationship between natural gas consumption and GDP. Literature [30] argues that marketization facilitates the formation of a virtuous response between renewable energy and consumption, guiding the consumption of clean renewable energy through price signals.

The aforementioned studies include the search for clean and renewable alternatives to fossil energy through data models. The relationship between consumption has been explored and the factors influencing have been studied. This study further extends the study of natural gas energy to clean renewable energy based on the previous study. We analyze the factors influencing the consumption of clean renewable energy in the context of ecological environmental protection and air pollution prevention. We also combine the panel data of 30 Chinese provinces to build a mathematical model and estimate the model using differential GMM, systematic GMM, and bias-corrected LSDV methods for the national and regional levels, respectively. Based on this, the Tobit regression method is applied to validate the results. Based on the data model, the influencing factors of energy consumption were analyzed, to provide some theoretical references for ecological environmental protection and air pollution control.

2. RESEARCH BASIS

2.1. CURRENT SITUATION OF CLEAN RENEWABLE ENERGY CONSUMPTION

To examine the regional differences in energy consumption, the specifics of each region in 2020 were investigated and plotted in Figure 1.

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.331-345

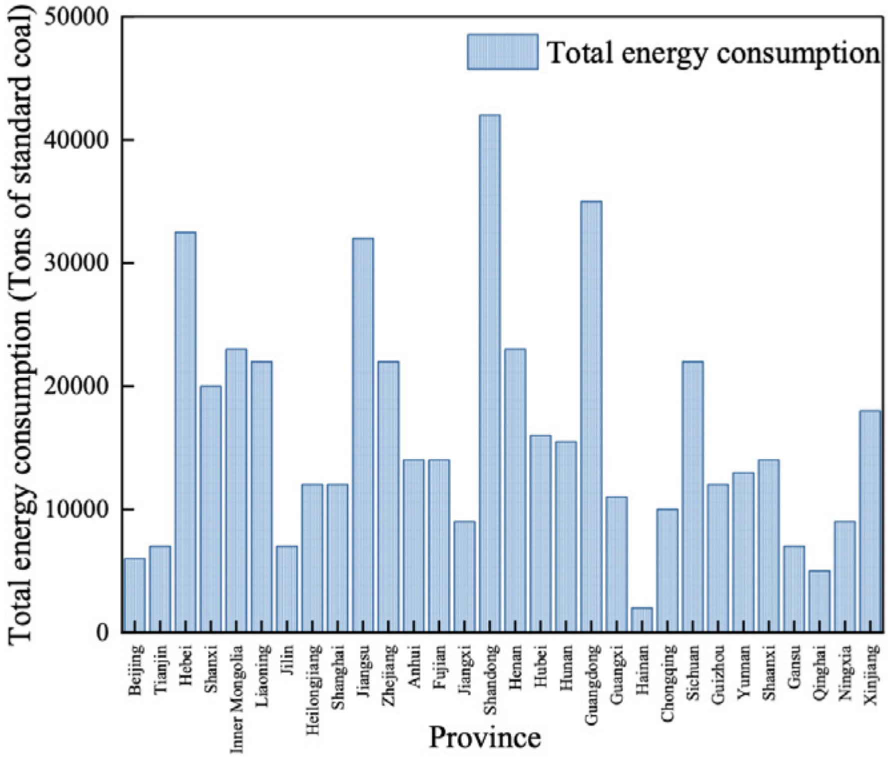


Figure 1. Clean Renewable energy consumption by Provinces in 2020

From Figure 1, we can see that the top three clean renewable energy consumption in 2020 are Shandong Province, Guangdong Province, and Hebei Province respectively. The highest consumption of clean renewable energy is over 40,000 million tons [31] in Shandong province, while the lowest consumption is only about 20 million tons of standard coal in Hainan, so we can easily see through the above chart that there are big differences in the consumption data of clean renewable energy in different regions at the same point of time.

2.2. MODEL PARAMETER SETTING

Panel data is adopted by a wide range of scholars for its advantages of large data size. Economic theory suggests that the individual's past state determines the current behavioral state due to inertia, so the lagged values can be included in the panel model, and this type of data is dynamic.

The following dynamic panel parameters are considered:

$$y_{it} = \alpha + \rho y_{i,t-1} + x_{it}\beta + Z_i\delta + \mu_i + \varepsilon_{it}, t = 2,3,\cdots,T \quad (1)$$

First-order differencing to eliminate individual effects μ_i.

$$\Delta y_{it} = \rho \Delta y_{i,t-1} + \Delta x_{it}\beta + \Delta \varepsilon_{it} \quad (2)$$

https://doi.org/10.17993/3ctecno.2023.v12n2e44.331-345

However, the DIF-GMM method has some shortcomings, such as the elimination of non-observed section individual effects and other variables that do not change with time when differencing. Also, its estimator is often not efficient (minimum variance).

Blundell and Bond combined the difference GMM with the level GMM to perform GMM estimation of the difference and level equations as a system of equations, called System GMM (SGS).

The methods mentioned above are more suitable for short dynamic panels. Because while instrumental variable or GMM-based estimators are consistent estimators, they may be more heavily biased for smaller and larger long panels. After Monte Carlo simulations, the results show that the LSDV method is significantly better than the differential GMM or the systematic GMM for smaller long panels. The basic idea of the LSDV method is to first estimate the dynamic panel model using the LSDV method, and the estimated coefficient is β. Secondly, the bias of the LSDV method is estimated as Bias; finally, this bias is subtracted from the estimated LSDV coefficient to obtain a bias-corrected consistent estimate.

In this paper, the Dynamic Panel Model (DPM) with a first-order lag is considered because the consumption target is expressed using the previous year's renewable energy generation, so it contains first-order lagged data of the explanatory variables [32]. Since the national and regional panels are studied separately in this paper, the bias-corrected LSDV method is used considering the existence of bias in the differential GMM and the systematic GMM.

The variables are selected according to the validity of the data, and the model is as follows:

$$RE_{it} = \alpha + \beta_1 \times RE_{i,t-1} + \sum_{k=1}^{K} \gamma_k \times X_{kit} + \sum_{m=1}^{M} \delta_m \times Y_{mit} + \sum_{n=1}^{N} \omega_n \times Z_{nit} + \sum_{s=1}^{S} \rho_s \times V_{sit} + \varepsilon_{it} \quad (3)$$

Where RE_{it} denotes renewable energy generation in year t of region i; V_{sit} is a random disturbance term.

3. DATA, VARIABLES, AND DESCRIPTIVE STATISTICS

The factors influencing the production of renewable energy generation include the green financial development index (Gfi), government intervention (Gov), openness to the outside world (Trade), R&D investment intensity (RD), tertiary industry share (TI), energy consumption structure (ES), urbanization rate (Urban), and Internet penetration rate (Ipr).

To make a more accurate and comprehensive measurement, this paper quantifies the green financial development level by constructing a more reasonable index. The composition of the index system is shown in Table 1. The degree of government intervention is expressed as the ratio of general budget expenditures to GDP. The intensity of R&D investment by provinces and municipalities is used to express the indicator of technological progress. The development level of the tertiary industry can well represent the development trend. The level of urbanization is represented by the

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.331-345

urbanization rate of each province and city. The indicator of Internet penetration rate is used to measure the degree of Internet development.

Each influencing factor is quantified on the premise that the possible influencing factors are clarified. The explanatory variables used for the specific quantified influencing factors are shown in Table 1.

Table 1. Description of explanatory variables

Variable Name	Variable	Definition
Green Finance Index	GIF	The entropy method is calculated from the exponent
Government Intervention	Gov	General budget expenditure of government finance as a percentage of GDP
Degree Of Openness	Trade	The ratio of total imports and exports to GDP
R&D investment intensity	RD	Proportion of R&D investment in GDP by province and city
Industrial Structure	TI	The ratio of the output value of the tertiary industry to GDP
Energy Consumption Structure	ES	Coal consumption as a percentage of total energy consumption
Urbanization Rate	Urban	The proportion of urban population to total population
Internet Penetration	Ipr	Proportion of Internet users and population

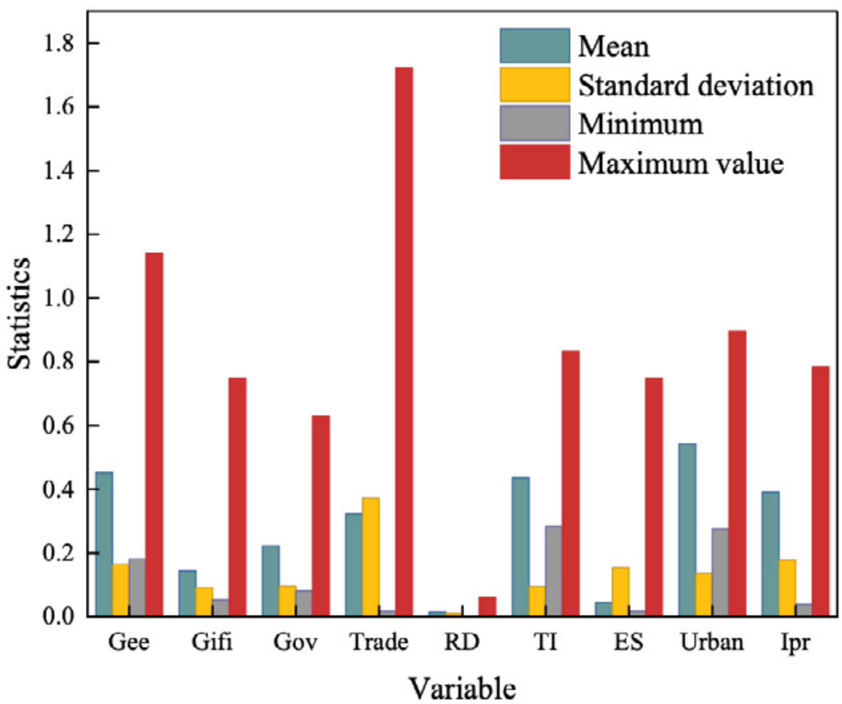


Figure 2. Descriptive statistics of the explanatory variables

https://doi.org/10.17993/3ctecno.2023.v12n2e44.331-345

The results of the descriptive statistics of the explanatory variables for the whole country show that the maximum value is 1.15 and the minimum value is 0.17, which proves that the selected observations have a wide range. The selected observations are somewhat representative. The mean value of the explanatory variables for the nation as well as for each province and city is 0.47, and since the mean value is susceptible to extreme values, we use the standard deviation to indicate the degree of aggregation of the data. From the above figure, it can be seen that all the interpretive variables for the country as well as for each province and city are less than 0.18, which proves that the data are more aggregated and less volatile4

4. RESULTS AND ANALYSIS

First of all, to avoid the problem of biased regression results brought about by the problem of multicollinearity [33], the corresponding test must first be performed on the collated sample data. The most direct and effective method is to use the variance inflation factor (VIF) method for the test [34]. The following information can be found: none of the selected explanatory variables has a VIF above 10 and their mean does not exceed 5. Therefore, Table 2 indicates that there is no serious multicollinearity among the eight explanatory variables we have selected and a panel Tobit regression can be performed.

Table 2. Multicollinearity test for each explanatory variable

Variable	VIF	1/VIF
Gif	9.15	0.1355
Urban	8.65	0.1438
RD	7.92	0.1578
TI	5.30	0.2496
Ipr	5.04	0.2654
Trade	4.72	0.2878
ES	3.74	0.3919
Gov	2.02	0.5350

In this study, the quantitative value of clean renewable energy is used as the dependent variable. The independent variables are eight variables: green financial development index (Gfi), government intervention (Gov), openness to the outside world (Trade), R&D investment intensity (RD), tertiary industry share (TI), energy consumption structure (ES), urbanization rate (Urban), and Internet penetration rate (Ipr). In this regard, we constructed panel data and used Tobit regression models to conduct sub-sample regressions for the whole country and the eight economic regions, and obtained two regression analysis results of positive and negative effects, respectively, as shown in Figure 3 and Figure 4.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.331-345

From the Tobit regression results, all the explanatory variables are significant except for the urbanization rate, the degree of openness to the outside world, and the share of tertiary industry, which are not significant in the model. The specific analysis is as follows:

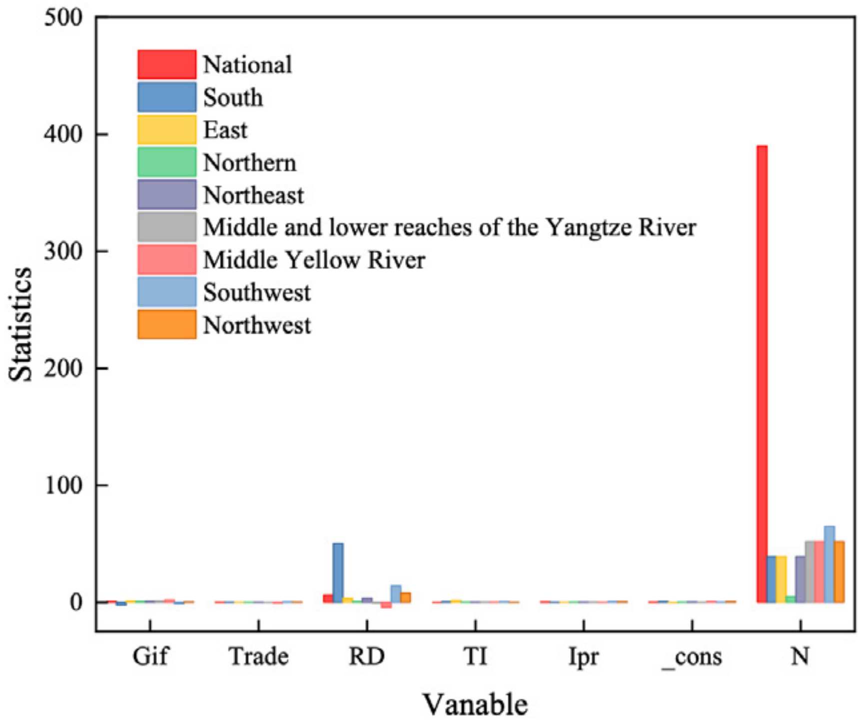


Figure 3. Results of regression analysis of the positive influence of inter-provincial clean renewable energy in China

Figure 3 shows that the level of green financial development has a significant contribution to clean renewable energy efficiency. Overall, for every 1% increase in the green finance index, the consumption of clean renewable energy increases by 0.882. The level of green finance development provides green credit specifically to the relevant transition enterprises through banks. Financial instruments such as green bonds offered in the market by the government and other market players can give financing support to environmental protection companies and green transformation companies, and policy incentives to motivate them to improve their production processes. Reduce factor inputs, and thus increase the consumption of clean and renewable energy. At the same time, the relevant policies introduced together with green finance have formed financing constraints for the "three high" enterprises, restraining the continuation of the crude development approach and forcing the "three high" enterprises to transform and upgrade their energy structures to increase the consumption of clean renewable energy. By economic zone, the most obvious role of green financial development level for the promotion of clean renewable energy consumption is the Yellow River Middle River Economic Zone. Many of the provinces in the Middle Yellow River Economic Zone have an industrial system that was previously dominated by secondary industries and is now undergoing an important journey of industrialization and transformation. A deep policy dividend has been given to these regions through credits and bonds under the green finance policy. The region

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.331-345

where the effect is not obvious is the Northwest Economic Zone. Possible reasons for this are, on the one hand, that there is a lag in the use of more practical green financial instruments tools because the pilot scope of green finance has not yet been fully spread. On the other hand, the northwestern region has not been very effective in bringing the advantages of the financial system into play at this stage due to the limitations of its own economic and financial development level [35].

R&D investment intensity has an impact on consumption. At the national level, each unit increase in R&D investment intensity increases clean renewable energy consumption by 6.425 units. The coefficient value is the largest of all explanatory variables and has the strongest effect, indicating that technological progress is particularly critical to the increase in clean renewable energy consumption. This proves that technological progress is the most powerful and sustainable means to increase the consumption of clean renewable energy. Further, it can be found that the southern economic zone has the most significant release of dividends from technological progress due to the strong technological strength of the provinces and the high degree of integration between industry, academia, and research. RD has the greatest impact on consumption, while the eastern, northern and middle, and lower reaches of the Yangtze River economic zones are not significant [36].

The increase in Internet penetration significantly contributes to the increase in clean renewable energy consumption, in a homogeneous relationship. For every unit increase in Internet penetration, clean renewable energy consumption can increase by 0.34 units. This has great policy implications in the context of the strong Internet development and the emergence of the digital economy. The greatest impact has been in the Northern Economic Zone, where the Internet has led to the construction of an online platform on the one hand, which has greatly reduced the intermediate costs for the energy companies involved. On the other hand, the penetration rate has improved the quality of the workforce and optimized the consumption of clean and renewable energy. In contrast, the southwestern and northwestern economic regions are more in need of a better role in the improvement of energy consumption through the upgrading of the Internet [37].

The sign of the regression results of the degree of external openness and the share of tertiary industry is consistent with the theoretical analysis. The deepening of external openness can improve the learning effect of domestic enterprises through foreign technology spillover and trade connection, forming a virtuous cycle of "foreign spillover, domestic learning, and exchange and progress". Specifically, the positive effects are evident in the northern, southwestern, and northwestern economic regions. The increase in the share of the tertiary sector indicates that the industrial structure is in the process of upgrading, which is disadvantageous compared to the secondary sector with high energy input. The tertiary sector is more conducive to increasing consumption because it is dominated by the service sector, which has a lower energy input and a larger share of clean energy use. In particular, the effect of the eastern economic zone is the most obvious. The eastern economic zone has attracted a large number of high-quality labor forces through its advantages of high urbanization and perfect basic public services, which further optimized its industrial structure. The tertiary industry is more developed and has a higher proportion.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.331-345

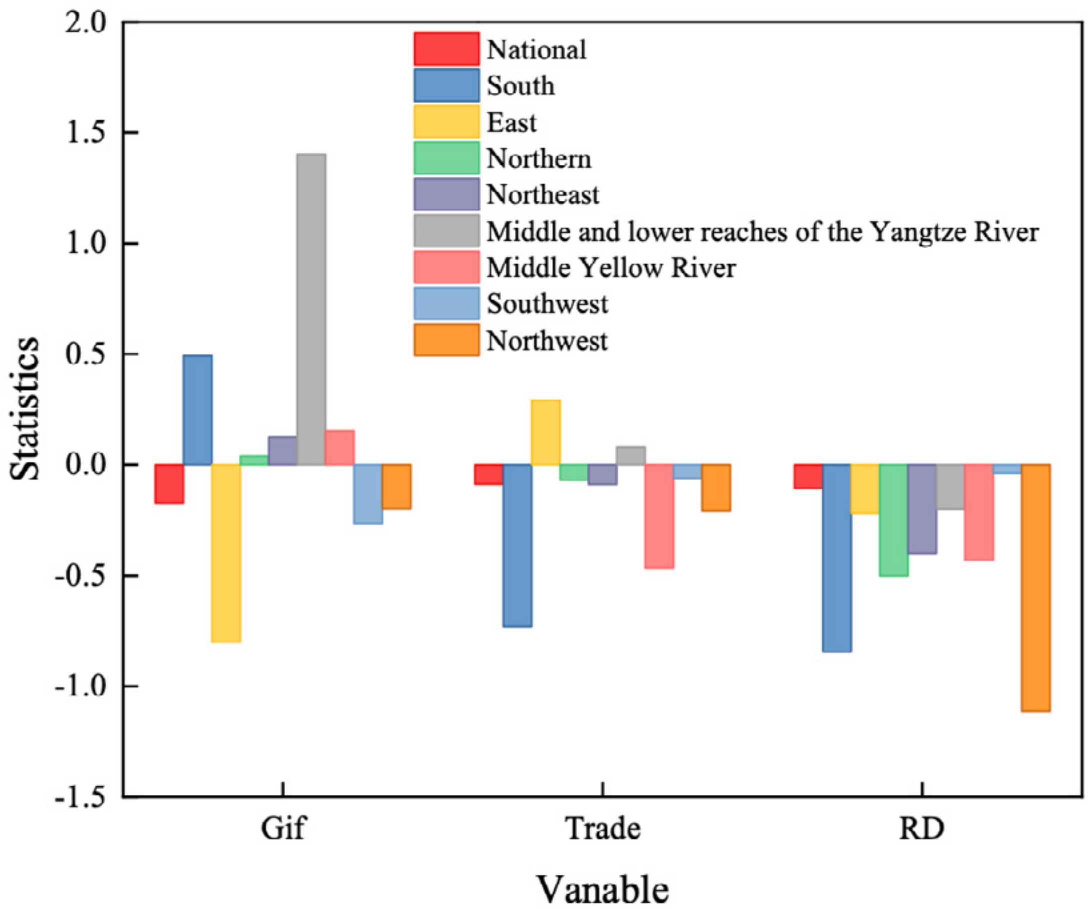


Figure 4. Results of regression analysis of negative influencing factors of inter-provincial clean renewable energy in China

As seen in Figure 4, the degree of government intervention has a dampening effect on clean renewable energy consumption in the Tobit regression results. Overall, each unit increase in the degree of government intervention. Instead of increasing, the consumption of clean renewable energy decreases by 0.173 units, which has a significant counter effect. This reflects that the government's intervention in energy-related aspects will, to a certain extent, restrict the increase of clean renewable energy consumption and fail to give full play to the regulation and allocation function of the market for the relevant factors. Further subsampling reveals that the overall governance capacity of the government in the northwest economic zone is limited by historical development factors compared to the developed economic zones. Therefore, government intervention in energy is not conducive to the allocation of factors. The improved governance capacity of local governments promotes market circulation and rational allocation of energy and other factors. The results demonstrate that government intervention is effective in not hindering the progress of energy consumption.

Each unit increase will lead to a 0.0876 unit decrease. And the absolute value of the coefficient impact is high compared to the rest of the explanatory variables, indicating that the energy consumption structure with the share of coal can

https://doi.org/10.17993/3ctecno.2023.v12n2e44.331-345

significantly and negatively affect the energy consumption enhancement. The results of the sub-sample regression also corroborate the national regression results.

The increase in the urbanization rate inhibits the increase in the consumption of clean renewable energy. Specifically, each unit increase in the urbanization rate decreases clean renewable energy consumption by 0.107 units. A possible explanation for the insignificant regression is that the income effect created by the urbanization process leads to an increase in the demand for residential energy consumption. At the same time, the negative externalities of urban pollutant emissions inhibit the improvement of energy consumption. The significant negative regressions in the northern, northeastern, and middle reaches of the Yellow River and northwestern economic zones also support the analysis of the previous theoretical mechanism.

5. DISCUSSION

Given the above research deficiencies, it is necessary to investigate, understand and grasp the situation, characteristics, and patterns of Chinese household energy consumption from multiple levels and in-depth in the future research process. In addition, the structure is changing dramatically with the intensive development of clean and renewable energy sources. Therefore, further research on the factors influencing the consumption of clean renewable energy is of great significance and has important reference value for China's future inquiry on the formulation of related policies.

6. CONCLUSION

This paper adopts the input-output-related data of 30 provinces and cities nationwide from 2010 to 2020 to establish a mathematical model. The different influencing factors of clean renewable energy consumption are sorted out. The trends and characteristics of spatial differences in clean renewable energy consumption in China are revealed. The spatial effects of the influencing factors are quantitatively analyzed, which can provide some reference for energy policy formulation and energy planning in China. It provides some references for developing energy structure optimization strategies and energy saving and emission reduction measures with regional characteristics.

1. In this paper, differential GMM, systematic GMM, and bias-corrected LSDV methods are used to build the national and regional models. The highest consumption of clean renewable energy is over 40,000 million tons, while the lowest consumption is only about 20 million tons. The evolution and spatial differences in its development are fully recognized and understood.

2. The absolute values of the results analyzed by the Tobit regression method, except for the urbanization rate, the degree of openness to the outside world, and the share of tertiary industry, which are less than 0.15, all the explanatory variables are greater than 0.15. This result fully demonstrates that all the

https://doi.org/10.17993/3ctecno.2023.v12n2e44.331-345

relevant variables have significant effects on the results, except for the insignificant effects of urbanization rate, degree of openness to the outside world, and tertiary industry.

3. The results of the regression analysis are obtained by the Tobit regression method, such as every 1% increase in the green finance index increases the consumption of clean renewable energy by 0.796. The level of green financial development, the degree of Internet development, and technological advances are analyzed to have a significant positive effect on the consumption of clean renewable energy. The results that the industrial structure represented by the share of secondary industry, the degree of openness to the outside world, and the level of urbanization do not have a significant effect on the consumption of clean renewable energy are also derived.

REFERENCES

(1) Meng, F., Guo, J., Guo, Z., et al. (2021). Urban ecological transition: The practice of ecological civilization construction in China. Science of The Total Environment, 755(Pt 2), 142633.

(2) Kuzma, L., Kurasz, A., Dabrowski, E. J., et al. (2021). Association between air pollution and case-specific mortality in the north-eastern part of Poland. Case crossover study with 4,500,000 person-years of follow-up. European Heart Journal, Supplement_1.

(3) Rodrigues, V., Gama, C., Ascenso, A., et al. (2021). Assessing air pollution in European cities to support a citizen-centered approach to air quality management. Science of The Total Environment, 799(11), 149311.

(4) Du, X. , & Huang, Z. . (2017). Ecological and environmental effects of land use change in rapid urbanization: the case of hangzhou, china. Ecological Indicators, 81(oct.), 243-251.

(5) Malaspina, P. , Modenesi, P. , & Giordani, P. . (2018). Physiological response of two varieties of the lichen pseudevernia furfuracea to atmospheric pollution. Ecological Indicators, 86, 27- 34.

(6) Thapar, S., Sharma, S. , & Verma, A. . (2017). Local community as shareholders in clean energy projects: innovative strategy for accelerating renewable energy deployment in india. Renewable Energy, 101(FEB.), 873-885.

(7) Zhang, Y. J. , Bian, X. J. , Tan, W., & Song, J.. (2017). The indirect energy consumption and co2 emission caused by household consumption in china: an analysis based on the input-output method. Journal of Cleaner Production, 163 (oct.1), 69-83.

(8) Duda, A. M. . (2017). Leadership and political will for groundwater governance: indispensable for meeting the new sustainable development goals (sdgs). Brazilian Journal of Microbiolo gy.

(9) Jing-Li, Fan, Yue-Jun, Zhang, Bing, & Wang. (2017). The impact of urbanization on residential energy consumption in china: an aggregated and disaggregated analysis. Renewable & Sustainable Energy Reviews.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.331-345

(10) Sagastume, Gutierrez, Alexis, Cabello, Eras, & Juan, et al. (2018). The current potential of low-carbon economy and biomass-based electricity in cuba. the case of sugarcane, energy cane and marabu (dichrostachys cinerea) as biomass sources. Journal o f Cleaner Production.

(11) Harini, G., Balasurya, S., & Khan, S.S.. (2022). Recent advances on gadolinium-based nano-photocatalysts for environmental remediation and clean energy production: properties, fabrication, defect engineering and toxicity. Journal of Cleaner Production, 345, 131139-.

(12) Ma, Q. , Zhao, Y. , Ji, C. , Zhang, Y. , & Ming, B.. (2021). Electricity curtailment cost coupled to operation model facilitates clean energy accommodation in grid-connected system. Energi es, 14.

(13) Leenaers, A., Renterghem, W. V., & Van D. (2016). High burn-up structure of U(Mo) dispersion fuel. Journal of Nuclear Materials, 476, 218-230.

(14) Wrman, A., Uvo, C. B., Brandimarte, L., et al. (2020). Virtual energy storage gain resulting from the spatio-temporal coordination of hydropower over Europe. Applied Energy, 272, 115249.

(15) Li, Z., Tian, Q., Xu, J., et al. (2021). Easily Fabricated Low-Energy Consumption Joule-Heated Superhydrophobic Foam for Fast Cleanup of Viscous Crude Oil Spills. ACS Applied Materials And Interfaces, 13(43), 51652-51660.

(16) Liu, Y., Sadiq, F., Ali, W., et al. (2022). Does tourism development, energy consumption, trade openness and economic growth matter for ecological footprint: Testing the Environmental Kuznets Curve and pollution haven hypothesis for Pakistan. Energy, 245.

(17) Shan, S., Cai, X., Li, K., et al. (2021). Spectral energy characteristics of radiation in oxy-coal combustion for energy utilization. Fuel, 289(3), 119917.

(18) Wang, Y., Ji, Q., Shi, X., et al. (2020). Regional renewable energy development in China: A multidimensional assessment. Renewable and Sustainable Energy Reviews, 124.

(19) Anelkovi, A. S. , & Bajatovi, D. . (2020). Integration of weather forecast and artifi-cial intelligence for a short-term city-scale natural gas consumption prediction. Journal of Cleaner Prod uction, 266(2823), 122096.

(20) Ergun Uzlu, Murat Kankal, Adem Akpmar, Tayfun Dede. (2017). Estimates of energy consumption in Turkey using neural networks with the teaching-learning-based optimization algorithm. Energy, 75.

(21) Cem I,sik. (2018). Natural gas consumption and economic growth in Turkey: A bound test approach. Energy Syst, 1.

(22) Baz, K., Cheng, J., Xu, D., et al. (2021). Asymmetric impact of fossil fuel and renewable energy consumption on economic growth: A nonlinear technique. Energy, 2, 120357.

(23) Ozturk, I., Al-Mulali, U. (2015). Natural gas consumption and economic growth nexus: Panel data analysis for GCC countries. Renewable and Sustainable Energy Reviews, 51.

(24) Mujtaba, A., Jena, P. K., Bekun, F. V., et al. (2022). Symmetric and asymmetric impact of economic growth, capital formation, renewable and non-renewable energy consumption on environment in OECD countries. Renewable and Sustainable Energy Reviews, 160, 112300-.

(25) Yang, M., Wang, E. Z., Hou, Y. (2021). The relationship between manufacturing growth and CO2 emissions: Does renewable energy consumption matter? Energy, 2, 121032.

(26) Namahoro, J. P., Nzabanita, J., Wu, Q. (2021). The impact of total and renewable energy consumption on economic growth in lower and middle- and upper-middle-income groups: Evidence from CS-DL and CCEMG analysis. Energy, 237.

(27) Niu, C., Tan, K., Jia, X., et al. (2021). Deep learning based regression for optically inactive inland water quality parameter estimation using airborne hyperspectral imagery. Environmental Pollution, 117534.

(28) Mo, X. B., Zhang, Y. H., Lei, S. F. (2020). Integrative analysis identifies potential causal methylation-mRNA regulation chains for rheumatoid arthritis. Molecular Immunology.

(29) Sun, Z., Li, X., Cui, G., et al. (2021). A Fast Approach for Detection and Parameter Estimation of Maneuvering Target With Complex Motions in Coherent Radar System. IEEE Transactions on Vehicular Technology, PP(99), 1-1.

(30) Estelle, R., Adrien, W., Salamanca-Giron, R. F., et al. (2021). Functional Segregation within the Dorsal Frontoparietal Network: A Multimodal Dynamic Causal Modeling Study. Cerebral Cortex.

(31) Roldan-Fernandez, J. M., Burgos-Payan, M., Riquelme-Santos, J. M., et al. (2016). Renewable Generation Versus Demand-side Management. A Comparison for the Spanish Market. Energy Policy, 96(9), 458-470.

(32) Orndahl, C. M., Perera, R. A., Riddle, D. L. (2020). Associations Between Physical Therapy Visits and Pain and Physical Function After Knee Arthroplasty: A Cross-Lagged Panel Analysis of People Who Catastrophize About Pain Prior to Surgery. Physical Therapy, 1.

(33) Fan, J., Wang, J., Liu, M., et al. (2022). Scenario simulations of China's natural gas consumption under the dual-carbon target. Energy, 252.

(34) Li, R., Zhang, H., Gao, S., et al. (2021). An improved extreme learning machine algorithm for transient electromagnetic nonlinear inversion. Computers & Geosciences, 156(20), 104877.

(35) Richards, K. C., Vallabhaneni, V., Moelter, S., et al. (2020). 0861 Age, Race, And Continuous Positive Airway Pressure (CPAP) Confidence Score At 1-week Predict 3-month CPAP Adherence In Older Adults With Amnestic Mild Cognitive Impairment And Moderate To Severe Obstructive Sleep Apnea. SLEEP, Supplement_1.

(36) Mei, Dong. (2022). Reconstruction of multimodal aesthetic critical discourse analysis framework. Applied Mathematics and Nonlinear Sciences. doi:10.2478/AMNS.2021.2.00165.

(37) Wang, Q., Li, S., Pisarenko, Z. (2020). Heterogeneous effects of energy efficiency, oil price, environmental pressure, R&D investment, and policy on renewable energy -- evidence from the G20 countries. Energy, 209.

(38) Ghaffari, A., Askarzadeh, A. (2020). Design optimization of a hybrid system subject to reliability level and renewable energy penetration. Energy, 193, 116754.

/20/

APPLICATION OF MACHINE VISION TECHNOLOGY IN DEFECT DETECTION OF HIGH-PERFORMANCE PHASE NOISE MEASUREMENT CHIPS

Jing Zhou*

School of Pharmaceutical Business, Zhejiang Pharmaceutical University, Ningbo, Zhejiang, 315100, China.

zhoujing_calla@163.com

Reception: 15/05/2023 **Acceptance**: 29/06/2023 **Publication**: 23/07/2023

Suggested citation:

Zhou, J. (2023). **Application of machine vision technology in defect detection of high-performance phase noise measurement chips**. *3C Tecnología. Glosas de innovación aplicada a la pyme, 12(2)*, 347-362. https://doi.org/10.17993/3ctecno.2023.v12n2e44.347-362

ABSTRACT

The problem of chip defects has always existed in industrial production, and since there are more and more environmental problems caused by chip defects, people have attached greater importance to the identification and detection of chip defects. Pursuant to the ecological environmental problems caused by chip defects in the process of chip production, this paper uses machine vision technology to detect the defects of high-performance phase noise measurement chips. The results suggest that the accuracy of machine vision technology for the identification of chip defects reaches up to 98%. The production volume of organic waste gas decreases from 5968.0t/a to 4000t/a. The yield of organic wastewater decreases from 5496m3/d to 4600m3/d. The production amount of solid waste reduces from 8000t/a to 6500t/a. The aforementioned data all confirm that machine vision technology has the advantages of automation, high detection efficiency, and high accuracy of defect identification for the defect detection of high-performance phase noise measurement chips. And also, by improving the chip defects, the discharge volume of waste gas, wastewater, and solid waste in the chip production process is reduced, and thereupon the ecological environment is ameliorated.

KEYWORDS

Machine vision technology; Chips; Defect detection; Environmental pollution; Ecological environment

INDEX

https://doi.org/10.17993/3ctecno.2023.v12n2e44.347-362

1. INTRODUCTION

In the process of chip production and manufacturing, the processes are interlinked. The technology is complex, and slight variations in materials, environment, process parameters, and other factors often lead to defects in the chip and affect the product yield. The problem of chip defects has always existed in industrial production [1]. And there are more and more environmental problems due to chip defects [2]. Therefore, more and more attention has been paid to the identification and detection of chip defects. The traditional chip defect identification and detection approach relies on the manual operation of professional technicians. This method is not only inefficient but also relies on the subjective judgment of the operator, and the accuracy of detection is difficult to be guaranteed. The combination of non-destructive testing equipment and industrial production lines not only ensures the quality of products but also reduces the cost of manual inspection and improves the efficiency of production. Later, along with the rapid rise of machine vision technology, many scholars gradually extended the application of this technology in the field of chip defect detection, making the chip defect detection method more and more mature and perfect [3].

The traditional chip defect detection technology is usually used to detect and identify the defect information such as cracks, white spots, defects, and internal defects contained in the target chip sample by inspection methods such as magnetic particle inspection method, penetrant inspection method, eddy current inspection method, ultrasonic inspection method, and X-ray inspection [4-10]. Despite the achievements of traditional chip defect detection methods, there are some drawbacks. First, the chip and shape of the sample under inspection are demanding, and second, the professional requirements for the operator are high. For example, the detection results of penetrant flaw detection by the operator's influence, X-ray flaw detection if improper operation will produce radiation hazards to the operator, etc. Third, the traditional chip defect identification method is difficult to achieve the multiple requirements of intelligence, automation and high accuracy, low detection efficiency, etc. [11-13].

Machine vision technology plays an important role in chip defect detection technology. Features are mainly a combination of nondestructive testing, automation, and intelligence. Not only is it safe and efficient, but also has high detection accuracy [14]. Machine vision inspection technology is composed of three aspects: image acquisition, software image processing, and image analysis [15-17]. The image acquisition part is mainly to select a suitable light source, professional camera, and lens to realize the picture acquisition of the sample. The principle is mainly to use the image sensor to convert the light converged by the lens into an electrical signal, and then into a digital signal, and pass it to the software processing part for analysis. The software processing part mainly covers measures such as image denoising, image enhancement, and edge detection [18-20]. The image analysis part includes three parts: extraction of feature information, screening of effective features, and recognition of images using classifiers. Mainly based on the extraction of effective feature information from the pixels of the image, algorithms such as PCA are often used to

https://doi.org/10.17993/3ctecno.2023.v12n2e44.347-362

compress the image pixel data and reduce the high-dimensional image data to obtain the features [21-22]. This makes it easier for the classifier to recognize feature information during image recognition, thus improving the accuracy of classification and more correct classification recognition [23-24].

Machine vision techniques are used in a large number of applications for defect detection and target classification. In the literature [25], the location of the damage appearance and identification of the damage type was roughly calculated using the YOLOv3 detection network based on the image dataset of untouchable damage. Using the designed level set algorithm, more accurate damage locations are obtained in the image blocks. In the literature [26], a machine vision system based on a recorder and image signal processing was proposed for automatic assessment. The machine vision system consists of four modules, including a video acquisition module, an image extraction module, an image processing module, and a trajectory state evaluation module. Three classical edge detection methods were used and compared. The literature [27] provides an overview of the application of machine vision models in the field of fish classification and then discusses in detail the specific applications of various classification methods. In addition, the challenges and future research directions in the field of fish classification are discussed. The literature [28] reviews the application of machine vision techniques for 3D dimensional and morphological measurements of high-temperature metal components. In addition, two aspects are described in detail, based on the principles and methods of measuring device construction: laser scanning measurement and multi-view stereo vision techniques. Through comparison and analysis, special attention is given to each method to provide the necessary technical references for subsequent researchers. The literature [29] presents a multi-defect stereo inspection system for magnetic rings based on multi-camera vision technology to accomplish the automatic inspection of magnetic rings. The system can simultaneously detect surface defects and measure ring height. Two image processing algorithms are proposed, namely the image edge removal algorithm (IERA) and the magnetic ring localization algorithm (MRLA). Based on these two algorithms, a connected-domain filtering method for cracks, fibers, and large-area defects is established to accomplish defect detection. The results show that the system achieves a 99% recognition rate for defects such as cracks, adhesion, hanger adhesion, and pitting. The literature [30] reviewed the principles, cameras, and thermal data of infrared imaging-based machine vision and discussed the application of deep learning in infrared imaging machine vision. Case studies of IR imaging-based machine vision and deep learning on various platforms such as unmanned vehicles, cell phones, and embedded systems are also reported. Machine vision techniques have been rapidly developed in recent years for the detection of defects in high-performance phase-noise measurement chips. By combing and analyzing chip defect detection methods, the traditional machine vision problem of requiring different image processing algorithms for classifying different tasks is solved, and the further development of machine vision technology in the field of high-performance phase noise measurement chip defect detection is promoted.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.347-362

The environmental problems caused by chip defects have been a hot issue of great concern. To improve the correct rate and detection rate of high-performance phase noise measurement chip defect detection, and improve the ecological environment pollution caused by the chip production process. In this paper, based on the ecological environments problems such as waste gas, wastewater, and solid waste caused by chip defects in the chip production process, we build a machine vision inspection technology for detecting defects contained in high-performance phase noise measurement chips using three aspects: image acquisition, software image processing, and image analysis.

2. ENVIRONMENTAL POLLUTION CAUSED BY CHIP DEFECTS

The environmental pollution caused by chip defects mainly comes from the three wastes generated in the manufacturing process, namely wastewater, exhaust gas, and solid waste. The exhaust gas, wastewater, and solid waste generated during the chip manufacturing process contain high concentrations of organic pollutants as well as fluorinated pollutants and other pollution factors that are seriously harmful to the environment. A large number of gases are produced during the manufacturing process of chips due to defects. For example, PH3, BF3, Cl2, SF6, CF4, C4F8, BCl3 and other organic substances, ammonia nitrogen, fluorine-containing pollutants, and other factors. If these gases are directly discharged without treatment, they will cause great pollution to the environment and direct harm to human health.

With the continuous improvement of air pollution control, the concentration of flue gas emissions is becoming more and more strict, and as far as the enterprises themselves are concerned, the urgency of waste gas treatment is much greater than that of wastewater treatment. The more harmful components of the exhaust gas produced in the manufacturing process are hydrogen sulfide, fluorinated dust, and sulfur dioxide. These harmful substances can cause acute and chronic diseases of the human respiratory system. The wastewater produced in the chip manufacturing process contains a large amount of organic pollutants. Once these pollutants enter the surrounding water bodies, they will cause the microorganisms in the water bodies to multiply rapidly. This causes a dramatic decrease in dissolved oxygen in the water, which leads to the death of aquatic organisms in the water body due to lack of oxygen. Ammonia nitrogen is an important nutrient in the environment of water bodies, and its random discharge will lead to eutrophication of water bodies. At the same time, ammonia nitrogen is also a major oxygen-consuming pollutant, and when dissolved oxygen reacts with ammonia nitrogen in the water body, it will bring great toxic effects to other kinds of aquatic organisms in the water body. In addition, if ammonia nitrogen is ingested by the human body for a long time through the food chain, it will be transformed into ammonium nitrite in the human body under specific conditions, and the long-term accumulation of this substance in the human body will make the risk of cancer rise sharply. Fluorine is an essential element for the human body and is one of the main components of human bones and teeth. It also plays an important role in the

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.347-362

formation of bone tissue and tooth enamel and participates in metabolic processes by activating or inhibiting the activity of various enzymes. Lack of fluoride in the body or excessive fluoride inhalation can have serious health consequences. The cavities we usually see formed by erosion of tooth enamel, muscle atrophy, thickening of joints, and other large bony conditions are all unfavorable lesions due to the lack of fluoride in the body. Excess fluoride, on the other hand, can likewise bring about unfavorable some lesions, including bone deformation, back and leg pain, loss of labor force, and even worse, death. Fluorine is not only harmful to humans but also to the natural environment we live in. Some plants absorb some fluorine dissolved in water through the soil, and the excess fluorine can have a serious toxic effect on plants, which are eventually eaten by animals and humans.

2.1. EXHAUST GAS AND SOLID WASTE GENERATION DUE TO CHIP DEFECTS

Acid exhaust gas mainly comes from the exhaust gas generated by the volatilization of acidic raw materials from the wet etching of the array production process and the medium gas periodically emitted from the excimer laser annealing device. The main pollutants are acid mist such as HCL and fluoride. The alkaline exhaust gas mainly comes from the alkaline volatile substances generated from the development process of the array and color film production process, and the main pollutants are NH3. dry etching and chemical vapor deposition exhaust gas mainly come from some gas raw materials in the dry etching process to produce a certain amount of reaction exhaust gas and unreacted raw material gas. The main pollutants are N2O, SiH4, NH3, NF3, PH3, BF3, Cl2, SF6, CF4, C4F8, BCl3 and reaction waste gas fluoride and chloride, etc. Organic waste gas mainly comes from the volatilization of organic gases from organic raw materials in the production process, and the main pollutants are non-methane total hydrocarbons. Solid waste mainly comes from the waste of various raw materials used in the production process of array, color film, organic vapor deposition, and box formation. This includes their packaging containers, organic wiping materials, residual liquids, and expired unusable materials. Chip manufacturing waste gas as well as solid waste generation is shown in Table 1.

https://doi.org/10.17993/3ctecno.2023.v12n2e44.347-362

Table 1. Generation of chip defect waste gas and solid waste

Pollution category	Pollution source	Major pollutants	Emission method	Production (t/a)	Yield concentration (mg/m^3)
Acid waste gas	Acidic volatile gases from array wet etching	Fluoride	Continuous	28.26	40
		NOX		83.79	120
Alkaline waste gas	Volatile alkaline gases emitted from developing production processes such as arrays and color filters	NH3	Continuous	20.56	65
		HCL		118.02	350
		Fluoride		201.7	520
Dry etching and chemical vapor depositio n exhaust	Unreacted gas and reaction waste gas discharged from vapor deposition, dry etching, doping, etc.	NOX	Continuous	48.01	128
		SO2		37.67	1500
		Cl2		198.70	600
Organic waste gas	Organic waste gas generated by coating, peeling, evaporation, etc. from arrays, color filters, organic evaporation, and box formation	Total non-methane hydrocarbon s	Continuous	5968.0	6000
Solid waste	Waste reagent containers, organic wiping materials, expired raw materials, residual liquids	Chemical reagents containing acids, bases, alcohol esters, ethers, etc.	Regular	8000	

2.2. CHIP DEFECT WASTEWATER GENERATION

The main pollutants of acid-base wastewater are pH, COD, BOD5, SS, F-, NH3-N. The fluorinated wastewater mainly comes from the PECVD deposition and dry etching process waste gas POU purification system discharge, and the array process fluorinated cleaning wastewater. purification device for treatment. The main pollutants in the discharged wastewater are F-, pH, COD, BOD5, SS, NH3-N. The phosphorus-containing wastewater mainly comes from wet etching using phosphoric acid, sulfuric acid, nitric acid, and other raw materials. Organic wastewater mainly comes from the production process of film, organic vapor deposition, box formation, etc., glue

https://doi.org/10.17993/3ctecno.2023.v12n2e44.347-362

application, glue stripping, detergent cleaning, etc. The production processes all use organic materials as raw materials and ultra-pure water is used for cleaning after the processes. Therefore, organic wastewater mainly comes from the cleaning wastewater of production processes such as array, color film, organic vapor deposition, and box formation, and organic wastewater is discharged from alkaline and etching exhaust gas washing and purification system. The main pollutants are COD, BOD5, SS, NH3-N, pH, etc. The wastewater generation situation of the chip manufacturing industry is shown in Table 2.

Table 2. Wastewater generation of chip defect

Pollution category	Pollution source	Major pollutants	Emission method	Wastewater volume(m^3/d)
Acidic wastewater	Acid-base waste gas treatment system discharge waste water pure water preparation of waste water	PH, COD, BOD5, SS、F^- , NH3-N	Continuous	4202
Fluorinated wastewater	Wastewater from exhaust gas purification systems for ECVD deposition and dry etching processes	PH, COD, BOD5, SS、F^- , NH3-N	Continuous	2518
Phosphorus-containing wastewater	Array wet etching discharge cleaning wastewater	PH, COD, BOD5, SS, Phosphate	Continuous	683
Organic wastewater	Equipment circulating cooling water system sewage, boiler sewage, etc.		Continuous	5496

3. APPLICATION OF MACHINE VISION-BASED TECHNOLOGY FOR HIGH-PERFORMANCE PHASE NOISE MEASUREMENT CHIP DEFECT DETECTION

Machine vision technology plays an important role in chip defect detection. Features are mainly non-destructive testing, automation, and intelligence combined, not only good safety, and high efficiency, but also high detection accuracy.

Machine vision inspection technology is composed of three aspects: image acquisition, software image processing, and image analysis. The image acquisition part is mainly to choose the appropriate light source, professional cameras, and lenses, to achieve the picture acquisition of chip samples. The principle is mainly to use the image sensor to convert the light converged by the lens into electrical signals, and then into digital signals, and pass to the software processing part for analysis. The software processing part mainly covers measures such as image denoising,

https://doi.org/10.17993/3ctecno.2023.v12n2e44.347-362

image enhancement, and edge detection. The image analysis part includes three parts: extraction of feature information, screening of effective features, and recognition of images using classifiers. It is mainly based on the extraction of effective feature information from the pixels of the image. Algorithms such as PCA are often used to compress the image pixel data and reduce the high-dimensional image data to obtain features. This makes it easier for the classifier to recognize feature information during image recognition, thus improving the accuracy of classification and more correct classification recognition. The detection workflow diagram is shown in Figure 1.

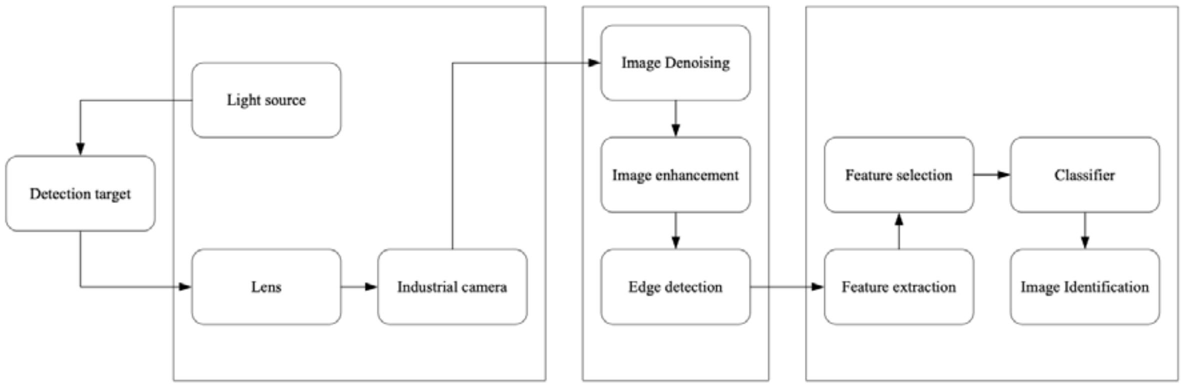


Figure 1. Detection workflow diagram

4. RESULTS AND ANALYSIS

Machine vision technology for chip defect identification detection has the advantages of automation, high detection efficiency, and high accuracy of defect identification. With the rapid development of machine vision technology in recent years, machine vision inspection technology has been used in a large number of applications in chip defect detection. Selected 100 high-performance phase noise measurement chips containing different kinds of defects, through the application of machine vision technology detection, two cases of false detection occurred. Once a foreign object on the chip surface was not detected and once a metallic contaminant present on the chip was not detected. This resulted in a 98% correct rate of chip defect detection. By fixing the chip defect problem, the environmental problems caused by chip defects were improved in three ways.

1. Acidic emissions from the manufacturing process due to chip defects mainly come from the volatilization of acidic raw materials from the wet etching process of the array manufacturing process, and the periodic emission of dielectric gases from the excimer laser annealing unit. The main pollutant is "fluoride". The alkaline exhaust gas mainly comes from the alkaline volatile substances generated from the development process of the array and color film production process. The main pollutant is "NH3". Dry etching and chemical vapor deposition waste gas mainly come from some gas raw materials in the dry etching process to produce a certain amount of reaction waste gas and unreacted raw material gas. The main pollutant is "NOX". Organic waste gas

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.347-362

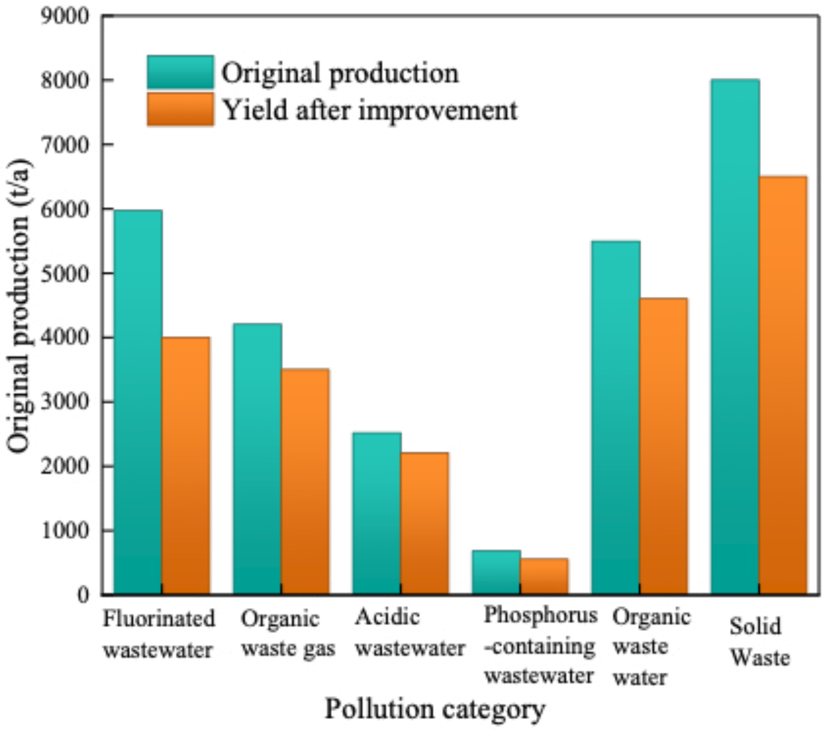
mainly comes from the volatilization of organic gases in the organic raw materials during the production process, and the main pollutant is non-total methane hydrocarbon. The application of machine vision technology in the detection of defects of chips with high-performance phase noise measurement has improved the defects of chips and reduced the amount of acidic exhaust gas "fluoride" from 28.26t/a to 20.53t/a. The amount of "NH3", the main pollutant of dry etching and chemical vapor deposition waste gas, is reduced from 48.01t/a to 35.23t/a. The amount of "NOX", the main pollutant of organic waste gas, is reduced from 20.56t/a to 15.2t/a. The amount of "non-methane total hydrocarbons", the main pollutant of organic waste gas, was reduced from 5968.0t/a to 4000t/a.

2. The wastewater generated in the manufacturing process due to chip defects mainly includes acid and alkali wastewater, phosphorus-containing wastewater, fluorine-containing wastewater, and organic wastewater. Acid-base wastewater mainly comes from acid-base cleaning wastewater discharged from the production system, acid exhaust gas scrubbing and purification system discharge wastewater, and regeneration backwash wastewater discharged from the pure water preparation system. Fluorine-containing wastewater mainly comes from wastewater discharged from PECVD deposition and dry etching process exhaust gas POU purification system, and fluorine-containing cleaning wastewater from array process. Phosphorus-containing wastewater mainly comes from wet etching using phosphoric acid, sulfuric acid, nitric acid, and other raw materials, and the cleaning wastewater after etching mainly contains pH, COD, BOD5, SS, phosphate, and other pollutants. Organic wastewater mainly comes from the array, color film, organic vapor deposition, box formation, and other production process cleaning wastewater, and organic wastewater discharged from alkaline and etching exhaust gas scrubbing and purification systems. Through the application of machine vision technology in the detection of defects of chips with high-performance phase noise measurement, the defects of chips are improved, so that the wastewater volume of acidic wastewater from the chip manufacturing process is reduced from 4202m^3/d to 3500m^3/d. The wastewater volume of phosphorus-containing wastewater is reduced from 683m^3/d to 552m^3/d. The wastewater volume of fluorine-containing wastewater is reduced from 2518m^3/d to 2208m^3/d. The wastewater volume of organic wastewater is reduced from 5496m^3/d to 4600m^3/d.

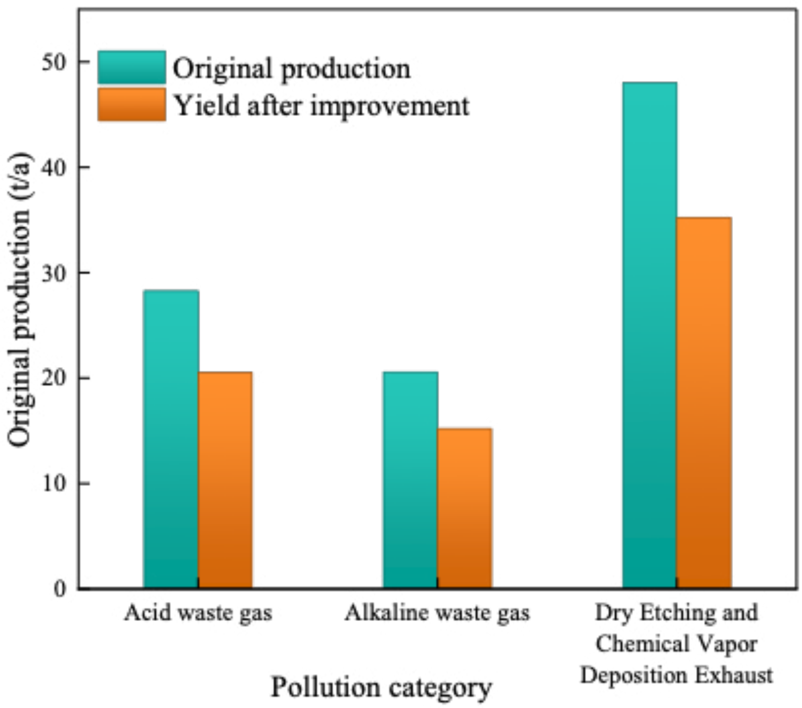
3. The solid waste generated in the manufacturing process due to chip defects mainly comes from the waste of various raw materials used in the production processes of the array, color film, organic vapor deposition, and box formation. This includes their packaging containers, organic wiping materials, residual liquids, expired unusable materials, etc. Through the application of machine vision technology in the detection of defects in high-performance phase noise measurement chips, the defects of chips have been improved and the amount

 https://doi.org/10.17993/3ctecno.2023.v12n2e44.347-362

of solid waste generated from the chip manufacturing process has been reduced from 8000t/a to 6500t/a. See Figure 2 for details.



(a) Organic waste gas, wastewater, and solid waste



(b) Acid and alkaline waste gas, dry etching, and chemical vapor deposition waste gas

Figure 2. Quantification of waste generation

https://doi.org/10.17993/3ctecno.2023.v12n2e44.347-362

Inspection using machine vision technology is an important step in the chip production process. Geometric measurement is the key technology for automatic inspection in traditional automated inspection. Although this technology can achieve automatic inspection, in terms of detection accuracy, speed is relatively poor, and has gradually failed to meet the automation efficiency to further enhance the requirements. The application of machine vision technology in automatic inspection can use CT, laser scanning, and other technologies to synchronize automatic inspection, which can not only effectively improve the speed of automatic inspection, but also further improve the accuracy of automatic inspection. Secondly, the biggest advantage of machine vision technology in automatic inspection is that automatic inspection technology can realize the detection of chip appearance. The traditional geometric inspection method cannot realize the processing of chip appearance information and can only deal with geometric dimensions. Machine vision technology, on the other hand, can effectively realize the processing of the chip surface, thus further enhancing the accuracy of the detection. Based on the generation and emission of major pollutants before and after chip defect detection, it can be seen that the use of machine vision technology to detect chip defects not only helps to repair chip defects promptly but also greatly reduces the amount of waste gas, wastewater and solid pollutants generated by chip defects, alleviating the degree of harm caused to the surrounding environment. In summary, machine vision-based chip defect detection technology is of great importance to improve the ecological level.

5. DISCUSSION

Machine vision technology is not only the core of artificial intelligence technology, but also has a very important significance for the current social production efficiency improvement. In the future machine vision technology is bound to achieve further development. Extraction of chip defect information characteristics, not only can achieve high precision detection of high-performance noise measurement chip defects but also can directly achieve end-to-end chip defect detection, reducing the complexity of engineering. Also, the scope of application in social production will be further promoted. Most of the current methods for chip defect detection are based on two-dimensional images. Such methods can only obtain limited flat feature information, and cannot obtain the spatial feature information of material defects. Therefore, how to capture and use three-dimensional defect information more accurately to detect defects is also a direction worthy of future research.

6. CONCLUSION

This paper is based on the ecological environmental problems caused by chip defects in the chip production process. Choose the appropriate light source, professional camera, and lens to achieve the picture acquisition of chip samples. Through image denoising, image enhancement, edge detection, and other measures, image processing is completed. After three parts: extraction of feature information,

https://doi.org/10.17993/3ctecno.2023.v12n2e44.347-362

screening of effective features, and recognition of images using classifiers, high-performance phase noise measurement chip defects are detected. The conclusions of the obtained study are as follows.

1. Through the comparison of traditional chip defect detection technology and machine vision technology, it is concluded that machine vision technology for chip defect identification and detection has the advantages of automation, high detection efficiency, and high accuracy of defect identification. The biggest advantage of machine vision technology in automated inspection is that the automatic detection technology can achieve the detection of chip appearance. Traditional geometric inspection methods can not achieve the processing of chip appearance information, only geometric size, while machine vision technology can effectively achieve the processing of the chip surface, thereby further enhancing the accuracy of detection.

2. Chip defect identification detection by machine vision technology has the advantages of automation, high detection efficiency, and high accuracy of defect identification. Machine vision inspection technology has been applied in a large number of chip defect detection, and the correct rate of chip defect detection is as high as 98% through the application of machine vision technology detection.

3. Analysis of the type of environmental pollution caused by chip defects, and the use of machine vision technology for chip defect detection. By dealing with chip defects promptly, the amount of waste gas, wastewater, and solid waste generated is reduced. The amount of organic waste gas generated was reduced from 5968.0t/a to 4000t/a, the amount of organic wastewater generated was reduced from 5496m^3/d to 4600m^3/d, and the amount of solid waste generated was reduced from 8000t/a to 6500t/a. The ecological environment around the enterprise was improved.

REFERENCES

(1) Wu, J. (2021). Chip Appearance Defect Recognition Based on Convolutional Neural Network. Sensors, 21.

(2) Larouci, B., Ayad, A. N. E. I., Alharbi, H., et al. (2022). Investigation on New Metaheuristic Algorithms for Solving Dynamic Combined Economic Environmental Dispatch Problems. Sustainability, 14.

(3) Li, C., Chen, H., Li, X., et al. (2020). A review for cervical histopathology image analysis using machine vision approaches. Artificial Intelligence Review, 53(1).

(4) Zhang, X., Gong, W., Xu, X. (2020). Magnetic Ring Multi-Defect Stereo Detection System Based on Multi-Camera Vision Technology. Sensors, 20(2), 392.

(5) Choi, S. M., Jeong, J. C., Kim, J., et al. (2020). A novel three-dimensional magnetic particle imaging system based on the frequency mixing for the point-of-care diagnostics. Scientific Reports, 10(1).

https://doi.org/10.17993/3ctecno.2023.v12n2e44.347-362

(6) Wang, D., Sun, B. C., Wang, J. X., et al. (2020). Can Masks Be Reused After Hot Water Decontamination During the COVID-19 Pandemic? Engineering.

(7) Huang, Y. (2021). Flaw Detection in Highly Scattering Materials Using a Simple Ultrasonic Sensor Employing Adaptive Template Matching. Sensors, 22.

(8) Liu, E., Liu, Y., Chen, Y., et al. (2022). Measurement method of bolt hole assembly stress based on the combination of ultrasonic longitudinal and transverse waves. Applied Acoustics, 189, 108603.

(9) Anderson, D. L., Cunningham, W. C. (2020). Nondestructive Determination of Lead, Cadmium, Tin, Antimony, and Barium in Ceramic Glazes by Radioisotope X-Ray Fluorescence Spectrometry. Journal of AOAC International, 5.

(10) Li, D., Wang, Q., Li, X., et al. (2022). Recent advances of machine vision technology in fish classification. ICES Journal of Marine Science, 2.

(11) Tian, Q., Conceptualization, Methodology, Data Curation, Software, Formal analysis, Writing - original draft, Writing - review & editing, Analysis C. F., Conceptualization methodology Q. F., et al. (2021). Improved cortical surface reconstruction using sub-millimeter resolution MPRAGE by image denoising. NeuroImage.

(12) Yang, W., Wang, S., Fang, Y., et al. (2021). Band Representation-Based Semi-Supervised Low-Light Image Enhancement: Bridging the Gap Between Signal Fidelity and Perceptual Quality. IEEE Transactions on Image Processing.

(13) Lu, S., Liu, Z., Chen, Y., et al. (2021). A novel subpixel edge detection method of pantograph slide in complicated surroundings. IEEE Transactions on Industrial Electronics, PP(99), 1-1.

(14) Tran, N., Wang, C. C. (2021). Enhancement of the accuracy of ultrasonic flowmeters by applying the PCA algorithm in predicting flow patterns. Measurement Science and Technology, 32(8), 085901 (18pp).

(15) Jones, I., Zhu, M., Zhang, J., et al. (2021). The application of spent tyre activated carbons as low-cost environmental pollution adsorbents: A technical review. Journal of Cleaner Production, 312, 127566.

(16) Xie, C., Liu, J., Liang, J., et al. (2021). Optimizing environmental pollution controls in response to textile dyeing sludge, incineration temperature, CaO conditioner, and ash minerals. Science of The Total Environment, 785, 147219.

(17) Ciobanu, C., Tudor, P., Istrate, I. A., et al. (2022). Assessment of Environmental Pollution in Cement Plant Areas in Romania by Co-Processing Waste in Clinker Kilns. Energies, 15.

(18) Liu, D., Song, C., Fang, C., et al. (2021). A recommended nitrogen application strategy for high crop yield and low environmental pollution at a basin scale. Science of The Total Environment, 792(26), 148464.

(19) Zandalinas, S. I., Fritschi, F. B., Mittler, R. (2021). Global Warming, Climate Change, and Environmental Pollution: Recipe for a Multifactorial Stress Combination Disaster. Trends in Plant Science.

(20) Torres, F. G., De-La-Torre, G. E. (2021). Environmental pollution with antifouling paint particles: Distribution, ecotoxicology, and sustainable alternatives. Marine Pollution Bulletin, 169, 112529.

(21) Liu, Z., Wang, Z., Chen, H., et al. (2021). Hydrochar and pyrochar for sorption of pollutants in wastewater and exhaust gas: A critical review. Environmental Pollution, 268(Pt B), 115910.

(22) Pavlenko, A. (2021). Capture of Pollutants from Exhaust Gases by Low-Temperature Heating Surfaces. Energies, 15.

(23) Chao, S., Guo, L., Sun, S. (2021). Zombie problem: Normal firms' wastewater pollution. Journal of Cleaner Production, 330(4), 129893.

(24) Cheng, D., Ngo, H. H., Guo, W., et al. (2020). A critical review on antibiotics and hormones in swine wastewater: Water pollution problems and control approaches. Journal of Hazardous Materials, 387, 121682-.

(25) Tao, J., Chen, Q., Xu, J., et al. (2022). Utilization of Both Machine Vision and Robotics Technologies in Assisting Quality Inspection and Testing. Mathematical Problems in Engineering, 2022.

(26) Wang, S. M., Liao, C. L., Ni, Y. Q. (2020). A Machine Vision System based on Driving Recorder for Automatic Inspection of Rail Curvature. IEEE Sensors Journal, PP(99), 1-1.

(27) Li, D., Wang, Q., Li, X., et al. (2022). Recent advances of machine vision technology in fish classification. ICES Journal of Marine Science, 2022(2), 2.

(28) Li, Feng & Abo Keir, Mohammed Yousuf. (2021). Mathematical model of back propagation for stock price forecasting. Applied Mathematics and Nonlinear Sciences. doi:10.2478/AMNS.2021.1.00089.

(29) Zhang, X., Gong, W., Xu, X. (2020). Magnetic Ring Multi-Defect Stereo Detection System Based on Multi-Camera Vision Technology. Sensors, 20(2), 392.

(30) He, Y., Deng, B., Wang, H., et al. (2021). Infrared machine vision and infrared thermography with deep learning: A review. Infrared Physics & Technology, 116(2), 103754.

(31) Shang, Y., You, B., Shang, L. (2016). China's environmental strategy towards reducing deep groundwater exploitation. Environmental Earth Sciences, 75, 1439.

(32) Zhang, J., Shang, Y., Cui, M., Luo, Q., Zhang, R. (2022). Successful and sustainable governance of the lower Yellow River, China: A floodplain utilization approach for balancing ecological conservation and development. Environment, Development and Sustainability, 24, 3014-3038.

(33) Lu, S. B., Shang, Y. Z.*, Pei, L., Li, W., Wu, X. H. (2017). The effects of rural domestic sewage reclaimed water drip irrigation on characteristics of rhizosphere soil. Applied Ecology and Environmental Research, 15(4), 1145-1155.

(34) Wang, J., Liu, J., Shang, Y., Jiang, D., Xiao, W. (2015). China's campaign to create artificial water surfaces in drought-affected regions must consider prevention measures for ecological problems. Environmental Earth Sciences, 74(6), 5457-5462.

(35) Lu, S., Shang, Y., Zhang, H. (2020). Evaluation on Early Drought Warning System in the Jinghui Channel Irrigation Area. International Journal of Environmental Research and Public Health, 17(1), 374.

(36) Panagopoulos, A., Haralambous, K. J. (2020). Environmental impacts of desalination and brine treatment - Challenges and mitigation measures. Marine Pollution Bulletin, 161(Pt B), 111773.

(37) Wang, T., Wang, P., Cai, S., et al. (2020). A Unified Trustworthy Environment Establishment Based on Edge Computing in Industrial IoT. IEEE Transactions on Industrial Informatics, 16(9), 6083-6091.

/21/

IMPROVED ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM BASED ON MODIFIED SALP SWARM ALGORITHM AND GOLDEN EAGLE OPTIMIZER ALGORITHM FOR INTRUSION DETECTION IN NETWORKS

Alaa Majeed Shnain Al mrashde

Al-Furat Al-Awsat Technical University / Babil Technical Institute

alaa.shnen.iba@atu.edu.iq

Reception: 04/05/2023 **Acceptance**: 30/06/2023 **Publication**: 21/07/2023

Suggested citation:

Shnain Al mrashde, A.M. (2023). **Improved adaptive neuro-fuzzy inference system based on modified salp swarm algorithm and golden eagle optimizer algorithm for intrusion detection in networks**. *3C Tecnología. Glosas de innovación aplicada a la pyme, 12(2)*, 364-386. https://doi.org/10.17993/3ctecno.2023.v12n3e44.364-386

https://doi.org/10.17993/3ctecno.2023.v12n3e44.364-386

ABSTRACT

With the increase in the growth of computer networks throughout the past years, network security has become an essential issue. Among the numerous network security measures, intrusion detection systems play a dynamic function with integrity, confidentiality, and accessibility of resources. An Intrusion Detection System (IDS) is a software program or hardware device which monitors computer system and/or network activities for malicious activities and produces alerts to security experts. In IDS there are three major problems namely generating many alerts, a huge rate of false positive alerts, and unknown attack types per generated alerts. Alert management methods are used to manage these problems. One of the methods of alert management is alert reduction and alert classification. The proposed approach focuses on enhancing the efficiency of the adaptive neuro-fuzzy inference system (ANFIS) using a modified salp swarm algorithm (SSA) and Golden Eagle optimizer (GEOSSA). The present study uses the Golden Eagle optimization algorithm to improve SSA behaviors. The proposed model (GEO-SSA-ANFIS) intends to determine the appropriate parameters using the GEO-SSA algorithm because these parameters are considered the main component affecting the ANFIS forecasting process. The results of the intrusion detection based on the NSL-KDD dataset were better and more efficient compared with those models because the detection rate was 96.68% and the FAR result was 0.438%.

KEYWORDS

Intrusion Detection System (IDS), adaptive neuro-fuzzy inference system (ANFIS), modified salp swarm algorithm (SSA), Golden eagle optimizer (GEO), Intrusion Detection in Networks.

INDEX

https://doi.org/10.17993/3ctecno.2023.v12n3e44.364-386

 https://doi.org/10.17993/3ctecno.2023.v12n3e44.364-386

1. INTRODUCTION

With the recent interest and progress in the development of Internet and communication technologies over the last decade, network security has emerged as a vital research domain. It employs tools like firewalls, antivirus software, and intrusion detection system (IDS) to ensure the security of the network and all its associated assets within cyberspace. Among these, a network-based intrusion detection system (NIDS) is the attack detection mechanism that provides the desired security by constantly monitoring the network traffic for malicious and suspicious behavior [1].

IDS solutions are one of the key security components that in combination with firewalls can effectively handle various types of security attacks. IDS schemes can be mainly classified as misuse detection schemes and anomaly detection schemes, which can be realized by using various machine learning techniques. Misuse detection or signature-based systems heavily depend on the signature of the security attacks and malicious behaviors and support multi-class classification. However, they cannot detect new attacks in which their signature is not available for the IDS. However, as an advantage, these schemes benefit from more accuracy in recognizing known malicious behaviors and their variants [2].

A possible protection mechanism such as intrusion detection is indispensable as it involves preventive action used to get rid of any malignant acts within the computer network. one merit is that they can locate previously unknown attacks, however, they retain to have a high false positive rate (FPR). Quite the contrary, the latter performs attack detection based on some known attack signatures. Utilizing a pattern-matching algorithm, an attack pattern candidate in the network is checked by comparing it with those predetermined signatures. This results in a lower FPR, but fails to detect novel attack patterns [3].

1.1. PROBLEM DEFINITION

Network security plays a vital role in avoiding financial loss, protecting customers from monetary damages, avoiding disabling or crippling services, and limiting severe information loss due to network intrusions. Attackers generally exploit the configurations and vulnerabilities of popular software to mount attacks against network computer systems. The damage caused by these attacks may vary from a little disruption in services to high financial losses. Existing conventional security techniques like firewalls are only used as the first line of defense [4].

Intrusion detection systems (IDS) perform the crucial task of detecting such attacks on computers and networks and alerting the system operators. An IDS may be placed in individual hosts in a network, in a dedicated central location, or distributed across a network. IDS’s that are designed to detect attacks on a network of computers rather than a single host are called network intrusion detection systems (NIDS). These systems monitor network functionality in the form of network telemetry, which may

https://doi.org/10.17993/3ctecno.2023.v12n3e44.364-386

include network traffic, metadata of network flows (eg: protocols such as NetFlow), and activity logs from hosts, and attempt to detect attack occurrences [5].

Because of the large volume of data, the network gets expanded with a false alarm rate of intrusion, and detection accuracy decreased. This is one of the significant issues when the network experiences unknown attacks. The principle objective was to expand the accuracy and reduce the false alarm rate (FAR) [6]. This study presents a novel forecasting model for detecting the abnormalities which have the largest effect on networks. The proposed method depends on improving the performance of the adaptive neuro-fuzzy inference system (ANFIS) using a modified salp swarm algorithm (SSA). The SSA simulates the behaviors of a salp swarm in nature during searching for food, and it has been developed as a global optimization method.

1.2. EXISTING CHALLENGES

With the large volume of data, the network gets expanded with false alarm rate of intrusion and detection accuracy decreased. This is one of the significant issues when the network experiences unknown attacks.

1.3. RESEARCH OBJECTIVES

- Improve the intrusion detection rate.
- Improve the security performance of the network.

1.4. THESIS STRUCTURE

The thesis organization is as follows: In the second chapter, we first explain the basic concepts. In the third chapter, it provides an overview of previous works in the field of intrusion detection in networks. In the fourth chapter, we describe the proposed solution. In the fifth chapter, we target the results and evaluation of the proposed algorithm, and at the end, conclusions and suggestions for future works are presented.

2. INTRUSION DETECTION SYSTEMS

Intrusion Detection System was initiated by Anderson in 1980. Various IDS products were created in 4 decades of IDS development. During its development, various kinds of problems arose, for instance, the high rate of false alarms which is sending alerts when there was no dangerous traffic. This will increase the network security analyst workload. If the network security analyst keeps getting false alarm alerts, then the actual attack may be infiltrated into one of these false alarms. Therefore, many studies on IDS focus on reducing the number of false alarms and increasing the ability to detect malicious traffic. On the other hand, traditional IDS is

https://doi.org/10.17993/3ctecno.2023.v12n3e44.364-386

incapable of detecting unrecognized attacks. Changes in conditions and the network environment are very fast and the emergence of various new technologies on the network also raises various types of new attacks. Therefore, it is urgent to develop an IDS that can detect attacks that are not even recognized (unknown attacks) [7].

The components of IDS are as follows [8]:

(i) Monitoring Network: A network needs to be monitored to gather necessary packets containing network-related information.

(ii) Data Collection: It refers to gathering the details about the target system on which the attack is to be conducted. This can be achieved by performing queries using network commands or tools. For instance, packet-level details can be obtained by sniffing the packets flowing through the network using “Wireshark” or obtaining server and host-related details such as domain name using network commands like “nslookup”.

(iii) Analysis of Packet Details: This can be referred to as scanning the network packet for stealing confidential information.

(iv) Identifying and Storing the Signature/Attack Patterns: The next step after the analysis of packet details is to identify the attack patterns of already known attacks and novel attacks or signatures of some known exploits which can be used to launch insider attacks. These signatures and patterns are stored in the database for future reference; hence, the security administrator can easily report intrusive behavior, if found anomalous.

(v) Generating Alert: After recognizing the attack pattern, an alert/alarm is generated and reported to the security administrator. The alert is triggered based on the matching of the signature/pattern.

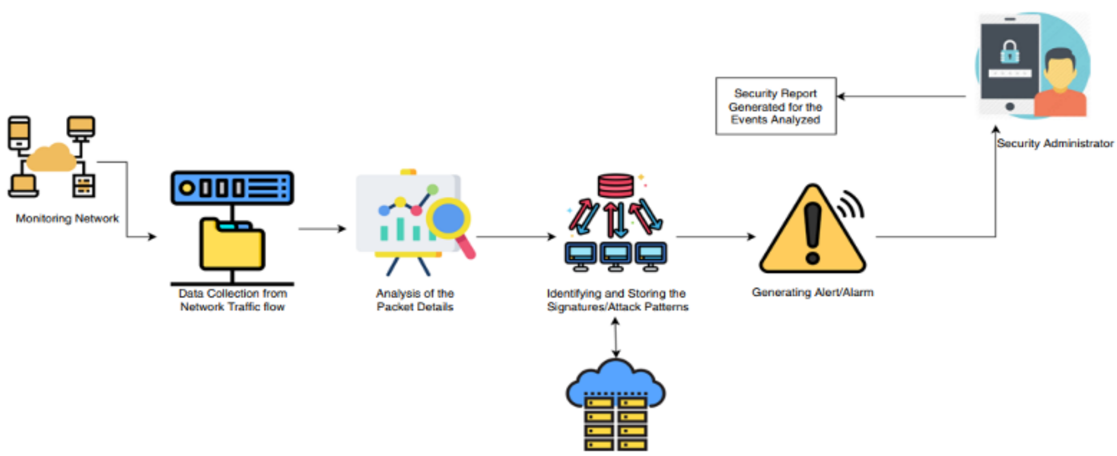


Figure 1. Components of IDS [8]

https://doi.org/10.17993/3ctecno.2023.v12n3e44.364-386

2.1. NETWORK IDS (NIDS)

Technological development resulted from dependence on global networks when using several businesses, educational and social activities. As a result of the increasing use of computer networks, several issues occurred in Internet security. Hence, keeping the security of devices connected to the Internet is important to ensure system availability and integrity.

2.2. HOST IDS (HIDS)

The main aim of HIDS is to control the behavior and dynamic state of the computer system. The flow of packets and all the activities on a network has been scrutinized by HIDS. The system administrators receive some network alerts if any alternation or adjustment happens in the network. HIDS is gradually becoming crucial in securing a host computer framework and its network. HIDS is incorporated into the computer system to identify the intruder's abnormal behavior. It also protects the information from intruders, and the incidents are reported to the system administrator. If an attack happens on any other part of the network, then host-based IDS will not only detect an attack but will also monitor incoming and outgoing traffic. The file system located on the host performs audits of the users' login, currently, active processes, resource utilization, and much more can also be analyzed by a host-based IDS. Following are some of the advantages of HIDS [10]:

- All users' activities can be monitored in HIDS, whereas it is not conceivable in a network-based system.
- An attack that has originated from the host side can be identified by HIDS.
- The decrypted traffic to find a host-based system can analyze an attack signature. Thus, they also have the capability of monitoring encrypted traffic.
- No extra hardware is required as they can be easily installed on the existing host devices.
- For a small-scale network, Host-based IDS is cost-effective.

2.3. INTRUSION DETECTION SYSTEM TAXONOMY

IDSs are categorized into three groups, i.e., anomaly-based detection, signature-based detection, and specification-based detection [11]. To summarize the taxonomy, we show a conceptual diagram in Figure 2.

https://doi.org/10.17993/3ctecno.2023.v12n3e44.364-386

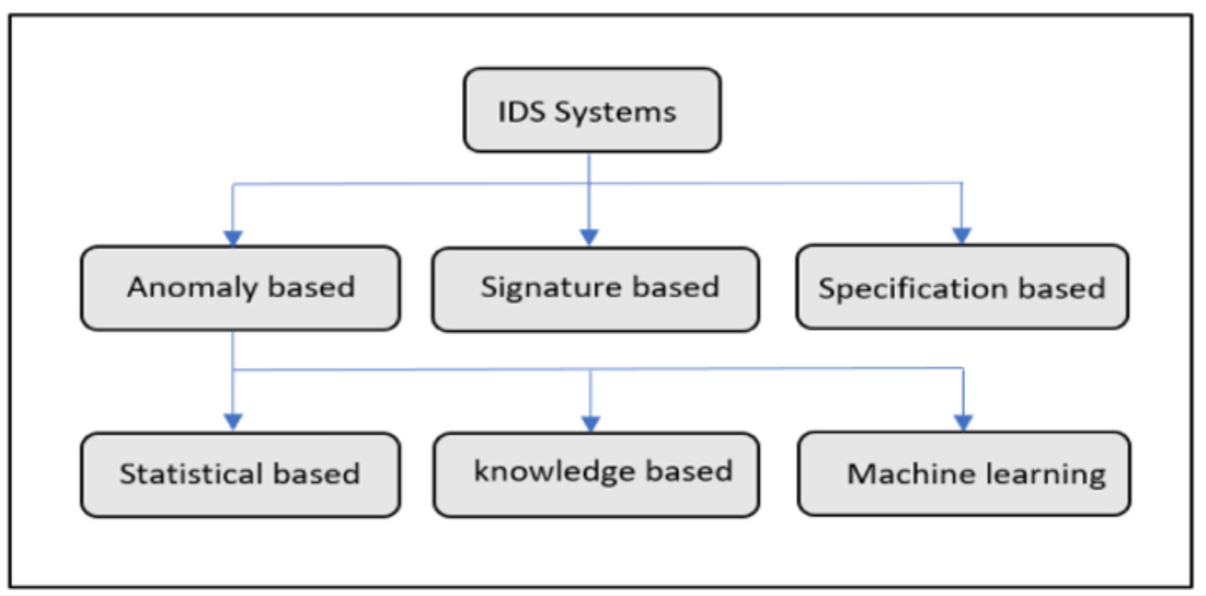


Figure 2. Taxonomy of intrusion detection system (IDS) systems [11].

2.3.1. ANOMALY-BASED TECHNIQUE

Anomaly detection refers to the deviation of network traffic from its normal profile. The normal profile is captured in the network's non-attack conditions and is represented mostly by statistical data. An example of such deviation is when a manager, who normally accesses the network in the daytime, uses his account to access it at night, which is regarded as a deviation of activity. Such a deviation is suspicious, and it can indicate an attack; however, such activity might not be associated with an attack. Thus, it is possible to have a false alarm based on this. Hence, continuous updates of the network's user activity patterns to avoid false alarms can be performed. In this study, we are interested in an anomaly-based IDS. Therefore, we create the following sub-taxonomy of such systems:

Statistical-based anomaly IDS: The statistical-based anomaly IDS matches the periodically captured statistical features from the traffic with a generated stochastic model of the normal operation or traffic. The attack is reported as the deviation between the two statistical patterns, i.e., the normal memorized one and the current captured one.

Knowledge-based anomaly IDS: In knowledge-based anomaly detection, numerous rules are provided by experts in the form of an expert system or fuzzy-based system to define the behavior of normal connections and attacks. In fuzzy-based anomaly detection, the rule-based is connected to inputs. A subset of the rules is enabled based on the input values, sometimes heuristics or a UML-based description of the attack's behavior is provided.

Machine learning-based anomaly IDS: An explicit or implicit model of the analyzed patterns is developed in a machine learning-based anomaly IDS. These

https://doi.org/10.17993/3ctecno.2023.v12n3e44.364-386

models are revised regularly to boost intrusion detection efficiency based on past results.

2.3.2. SIGNATURE-BASED TECHNIQUE

A signature-based technique is also referred to as knowledge-based or misuse detection. It uses the signature of the attack and performs matching between the current traffic and the signature, and then reports an attack on the existence of matching, otherwise, it does not report an attack. Such an approach does not suffer from a high rate of false alarms like other approaches. However, it requires a continuous update of the signature [11].

2.3.3. SPECIFICATION-BASED TECHNIQUE

A specification-based technique uses the specification or constraints to describe a certain program's operation and reports any violation of such specification or constraints based on matching with the prior determined and memorized specification and constraints [11].

2.4. IDS DEPLOYMENT STRATEGIES

IDS can also be classified based on the deployment used to detect IoT attacks. In IDS Deployment strategies, IDS can be classified as distributed, centralized, or hybrid [12].

2.4.1. DISTRIBUTED IDS

In distributed placement, the IoT devices could be responsible for checking other IoT devices. Distributed IDS be made up of several IDS over a big IoT ecosystem, all of which communicate with each other, or with a central server that assists advanced intrusion detection systems, packet analysis, and incident response. Several IDS deploy distributed architectures. This includes a subset of the network checking the other nodes. Distributed IDS offers the incident analyst many advantages over centralized IDS. The main benefit is the capability to identify attack forms across a whole IoT ecosystem. This might increase prompt IoT attack prevention and detection. The additional supported benefit is to allow early detection of an IoT Botnet creating its way through corporate IoT devices. This data could then be used to detect and clean systems that have been infected by the IoT Botnet and stop further spread of the Botnet into the IoT ecosystem consequently taking down any IoT devices damaged that would otherwise have occurred. Furthermore, the advantage of distributed IDS rather than centralized IDS computing resources also implies reduced control over those resources.

https://doi.org/10.17993/3ctecno.2023.v12n3e44.364-386

2.4.2. CENTRALIZED IDS

In the centralized IDS location, the IDS is placed in central devices, for instance, in the boundary switch or a nominated device. All the information that the IoT devices collect and then send to the network boundary switch passes through the boundary switch. Consequently, the IDS positioned in a boundary switch can check the packets switched between the IoT devices and the network. Despite this, checking the network packets that pass through the boundary switch is not adequate to identify anomalies that affect the IoT devices. The network traffic is monitored in centralized IDS. This traffic is extracted from the network through different network data sources such as packet capture, NetFlow, etc. The computers connected in a network can be monitored by Network-based IDS. Moreover, NIDS is also capable of monitoring the external malicious activities that could have been commenced from an external threat at an earlier stage, before these threats expand to other computer systems. However, NIDS comes with some limitations such as its restricted ability to inspect the whole data in a high bandwidth network because of the volume of data passing through modern high-speed communication networks. NIDS deployed at several positions within a particular network topology, together with HIDS and firewalls, can provide concrete, resilient, and multi-tier protection against both external and insider attacks. Data source consists of system calls, application program interfaces, log files, and data packets that are extracted from well-known attacks. These data sources can be useful to classify intrusion behaviors from abnormal actions [12].

2.4.3. HIERARCHICAL IDS

In Hierarchical IDS, the network is separated into clusters. The sensor nodes that are adjacent to each other typically belong to the same cluster. Each cluster is assigned a leader, the so-called cluster head that screens the member nodes and plays a part in network-wide analyses.

2.5. RECENT IMPROVED SOLUTIONS TO INTRUSION DETECTION

With the advancement of recent technologies like Cloud services, and IOT devices, the Intrusion Detection System (IDS) has become a prominent technology to detect anomalies and attacks in the network. Many researchers have integrated IDS with data mining, fuzzy logic, neural networks, machine learning, and optimization techniques to improve the methods of detecting anomalies and attacks to improve the accuracy of detections. Information security is the main concern with advanced technologies like IoT and Cloud computing. With the increased usage of IoT networks and clouds in different domains, these have become more vulnerable targets for intruders and attackers. Many researchers have proposed different methods and approaches to detect malicious actions of intruders and found the need for security in the cloud and IOT to be implemented on the layers as well as protocol levels in the

https://doi.org/10.17993/3ctecno.2023.v12n3e44.364-386

service models. Many IDS based on statistical methods, knowledge-based methods, and machine learning techniques have been studied and presented in Table 25.1 according to the algorithms used and the results produced with their detection performance. The existing AIDS techniques can be categorized as the following [13]:

1. Based on Statistical methods
2. Based on machine learning methods and Data mining techniques
3. Knowledge-based
4. Evolutionary methods
5. Based on Statistical methods

IDS based on the statistical methods uses a distribution model for normal behavior profiles to detect potential intrusions based on statistical metrics such as mean, median, standard deviations, and mode of packets. Statistical IDS generally uses one of the following models; Univariate, multivariate, and time series models. In univariate technique-based IDS statistical normal profile is created based on only one measure of behaviors in computer systems for identifying abnormalities in each metric. While the Multivariate technique considers more than one measure to specify the relationships between variables including multiple data variables which can be correlated. The multivariate statistical IDs face challenges to estimate correlations and distributions for high-dimensional data. Any time series data can be defined as a series of observations made over a certain time interval. A new observation can be considered abnormal if it is not occurring at that time interval. Researchers used any occurred abrupt variation in time series data for detecting network abnormalities.

2.5.1. BASED ON DATA MINING AND MACHINE LEARNING

Methods Machine learning process is used to infer knowledge from huge amounts of data by applying a set of rules, methods, or complex “transfer functions” to find out unusual data patterns and predict abnormal behavior of user profiles. Several researchers have applied machine learning techniques in the area of AIDS such as clustering, neural networks, association rules, decision trees, genetic algorithms, and nearest neighbor methods to improve accuracy and reduce the requirement of human interventions. Machine learning algorithms can be classified into supervised, unsupervised, and semi-supervised techniques which are extensively being used in building AIDS and finding patterns.

2.5.2. KNOWLEDGE-BASED

https://doi.org/10.17993/3ctecno.2023.v12n3e44.364-386

An expert system-based approach requires creating a knowledge base consisting of genuine traffic profiles with the help of human knowledge and detecting any action different from this defined profile as an intrusion. This technique helps in reducing false positive alarms but requires the regular update of the knowledge base regarding the normal expected behavior of traffic profiles. This group of techniques includes a Finite state machine, Description Language, Expert System, and Signature analysis-based IDS.

2.5.3. EVOLUTIONARY METHODS AND OPTIMIZATION TECHNIQUES

This group of techniques makes use of nature-inspired algorithms such as ACO, PSO, Genetic Algorithms, Evolutionary computing, etc. to improve accuracy. These evolutionary approaches based on the principle of evolution and the concept of fitness methods are used for classification and feature selection in intrusion detection systems.

3. THE REVIEW OF PREVIOUS WORKS

In this section, we study the works done in the field of intrusion detection systems based on Evolutionary Methods and Optimization Techniques.

4. THE PROPOSED METHOD

In this work, we proposed a new model for detecting the abnormalities present in the network or system using a modified salp swarm algorithm (SSA) to improve the performance of the adaptive neuro-fuzzy inference system (ANFIS). However, SSA still has some limitations such as it is easy to suck at a local point; therefore, we use the Golden Eagle optimizer (GEO) algorithm to improve the behavior of SSA. In addition, we argue that the proposed model can be successfully applied to detecting the abnormalities present in the network or system. Also, we can confirm that it can be used for future predictions. The description of the proposed method is presented in this section (see Fig. 4).

https://doi.org/10.17993/3ctecno.2023.v12n3e44.364-386

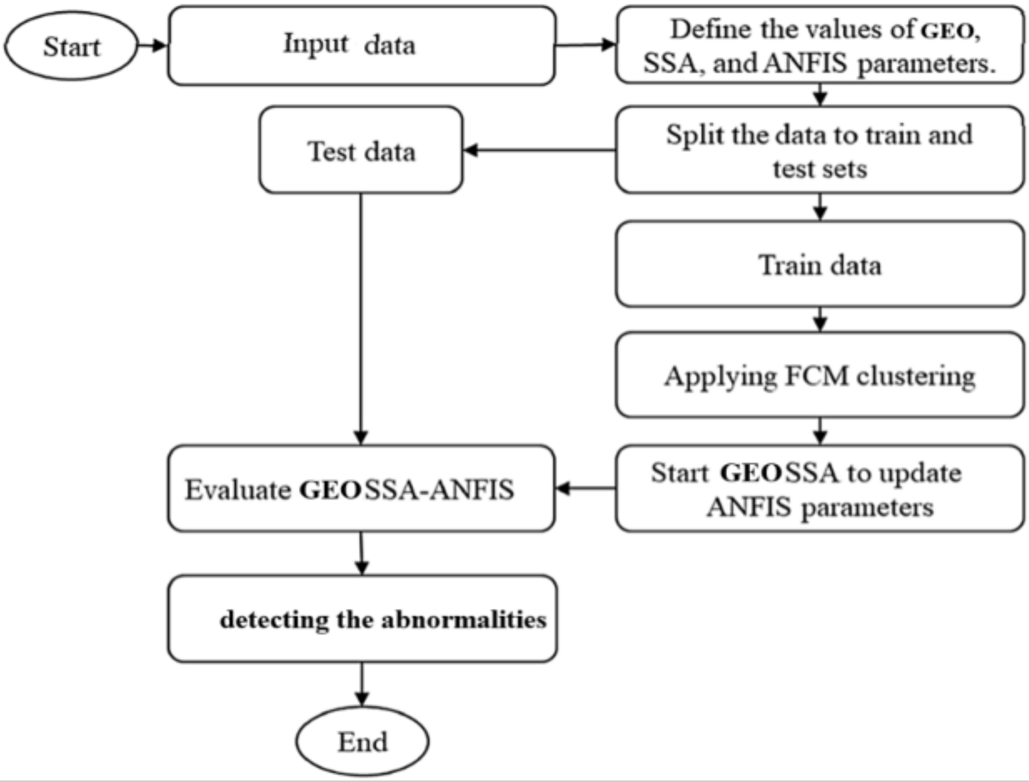


Figure 3. Proposed GEO-SSA-ANFIS.

4.1. ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM-ANFIS

ANFIS was a fusion of a fuzzy inference system (FIS) and ANN which has the benefits of both ANN and FIS. In ANFIS architecture, ANN extricates fuzzy rules from input information and the fuzzy membership function's parameters were adaptably utilized during the process of hybrid learning. ANFIS could create a relation between input and output dependent on human knowledge by utilizing data pairs of input-output and applying an algorithm based on hybrid learning. ANFIS was a sort of multilayer feedforward network made from five layers. The layers in the ANFIS architecture include many nodes defined by the function of the node.

The proposed method improves the ANFIS model using GEO and SSA algorithms which are called GEO -SSA-ANFIS. It applies GEO and SSA to adjust the parameters of the ANFIS by feeding the best weights between Layer 4 and Layer 5.

The rule basis of the ANFIS is:

If $v(x_1)$ is A_j, $v(x_2)$ is B_j, hence C_j is

$$S_j = a_j v\left(x_1\right) + b_j v\left(x_2\right) + c_j v\left(x_n\right) + g_j \tag{1}$$

https://doi.org/10.17993/3ctecno.2023.v12n3e44.364-386

Where $v(x_1), v(x_2)\ldots v(x_n)$ are the inputs, A_j, B_j, and C_j are the fuzzy sets, S_j is the output inside the fuzzy zone defined by the fuzzy rule. a_j, b_j, c_j, and g_j are the parameters that are specified by the training process.

Layer 1- In this la1yer, every j node was a square node with a function of the node.

$$L_{1,j} = \mu_{A_1} v\left(x_1\right), L_{1,j} = \mu_{B_1} v\left(x_2\right), L_{1,j} = \mu_{C_1} v\left(x_n\right) \tag{2}$$

Generally $\mu_{A_1} v(x_1)$, $\mu_{B_1} v(x_2)$, $\mu_{C_1} v(x_n)$are selected to be bell-shaped with max=1 and min=0 and are specified as

$$\mu_{A_1} v\left(x_1\right) = \mu_{B_1} v\left(x_2\right) = \mu_{C_1} v\left(x_n\right) = \left(\frac{1}{1 + \left(\frac{x - u_j}{v_j}\right)^{2y_j}}\right) \tag{3}$$

Where u_j, v_j, y_j are the set of parameters. In this layer, those parameters were described as basis parameters. Layer 2- In this layer, every node was a circle node labeled that multiplies the product out and the input signals. Example,

$$L_{2,j} = wp_j = \mu_{A_j} v\left(x_1\right) \times \mu_{B_j} v\left(x_2\right) \times \mu_{C_j} v\left(x_n\right), j = 1{,}2 \tag{4}$$

Every output node demonstrates the rule's firing strength. Layer 3- Each node was a circle node called N. The jth node computes the proportion of the jth rule firing strength to the addition of all rule's firing strength as,

$$L_{3,j} = wp_j = \frac{wp_j}{\left(wp_1 + wp_2\right)}, j = 1{,}2 \tag{5}$$

Layer 4- In this layer each node j was a square node with a function of node.

$$L_{4,j} = wp_j S_j, j = 1{,}2 \tag{6}$$

Where wp_j were the layer-3 output and a_j, b_j, c_j, and g_j are the parameters set? These layer parameters were described as consequence parameters.

Layer 5- A single node was a circle node labeled in this layer which calculates the total output as the sum of all input signals.

$$L_{5,j} = \frac{\sum_j wp_j s_j}{\sum_j wp_j} \tag{7}$$

Hence the predefined threshold value φ and the output of the neural network Z are compared which is expressed in the below equation,

https://doi.org/10.17993/3ctecno.2023.v12n3e44.364-386

$$\text{output} = \begin{cases} \text{error}, & Z < \varphi \\ \text{no error}, & Z \geq \varphi \end{cases} \tag{8}$$

To enhance the prescient accuracy of ANFIS and abstain from falling into the local optimum, parameter learning is performed by the modified salp swarm algorithm (SSA) and Golden Eagle optimizer (GEOSSA).

The GEO-SSA-ANFIS starts by preparing the inputs and dividing the problem into training and testing sets. Then the fuzzy c-mean (FCM) algorithm is used to determine a suitable number of the membership functions by clustering the dataset into different groups. Thereafter, the ANFIS uses these results to start the rest of the steps. The ANFISs parameters, namely the weights, are adapted using the GEO-SSA algorithm, where the GEO-SSA searches for the solution in the problem space by exploring various domains. In the first step in the proposed method, the GEO is used to generate the initial population of the SSA. Then the SSA uses this population to start searching for the best weights of the ANFIS. The fitness value of the population is calculated by the following fitness function.

$$Objective\ function = \|obs - pred\|^2 \tag{9}$$

Therefore, the selected weights are updated based on minimizing the error between the output and the real values in the training phase. These weights are passed to the ANFIS to prepare the output results of a given problem. The GEO-SSA works till meeting the stop condition in this paper which is the max number of iterations. After that, the test phase starts, and the best weights are passed to the ANFIS to produce the output.

4.2. SALP SWARM ALGORITHM (SSA)

Salp swarm algorithm (SSA) [24] is one of the recent optimization methods developed by Mirjalili et al. (2017). They tried to mathematically simulate the salp chains' behavior of the real salps. Salps are considered a kind of the Salpidaes family. They look like jellyfish in their moving behavior and their bodies contain a high water percentage. Salps use their swarm behavior (i.e., salp chain) in foraging and moving with fast harmonious changes. Food sources are the target of the swarm. The mathematical model of SSA begins by generating a population and then dividing it into leaders and followers based on their position. The leader is the front salp of the chain, and the followers are the rest of the salps. This study applies GEO and SSA to adjust the parameters of the ANFIS.

The position is formed in n-dimensions that denote the search space of a given problem, whereas the problem variables are represented by n. The position is frequently updated. The equation below is applied to update the position of the salp leader:

$$x_j^1 = \begin{cases} F_j + c_1\left(\left(ub_j - lb_j\right) \times c_2 + lb_j\right) & c_3 \leq 0 \\ F_j - c_1\left(\left(ub_j - lb_j\right) \times c_2 + lb_j\right) & c_3 > 0 \end{cases} \quad (10)$$

where x_j^1 denotes the leader's position in jth dimension. Fj denotes the food source. ub_j and lb_j are the upper and lower bounds, respectively. c_2 and c_3 are random variables in [0,1] that help in maintaining the search space. c_1 is a coefficient used to balance the exploitation and exploration phases. It is computed as follows:

$$c_1 = 2e^{-\left(\frac{4l}{L}\right)^2} \quad (11)$$

where l and L indicate the current loop and the max number of loops, respectively. Subsequently, the position of the followers is updated using the following equation:

$$x_j^i = \frac{1}{2}\left(x_j^i + x_j^{i-1}\right) \quad (12)$$

where x_j^i is the ith follower position, and $i > 1$. The entire sequence of the SSA is listed in Algorithm 1.

Algorithm 1 Salp Swarm Algorithm (SSA)

Create a population X.
repeat
    Calculate the objective function for solutions x_i.
    Update the best solution (salp) $(F = X^b)$.
    Update c_1 by Eq. ssa2.
    for $i = 1 to N$ **do**
        if $i == 1$ **then**
            Update the salps position of by Eq. (8)
        else
            Update the salps position of by Eq. (10)
        end if
    end for
until $(l \leq L)$
Return the best solution F.

Figure 4. Algorithm of Salp Swarm Algorithm (SSA)

https://doi.org/10.17993/3ctecno.2023.v12n3e44.364-386

4.3. GOLDEN EAGLE OPTIMIZER (GEO)

Golden Eagle Optimizer [25] is a swarm-intelligence metaheuristic algorithm and its multi-objective version is based on the golden eagles' hunting process. The authors are called Golden Eagle Optimizer (GEO) and Multi-Objective Golden Eagle Optimizer (MOGEO). GEO is founded on the intelligent adjustments of attack propensity and cruise propensity that golden eagles perform while searching for prey and hunting. MOGEO uses the same principles and is equipped with special tools to handle multi-objective problems. This study uses GEO as an optimization technique to improve the behavior of SSA.

This algorithm simulates the spiral foraging behavior of golden eagles. GEO completes the exploration and exploitation processes of the algorithm through attack vectors and cruise vectors.

4.3.1. ATTACK (EXPLOITATION)

The attack process of the golden eagle is represented by an attack vector A, which is shown in Eq. (13):

$$A_i = X_f^* - X_i \tag{13}$$

where A_i is the attack vector of the Ith golden eagle, X_f^* is the best position that golden eagle f has found so far, and X_i is the current position of golden eagle i.

where c_y is the yth element of C_i, b_j and by are the jth and yth elements of A_i, respectively. d corresponds to the value on the right side of Eq. (12). After determining the fixed variables of the cruise hyperplane, the cruise vector can be expressed by Eq. (4-17):

$$C_i = \left(c_1 = \text{ random }, c_2 = \text{ random }, \ldots, c_y = \frac{d - \sum_{j, j \neq y} b_j}{b_y}, \ldots, c_n = \text{ random } \right) \tag{14}$$

5. DATASET

NSL-KDD (National security lab–knowledge discovery and data mining) is the enhanced form of KDD99 to outperform its limitations. Initially, duplicated records in the training and test sets are eliminated. Second, there are different records chosen from the original KDD99 to accomplish dependable outcomes from classifier systems. Third, the issue of the unbalanced probability distribution was removed. The NSL-KDD data set has 125,973 training instances and 22,544 test instances, with 41 features, 38 consistent, and three categorical (discrete-valued) [26].

5.1. PARAMETERS' INITIALIZATION

https://doi.org/10.17993/3ctecno.2023.v12n3e44.364-386

To evaluate the quality of the proposed algorithm, we adjusted the parameters according to the parameters of the base paper [14]. In this way, 80% of the data were considered for training and 20% of the data were considered for testing. Table 1, shows the settings for the parameters of the proposed method.

Table 1. Initial values for the parameters in the proposed method

Parameters	Values
Train dataset	80 %
Test dataset	20 %
MaxIterations	20
nPop	30

5.2. EVALUATION CRITERIA

We will use more accurate measurement parameters to compare the proposed solution with algorithms. One of the criteria used to display the accuracy of data classification is the method of finding the accuracy.

The choice of a criterion for evaluating the effectiveness of the method depends on the problem we are trying to solve. Suppose several data samples are available. These data are given to the model individually and one class is received as output for each. The model predicted by the model and the actual data class can be displayed in a Table. Table 2 is called the confusion matrix.

Table 2. Confusion Table

	The label of predicted class		
	predicted / actual	Normal	Attack
The actual class of label	Normal	True negative (TN)	False positive (FP)
	Attack	False negative (FN)	True positive (TP)

True positive: Samples that have been correctly detected as attacks by the test.

False positive: Samples that have been wrongly detected as attacks by the test.

True negative: Samples that have been correctly detected as Normal by the test.

False negative: Samples that have been wrongly detected as Normal by the test.

To evaluate the performance of the proposed method model, a comparative analysis with the base paper has been performed using several performance criteria.

https://doi.org/10.17993/3ctecno.2023.v12n3e44.364-386

MATLAB 2020b was used to implement the simulations. The used performance metrics are accuracy, Kappa.

5.2.1. ACCURACY CRITERION

The ability of a test to correctly distinguish fluctuations and normal events from others is called accuracy. To calculate the accuracy of a test, one must obtain the ratio of the sum of true positive and true negative samples to the total number of tested items. Mathematically, this ratio can be expressed as follows:

$$ACC = \frac{TN + TP}{FP + FN + TP + TN} \tag{15}$$

Detection rate refers to the test's ability to correctly detect attacks on the network (connections that are intrusion). The DR of the test method is the ratio of several connections correctly predicted to the total number of connections that are an intrusion. Mathematically, this can be expressed as follows:

$$\mathrm{DR} = \frac{TP}{TP + FN} \times 100 \tag{16}$$

False Positive Rate: This percentage falsely classifies normal cases as malware attacks compared to the total number of normal cases. This is given by the following formula.

$$\mathrm{FPR} = \frac{FP}{FP + \mathrm{TN}} \times 100 \tag{17}$$

Where FP and TN are true positive and negative numbers, respectively. A complete intrusion detection method must be 100% accurate while having a 0% false positive rate (FPR), which indicates that it can detect all possible attacks without error (incorrect classification), which is very difficult and probably impossible in real environments.

5.3. THE RESULTS' EVALUATION

In this thesis, the NSL-KDD dataset is reduced to a two-class problem, and the dataset is divided into normal and abnormal data. i.e. one class is considered normal and the rest of the classes are considered abnormal. Hence, the original NSL-KDD dataset is processed before testing. First, the character features in the NSL-KDD dataset are mapped to numeric features, three of which are as follows: "protocol type", which consists of three-character types. "Service", which includes 70 types of characters. The "flag" contains 11 characters. For these three parts, sorted substitutions are made using the decimal number starting with "1". After placement, the range is "Protocol Type" [1,3], the range is "Service" [1,70] and the range is "Flag" [1,5]. Since the range of each feature in the NSL-KDD dataset is approximately different, it must be normalized before testing. The same as general datasets, each NSL-KDD dataset is divided into a training set and a testing set, which consists of the 80% training set and the 20% test set, and the same training set and test set are used for each algorithm. The number of populations and their repetition are 30 and 20, respectively.

GEOSSA has been used to find proper parameters for participating in the classification. The classification rate with ANFIS and the number of selected features act as the utility value for each solution. Table 3 shows the results related to the optimization of ANFIS parameters. By observing the results mentioned in this Table, it is determined that the use of the proposed method leads to better results in terms of accuracy, detection rate, and false positive rate. Using this mentioned method, the number of features is significantly reduced, which means reducing complexity and increased efficiency. Table 3. compares the proposed methods with other methods. The results of experiments performed in this study show that performing optimizing the ANFIS parameters leads to better results compared to other methods. In parameter optimization, the program runs in a shorter period and leads to higher accuracy, sensitivity, and specificity in implementation.

The results of the proposed method, and the base paper [14] in the NSL-KDD dataset are shown in Table 3, where "accuracy", "precision", "false positive rate", and "sensitivity" are provided for all two algorithms.

Table 3. Comparing the classification accuracy of the proposed method with the existing methods

Dataset	Evaluation criteria	Proposed method	Base article [14]
NSL-KDD	Accuracy	96.22	94.12
	False positive rate	438	3.45
	Detection Rate	96.68	95.80

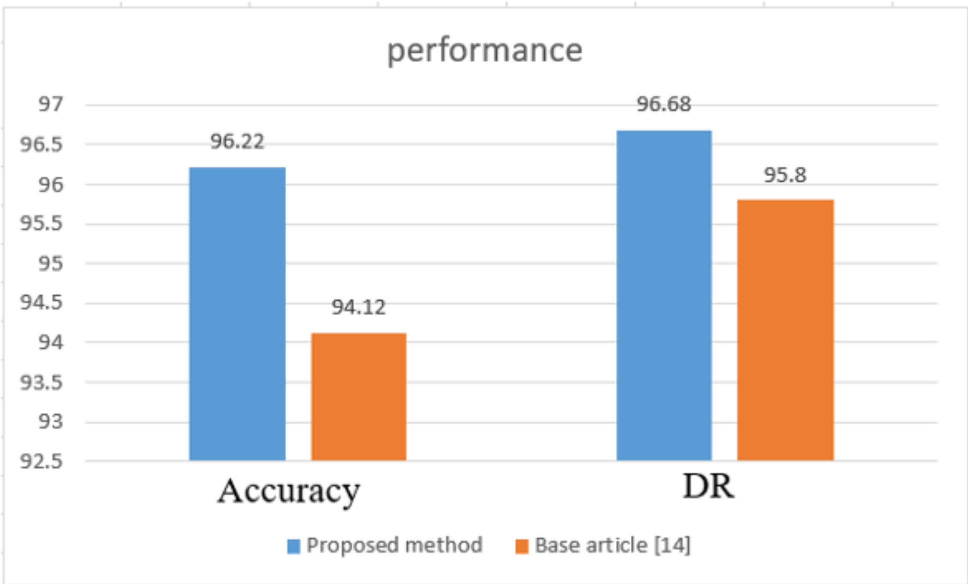


Figure 5. Comparison of the proposed method with existing methods

https://doi.org/10.17993/3ctecno.2023.v12n3e44.364-386

As shown in Figure 5, the proposed method is more efficient in the NSL-KDD dataset. Compared to the accuracy classification of the base paper method [14] the accuracy of the proposed method classification is higher, moreover, it has better sensitivity, accuracy, and false positives as shown in Table 3. For NSL-KDD random datasets, the classification accuracy of the proposed method can be more than 96.22%. The proposed method has a significant improvement in classification accuracy and better stability in network intrusion detection in comparison with existing methods.

The results of experiments performed in this study show that performing optimizing the ANFIS parameters leads to better results compared to other methods. The method of parameter optimization leads to a higher degree of accuracy, sensitivity, and specificity in the implementation.

The efficiency of intrusion detection is measured with the performance of detection rate and FAR. Because the detection rate and FAR are the essential parameters that are considered for the IDS to detect attacks. From the performance of the proposed model, the detection rate and false alarm rate are satisfactory compared with the other techniques as shown in Table 3. The GEOSSA-ANFIS model achieved a 96.68% detection rate and 0.438% false alarm rate, which is 3.012% FAR less than CSO-ANFIS [14] technique.

6. CONCLUSION

In this research, the intrusion detection system issues are presented and various techniques for solving the issues were discussed. ANFIS-based intrusion detection was a system proposed to detect attacks in networks. Because of the ANFIS, the combination of the fuzzy interference model and ANN has more advantages over other techniques. this thesis uses the Golden Eagle Optimizer (GEO) algorithm to improve the behavior of SSA. The proposed model (GEO-SSA-ANFIS) aims to determine the suitable parameters for the ANFIS by using the GEO-SSA algorithm since these parameters are considered the main factor influencing the ANFIS prediction process. Additionally, the GEO algorithm was used to optimize the ANFIS model to enhance its performance over intrusion detection which is an advantage for the IDS system. The proposed model has been used to solve the issues of intrusion detection and the model is validated using the familiar NSL-KDD dataset. The proposed model is compared with the other existing techniques like CSO-ANFIS. The results of the intrusion detection based on the NSL-KDD dataset were better and more efficient compared with those models because the detection rate was 96.68% and the FAR result was 0.438%.

6.1. FUTURE WORKS

The future work will be to enhance the detection and reduce the false alarm rate with a new machine learning-based classifier with another optimization technique for detecting attacks based on intrusion detection.

REFERENCES

(1) Ahmad, Z., Khan, A. S., Shiang, C. W., Abdullah, J., & Ahmad, F. (2021). Network intrusion detection system: A systematic study of machine learning and deep learning approaches. Transactions on Emerging Telecommunications Technologies, 32(1), e4150.

(2) Lansky, J., Ali, S., Mohammadi, M., Majeed, M. K., Karim, S. H. T., Rashidi, S., Hosseinzadeh, M., & Rahmani, A. M. (2021). Deep learning-based intrusion detection systems: A systematic review. IEEE Access, 9, 101574-101599.

(3) Tama, B. A., & Lim, S. (2021). Ensemble learning for intrusion detection systems: A systematic mapping study and cross-benchmark evaluation. Computer Science Review, 39, 100357.

(4) Kumar, G., Thakur, K., & Ayyagari, M. R. (2020). MLEsIDSs: Machine learning-based ensembles for intrusion detection systems—a review. The Journal of Supercomputing, 1-34.

(5) Gamage, S., & Samarabandu, J. (2020). Deep learning methods in network intrusion detection: A survey and an objective comparison. Journal of Network and Computer Applications, 169, 102767.

(6) Manimurugan, S., Majdi, A. Q., Mohmmed, M., Narmatha, C., & Varatharajan, R. (2020). Intrusion detection in networks using crow search optimization algorithm with adaptive neuro-fuzzy inference system. Microprocessors and Microsystems, 79, 103261.

(7) Alsyaibani, O. M. A., Utami, E., & Hartanto, A. D. (2021). Survey on Deep Learning Based Intrusion Detection System. Telematika, 14(2), 86-100.

(8) Thakkar, A., & Lohiya, R. (2021). A survey on intrusion detection system: Feature selection, model, performance measures, application perspective, challenges, and future research directions. Artificial Intelligence Review, 1-111.

(9) Jasim, A. D. (2022). A Survey of Intrusion Detection Using Deep Learning in Internet of Things. Iraqi Journal For Computer Science and Mathematics, 3(1), 83-93.

(10) Ayyagari, M. R., Kesswani, N., Kumar, M., & Kumar, K. (2021). Intrusion detection techniques in network environment: A systematic review. Wireless Networks, 27(2), 1269-1285.

(11) Adnan, A., Muhammed, A., Ghani, A. A. A., Abdullah, A., & Hakim, F. (2021). An Intrusion Detection System for the Internet of Things Based on Machine Learning: Review and Challenges. Symmetry, 13(6), 1011.

(12) Khraisat, A., & Alazab, A. (2021). A critical review of intrusion detection systems in the internet of things: techniques, deployment strategy, validation strategy, attacks, public datasets and challenges. Cybersecurity, 4(1), 1-27.

(13) Chauhan, M., & Agarwal, M. (2021). Study of Various Intrusion Detection Systems: A Survey. Smart and Sustainable Intelligent Systems, 355-372.

(14) Parfenov, D., Bolodurina, I., Zabrodina, L., & Zhigalov, A. (2021). Development of a solution for identifying network attacks based on adaptive neuro-fuzzy networks ANFIS. In 2021 Ural Symposium on Biomedical Engineering, Radioelectronics and Information Technology (USBEREIT), (pp. 0491-0495). IEEE.

(15) Sinha, S., & Paul, A. (2020). Neuro-fuzzy based intrusion detection system for wireless sensor network. Wireless Personal Communications, 114(1), 835-851.

(16) Kondaiah, R., & Sathyanarayana, B. (2018). Trust based Genetic Neuro-Fuzzy System for Intrusion Detection and Self Adaptive Firefly integrated Particle Swarm Optimization Algorithm for Secure Routing in MANET. International Journal of Applied Engineering Research, 13(8), 5722-5735.

(17) Devi, R., Jha, R. K., Gupta, A., Jain, S., & Kumar, P. (2017). Implementation of intrusion detection system using adaptive neuro-fuzzy inference system for 5G wireless communication network. AEU-International Journal of Electronics and Communications, 74, 94-106.

(18) Brahma, A., & Panigrahi, S. (2015). A new approach to intrusion detection in databases by using artificial neuro fuzzy inference system. International Journal of Reasoning-based Intelligent Systems, 7(3-4), 254-260.

(19) Abd Elaziz, M., Ewees, A. A., & Alameer, Z. (2020). Improving adaptive neuro-fuzzy inference system based on a modified salp swarm algorithm using genetic algorithm to forecast crude oil price. Natural Resources Research, 29(4), 2671-2686.

(20) Mohammadi-Balani, A., Nayeri, M. D., Azar, A., & Taghizadeh-Yazdi, M. (2021). Golden eagle optimizer: A nature-inspired metaheuristic algorithm. Computers & Industrial Engineering, 152, 107050.

/22/

THE SPATIAL STRUCTURE CHARACTERISTIC AND ROAD TRAFFIC ACCESSIBILITY EVALUATION OF A-LEVEL TOURIST ATTRACTIONS WITHIN WUHAN URBAN AGGLOMERATION IN CHINA

Wanying Liao
Faculty of Arts and Social Sciences, University of Malaya.
50603 Kuala Lumpur, Malaysia.
wanyingliao1998@gmail.com - https://orcid.org/0009-0002-3259-9663

Hongtao Wang
College of Urban and Environmental Sciences, Central China Normal University.
430079 Wuhan, Hubei, China.
hongtaowang2001@gmail.com - https://orcid.org/0009-0008-6454-0598

Jiajun Xu*
Institute for Advanced Studies, University of Malaya.
50603 Kuala Lumpur, Malaysia.
jiajunxu2000@gmail.com - https://orcid.org/0009-0000-9130-1025

Reception: 21/05/2023 **Acceptance**: 22/07/2023 **Publication**: 13/08/2023

Suggested citation:

Liao, W., Wang, H., and Xu, J. (2023). **The Spatial Structure Characteristic and Road Traffic Accessibility Evaluation of A-Level Tourist Attractions within Wuhan Urban Agglomeration in China**. *3C Tecnología. Glosas de innovación aplicada a la pyme, 12(3)*, 388-409. https://doi.org/10.17993/3ctecno.2023.v12n3e45.388-409

https://doi.org/10.17993/3ctecno.2023.v12n3e45.388-409

ABSTRACT

Against the backdrop of the post-pandemic COVID-19, regional short-distance tourism has become more prevalent. This paper used Wuhan Urban Agglomeration (WUA) as the research area and explored spatial structure characteristics and road traffic accessibility issues of A-level tourist attractions within WUA. The geospatial analysis methods of Average Nearest Neighbour (ANN) and Kernel Density Estimation (KDE) were used to identify the spatial structure distribution of A-level tourist attractions. Constructing Weighted Network Analysis to measure the traffic access time between tourist attractions and traveler origin and further using Network Analysis to measure the traffic access time between different tourist attractions. The traffic access time results were spatially visualized using Inverse Distance Weight (IDW). The study results were as follows. (1) The spatial structure of A-level tourist attractions in WUA indicated a core-periphery distribution in general. All tourist attractions showed clustering characteristics of the spatial distribution pattern. The spatial clustering degree was highest for human tourist attractions and lowest for nature tourist attractions. (2) Traffic access time results exhibited significant centrality with Wuhan as the core and regional differences in WUA. The road traffic accessibility of human tourist attractions was better than that of natural tourist attractions. (3) The spatial distribution and road traffic accessibility of tourist attractions in WUA indicated a circle structure centered on Wuhan, which aligned with the general rule of regional development. The accessibility of the north-south direction was weaker than the east-west direction in WUA. (4) Human tourist attractions were mainly concentrated in urban areas with high connectivity and intensive road networks. But natural tourist attractions were separated from traveler origin and other different tourist attractions. Most were in mountainous and hilly areas with poor accessibility, which could attract more tourists with better road networks and traffic infrastructure.

KEYWORDS

Tourist Attractions; National A-Level; Spatial Structure Characteristic; Road Traffic Accessibility Evaluation; Wuhan Urban Agglomeration (WUA), China

https://doi.org/10.17993/3ctecno.2023.v12n3e45.388-409

INDEX

https://doi.org/10.17993/3ctecno.2023.v12n3e45.388-409

1. INTRODUCTION

Accompanied by the rapid development of the Chinese economy, its economic growth mode was gradually inclined to the tertiary industry, and the position of the tourism industry was increasingly important in its social development [1]. In recent years, tourism has become a pillar industry of national development, and the theoretical study of urban tourism in China started late but developed very rapidly [2]. As an essential symbol for measuring the quality of attraction spots, Chinese national A-level tourist attractions were an essential indicator of the unique rating standard and resource standardization management, which played a positive role in promoting the construction of tourist attractions and the development of the tourism economy since its promotion in 1999 [3]. As one of the basic prerequisites for tourism operations, regional transportation was a critical factor in relating tourists to tourism destinations [4]. In the increasingly fierce competition faced by global tourist attractions, the requirements of consumers for tourist attractions were becoming higher and higher, with accessibility, attraction service quality and sustainable development serving as important competitive advantages [5]. Some scholars conducted forward-looking analyses to capture the supply and demand for regional tourism based on the importance of transportation elements to tourism facilities and the potential impact on regional tourist attractions [6]. Therefore, a correct understanding of the attraction's situation was essential in achieving optimal allocation and development of tourism resources.

The spatial structure and traffic accessibility of tourist attractions as the research hotspot were explored by scholars through mathematical statistics and spatial metrology. In terms of studies related to the spatial structure of tourist attractions, some scholars constructed a system conceptual model to improve the governance for regional tourism elements based on the development of land policies, which were used to optimize the design specifications and functions of the region's tourism [7]. Some scholars quantitatively studied the spatial pattern and accessibility of auto campsites in Chinese Beijing from the perspective of self-driving tourism [8]. Some scholars summarised the influencing factors affecting the distribution by analyzing the spatial distribution characteristics of tourism towns in the Wuling Mountains region of China [9]. In addition, some scholars explored the distribution of tourist attractions, the misallocation of resources and the future development trend from the perspective of spatial allocation dynamics [10]. In terms of studies related to the traffic accessibility of tourist attractions, some scholars explored the impact on regional spatial accessibility differences by using traffic data with different attributes, such as highway networks [11]. Some scholars used a potential model with different effective service radii to measure the spatial traffic accessibility of care facilities [12]. Some scholars investigated and designed tourism products by considering the accessibility problem of shore excursions with the limited docking time of cruise ships as the background [13]. Some scholars evaluated the accessibility issues of tourist attractions and perceptions of consumer satisfaction through empirical studies from rural tourism facilities, popular tourist attractions and protected tourism islands to optimize

https://doi.org/10.17993/3ctecno.2023.v12n3e45.388-409

management initiatives of regional tourism [14, 15, 16]. In addition, some scholars analyzed the impact of high-speed rail on regional transport accessibility and tourism economic linkages and further explored the synergistic effect of accessibility and tourism economic development through a coupled coordination degree evaluation model [17]. Based on the intrinsic correlation between tourism efficiency and location accessibility, some scholars quantitatively modeled the impact of accessibility on the total tourism output of attractions areas and its efficiency change [18].

Tourist attractions were a core tourism component and a prerequisite for its development. The spatial structure and accessibility of tourist attractions determined the behavior of tourists and profoundly influenced tourism development strategies [19]. Studies indicated that the development of short-distance tourism and the state of transportation development were important factors that affected the evolution of the spatial structure of attraction spots [20], and the short-term tourism trend of using short public holidays was becoming increasingly obvious [21]. In addition, the COVID-19 outbreak dramatically changed the behaviour of tourists [22], short-distance tourism was gradually becoming more popular in tourism after the post-pandemic. Therefore, this paper started from the research gap of a few empirical and applied studies on short-distance tourism and selected WUA (nine cities centered on Wuhan) as an appropriate scope of the study area for short-distance tourism. Through an empirical case study of the WUA region, the spatial structure of A-level tourist attractions was identified, and the road traffic accessibility of short-distance travel within the region was further measured. The study results were helpful in suggesting the development and optimization of the spatial layout of tourist attractions in WUA and providing scientific guidance for creating and managing A-level tourist attractions in the future.

2. METHODOLOGY

2.1. DESCRIPTION OF THE STUDY AREA

Wuhan Urban Agglomeration (WUA) was known as Wuhan "1+8" City Circle in the eastern part of Hubei Province within China. WUA was centered on Wuhan and covered Huanggang, Ezhou, Huangshi, Xianning, Xiantao, Qianjiang, Tianmen and Xiaogan (Figure 1). According to statistical information, its geographical location was in the Yangtze River's middle reaches and the Jianghan Plain's east-central part, with an area of about 57800 km².

https://doi.org/10.17993/3ctecno.2023.v12n3e45.388-409

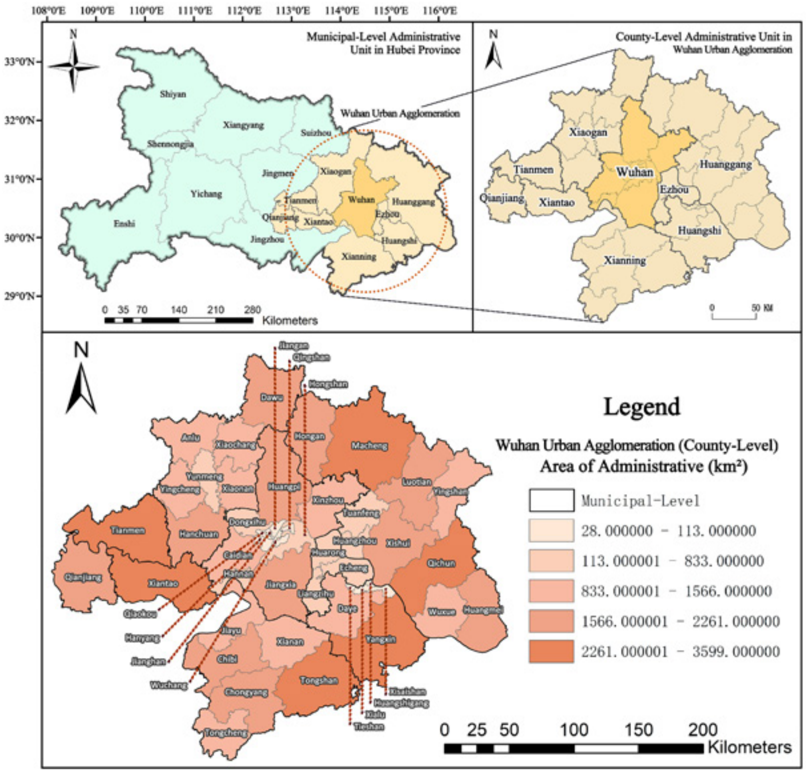


Figure 1. Location Map of Wuhan Urban Agglomeration (WUA) in China

2.2. DATA COLLECTION

This paper's data included the national A-level tourist attractions list, the total resident population and GDP. The list of national A-level tourist attractions within WUA was based on publicly available data from the Hubei Provincial Department of Culture and Tourism in China (http://wlt.hubei.gov.cn/). The national A-level attractions were evaluated and recognized by the China National Tourism Administration based on the indicators of landscape quality, historical and cultural value, service facilities provision and management level. A-level attractions were detailed into 1A, 2A, 3A, 4A and 5A, with 5A as the highest level of assessment. The total regional resident population was obtained from the 7th Chinese Population Census Bulletin of the National Bureau of Statistics (http://www.stats.gov.cn/). GDP data from Hubei Provincial Statistical Yearbook 2021 published by the Hubei Provincial Statistics Bureau in China (https://tjj.hubei.gov.cn/). This paper used the map projection coordinate system WGS_1984_UTM_Zone_49N for geographic data processing.

The county-level unit under the administrative jurisdiction of nine cities was used as the scale for this paper (48 county-level administrative units in total). As of 2021, 214 A-level tourist attraction spots existed in WUA. According to the different categories of tourist attractions, the tourist attractions were classified into two categories: natural and human. The final statistics were collected with 94 sites in the natural attractions and 120 sites in the human attractions (Figure 2).

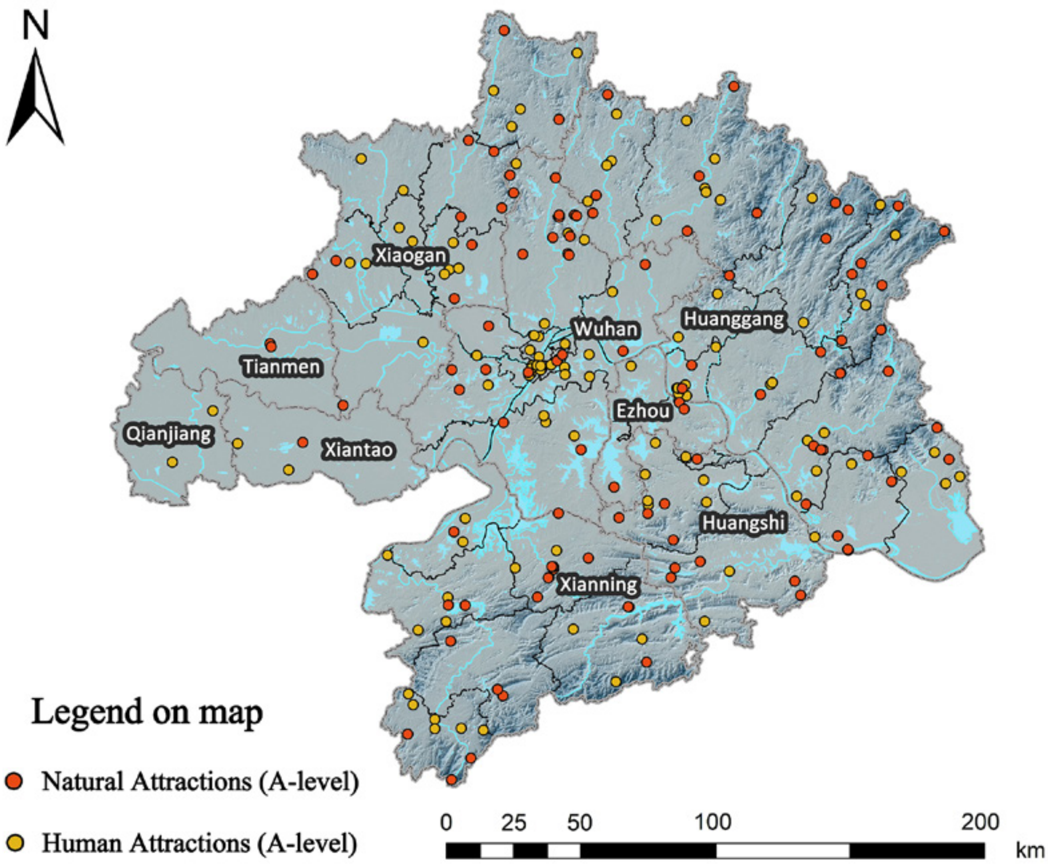


Figure 2. Location of Tourist Attractions in WUA (National A-level of China)

2.3. DESIGN OF THE STUDY

The study design was divided into two aspects: spatial structure characteristics and road traffic accessibility of the tourist attractions. The tourist attraction's spatial distribution and pattern were simulated using Average Nearest Neighbour (ANN) and Kernel Density Estimation (KDE) analysis.

ANN analysis measured the geospatial distribution and the proximity of point elements to each other in the regional space [23]. The Average Nearest Neighbour Ratio (ANN-R) was calculated as the observed average distance divided by the expected average distance, which was used to measure the distribution of point elements in geographic areas [24]. ANN-R less than 1 indicated that the distribution was a cluster, greater than 1 indicated that the distribution was discrete and equal to 1 indicated that the distribution was random [25]. The math expression of the existing model was as follows.

$$R = \frac{\bar{D}_o}{\bar{D}_e} \quad (1)$$

In the above expression (1), the observed average distance was the average distance between the tourist attractions point and the centroid of its nearest neighbor point, defined as $\bar{D}_o$. The expected average distance was the average distance in the

https://doi.org/10.17993/3ctecno.2023.v12n3e45.388-409

random distribution of each tourist attraction point, defined as $\bar{D}_e$. The Average Nearest Neighbour Ratio (ANN-R) was defined as R.

Kernel Density Estimation (KDE) analysis assumed that within a certain spatial range, a certain object could occur at any geographical location, but the probability of occurrence differed at each spatial site [26]. Estimating probability density values based on the distance between the element to be assessed and the sample element [27], KDE converted discrete points in a region into a continuous density map based on a cell [28]. It could provide a clear visual representation of the geospatial posture of the A-level tourist attractions in WUA. Using the spatial property of the data sample to explore its spatial evolution trend helped reveal the spatial concentration of the tourist attractions [29]. The math expression of the existing model was as follows.

$$F(x) = \frac{1}{Nh} \sum_{i=1}^{n} K_n \left(\frac{x - x_i}{h} \right) \tag{2}$$

In the above expression (2), $F(x)$ was the estimated density function at spatial location x. N was the number of tourist attractions points in WUA. h was the bandwidth that controlled the degree of smoothing and the effect range for the kernel function [30]. K was the kernel function for the spatial weights. $x - x_i$ was the distance between data sites x and x_i.

The traffic access time was related to the average speed of the different road classes, and the time cost of the highway access was quantified based on a proportional relationship (Table 1). The traffic access time was constructed using Weighted Network Analysis to measure the accessibility between tourist attractions and traveler origin and further using Network Analysis to measure the accessibility between different tourist attractions. The results were visualized using Inverse Distance Weight (IDW).

Table 1. Time Cost of Traffic Access to Major Road Networks in China

Highway Classification	Road Speed (km/h)	Time Cost (min)
Expressway	100	0.60
National Highway	80	0.75
Provincial Highway	60	1.00
County Highway	40	1.50
Township Highway	30	2.00
Other Highways	20	3.00

Note: Road driving speed regarding the "Technical Standard Highway Engineering of the People's Republic of China (JTGB01-2003)" and related studies.

Traffic accessibility was an indicator of the extent to which one element was connected to other elements. To better measure the accessibility between the tourist attractions and traveler origin, the travel intentions of tourists were not only considered in terms of spatial location and transport networks but also in terms of population, attractions level and accessibility time [31]. Using the weighted average access time of existing scholars' model to measure the road traffic accessibility between the tourist attractions and traveler origin by weighting total resident population, GDP and national attractions assessment indicators [8, 32]. Due to the reversible road network movements, using the tourist attraction site as the origin point and defined it as x, and the traveler origin site as the destination point and defined it as y. The math expression of the existing model was as follows.

$$Mxy = \sqrt[3]{Py \times Gy \times Lx} \tag{3}$$

$$Axy = \sum_{y=1}^{n} (Txy \times Mxy) / \sum_{y=1}^{n} Mxy \tag{4}$$

The above expression (3) was explored the weight of tourist attractions and traveler origin. P_y was the total resident population of the traveler origin site (y). Gy was the total GDP of the traveler origin site (y). Lx was the national assessment level of the tourist attraction site (x). The above expression (4) was used to calculate the average accessibility time between the tourist attraction site (x) and the traveler origin site (y) after weighting. Axy was the average weighted access time between the tourist attraction site (x) and the traveler origin site (y). n was the total number of the traveler origin site (y) (the geographical location of the traveler origin site was represented by the administrative location of the local government). Txy was the minimum access time cost between the tourist attraction site (x) and the traveler origin site (y). Mxy was the weighted result in the expression (3).

How to effectively organize a reasonable intra-city tourism spatial structure and routes according to the characteristics of tourist flow combined with the distribution of tourism resources was the key challenge to be solved in urban tourism development and planning [33]. Tourists sometimes would not return directly to their homes or hotels after arriving at one tourist attraction but continue traveling to another. Hence, this paper continued to measure the accessibility between different tourist attractions based on the movement trajectories of tourists. The road traffic accessibility of different tourist attractions was determined by measuring the average access time from one tourist attraction to another in the region [34]. The results of less average access time indicated the tourist attraction in the area with advantageous locations and more convenient accessibility for tourists [35]. Due to the reversible road network movements, defining two different tourist attraction sites as i and j. The math expression of the existing model was as follows.

$$Aij = \sum_{j=1}^{n} Tij/n \tag{5}$$

https://doi.org/10.17993/3ctecno.2023.v12n3e45.388-409

In the above expression (5), it explored the average accessibility time between tourist attractions. Tij was the minimum access time cost between one tourist attraction (i) and another tourist attraction (j) through the road networks. n was the total number of tourist attractions in the region.

3. RESULTS AND DISCUSSIONS

3.1. SPATIAL STRUCTURE OF A-LEVEL TOURIST ATTRACTIONS

3.1.1. AVERAGE NEAREST NEIGHBOUR ANALYSIS OF TOURIST ATTRACTIONS

Based on the mathematical expression (1), the Average Nearest Neighbour (ANN) analysis measured the observed average distance and expected average distance for the A-level tourist attractions of WUA. The Average Nearest Neighbour Ratio (ANN-R) was obtained as 0.892 for natural attractions, 0.764 for human attractions and 0.766 for all attractions (Table 2). The results showed that the spatial distribution of different tourist attractions showed clustering under the condition of passing the significance test. The human attractions had the highest degree of clustering, while the natural attractions had the lowest.

Table 2. Average Nearest Neighbor (ANN) Results of Tourist Attractions in WUA

Classification	Natural Attractions (A-level)	Human Attractions (A-level)	All Attractions (A-level)
Number of Attractions/individual	94	120	214
Observed Average Distance/m	12250.5340	9367.0158	7419.9275
Expected Average Distance/m	13726.5459	12252.6485	9682.9361
Average Nearest Neighbour Ratio	0.892470	0.764489	0.766289
Z-Score	-1.994451	-4.935516	-6.540590
Distribution Trend	Cluster Distribution	Cluster Distribution	Cluster Distribution

3.1.2. KERNEL DENSITY ESTIMATION ANALYSIS OF TOURIST ATTRACTIONS

Based on the mathematical expression (2), the Kernel Density Estimation (KDE) analysis was used to generate a kernel density distribution map and identify spatial distribution hotspots of the tourist attractions (Figure 3). The overall trend of the A-

https://doi.org/10.17993/3ctecno.2023.v12n3e45.388-409

level tourist attractions showed multiple core-periphery structures. The core high-value areas of kernel density were mainly distributed in the central urban area of Wuhan, while the sub-high-value areas were distributed in the surrounding regions of Xiaogan, Huanggang, Ezhou and Xianning.

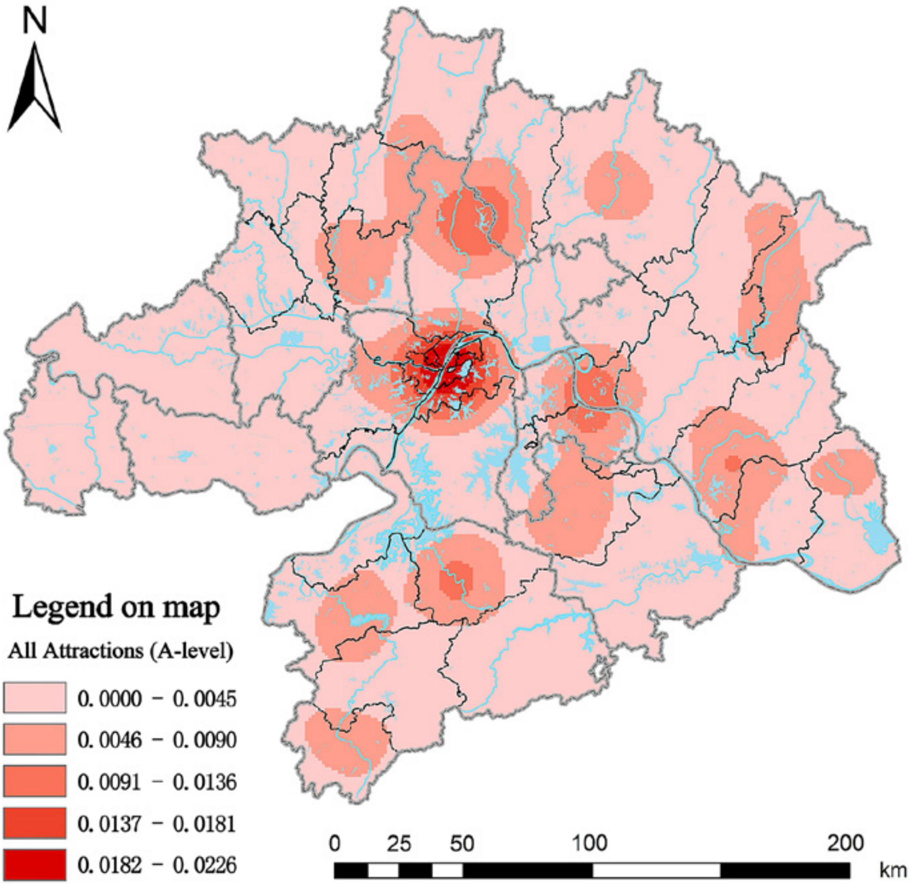


Figure 3. Kernel Density Estimation (KDE) Results for All Attractions in WUA

The natural and human attractions of WUA showed a core-periphery structure (Figure 4). The degree of core-density clustering was more significant in human tourist attractions than in natural tourist attractions. However, the core-density hierarchy of natural tourist attractions was more complex than that of human tourist attractions. The high core density areas of the natural tourist attractions were present in Wuhan Huangpi within WUA's northern part. The sub-high core density areas were presented in Xianning and Huangshi in WUA's southern region. The distribution results were closely related to the topography because the topography of the northern, southern and eastern parts of WUA was mainly mountainous and hilly. The unique natural landscape was more conducive to developing distinctive natural tourist attractions. To a certain extent, the shortage of natural tourist attractions in WUA's western part was due to the flat local terrain and the human farming culture of Jianghan Plain. The high core density of human tourist attractions was present in the central urban area of Wuhan and showed a very significant clustering compared to other surrounding areas. The distribution of human tourist attractions was related to Wuhan's deep historical heritage and developed economic level as a famous Chinese historical and cultural city.

https://doi.org/10.17993/3ctecno.2023.v12n3e45.388-409

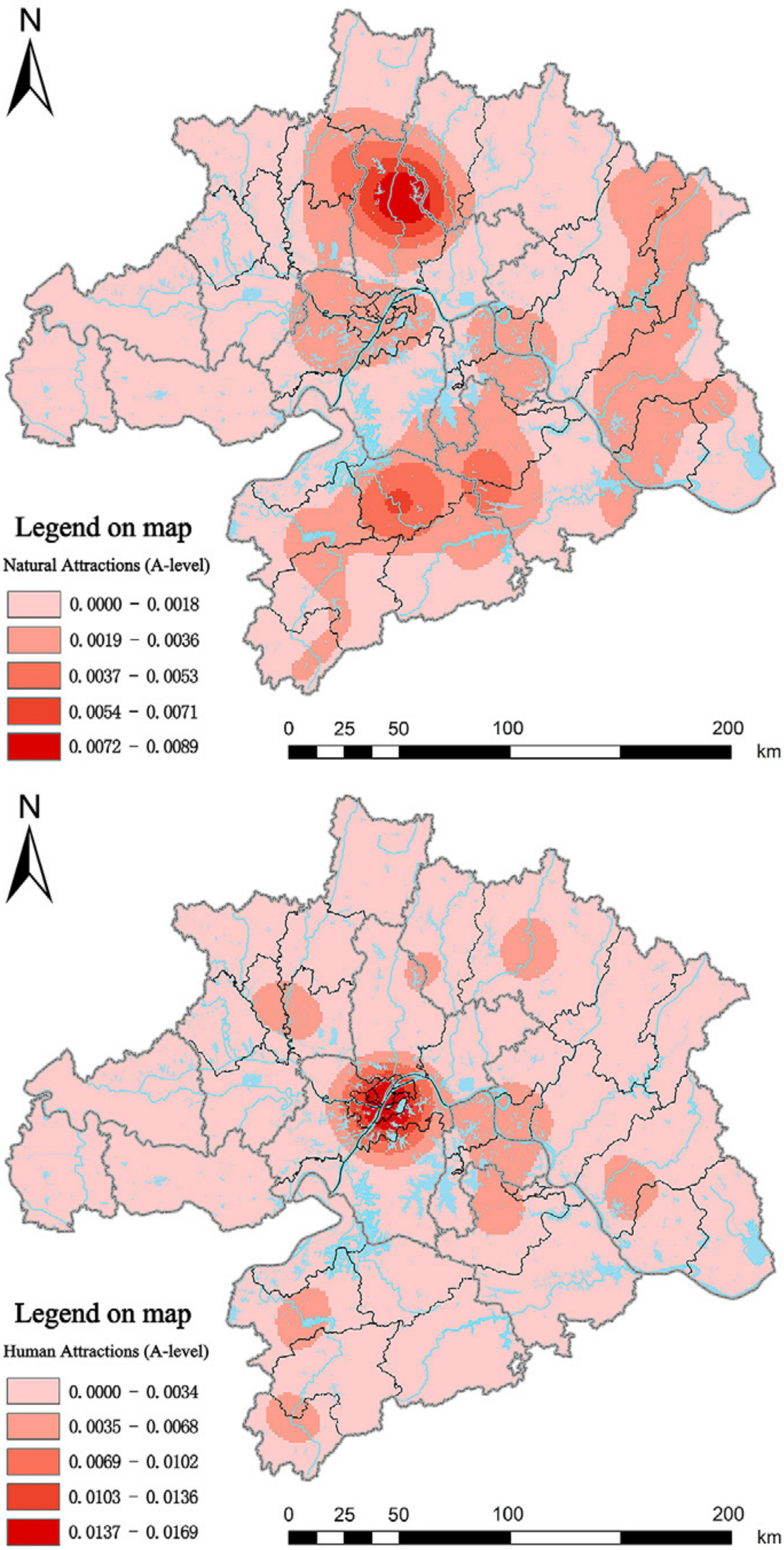


Figure 4. Kernel Density Estimation (KDE) Results for Natural and Human Attractions in WUA

https://doi.org/10.17993/3ctecno.2023.v12n3e45.388-409

3.2. ROAD TRAFFIC ACCESSIBILITY OF A-LEVEL TOURIST ATTRACTIONS

3.2.1. ROAD TRAFFIC ACCESSIBILITY ANALYSIS BETWEEN TOURIST ATTRACTIONS AND TRAVELER ORIGIN

The impact of the resident population, total GDP, and tourist attractions assessment on traffic accessibility was relevant [32]. Because economically developed regions usually had higher per capita income and more government investment in developing tourism infrastructure. The high numbers of resident population meant there were more potential tourists of traveler origin. In addition, higher assessment levels of tourist attractions indicated better infrastructure provision, accommodation and catering services in the vicinity. The mathematical expressions (3) and (4) were used to measure the weighted average accessibility time between tourist attractions and traveler origin (Table 3).

Table 3. Statistical Results of Average Traffic Accessibility Time between Tourist Attractions and Traveler Origin in WUA

Road Traffic Accessibility Time	Between Natural Attractions and Traveler Origin (A-level)	Between Human Attractions and Traveler Origin (A-level)	Between All Attractions and Traveler Origin (A-level)
$0.0 \le T \le 1.5$	5 (5.32%)	21 (17.50%)	26 (12.15%)
$1.5 < T \le 2.0$	19 (20.21%)	29 (24.17%)	48 (22.43%)
$2.0 < T \le 2.5$	38 (40.42%)	37 (30.83%)	75 (35.05%)
$2.5 < T \le 3.0$	27 (28.73%)	23 (19.17%)	50 (23.36%)
$3.0 < T \le 3.5$	3 (3.19%)	9 (7.50%)	12 (5.61%)
$3.5 < T$	2 (2.13%)	1 (0.83%)	3 (1.40%)
Total	94 (100%)	120 (100%)	214(100%)

The results showed that the weighted average accessibility time from the tourist attractions to traveler origin (48 county-level administrative units under WUA) ranged from 1.24h to 3.82h (Figure 5), with a mean value of 2.21h. The road traffic accessibility between tourist attractions and traveler origin indicated a spatial centrality trend with Wuhan as a core circle structure. In general, WUA had better east-west accessibility than north-south accessibility.

https://doi.org/10.17993/3ctecno.2023.v12n3e45.388-409

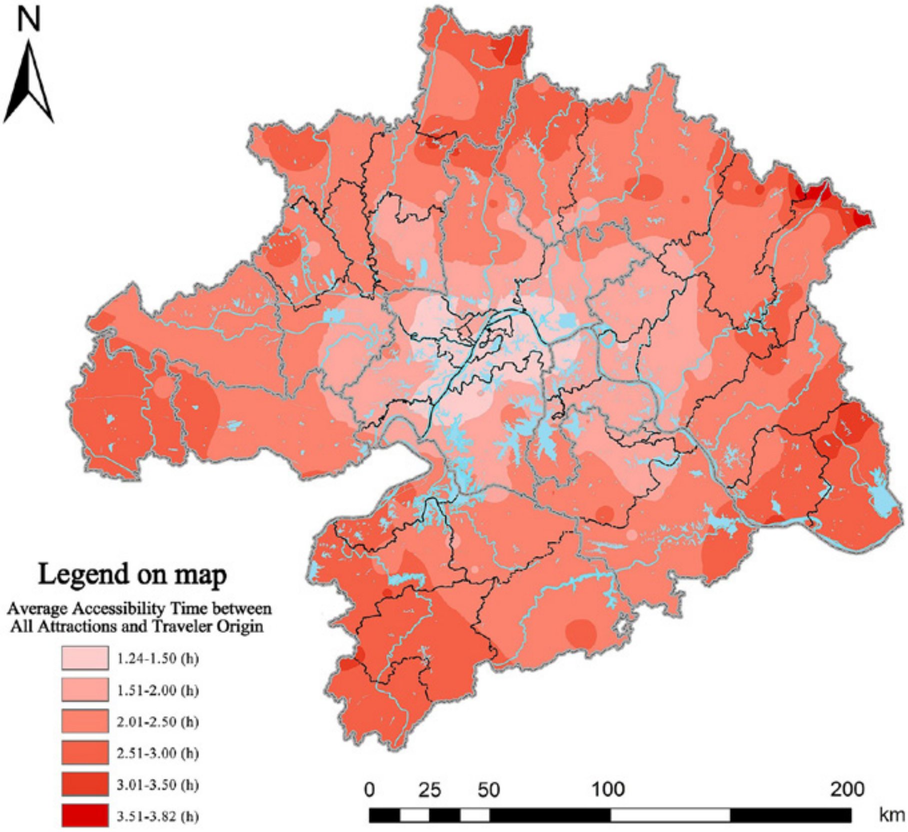


Figure 5. IDW Visualization Results of Average Accessibility Time between All Attractions and Traveler Origin in WUA

Road traffic accessibility from the natural and human tourist attractions to traveler origins under the WUA administration showed a core-periphery structure (Figure 6). The areas where the average access time of road traffic accessibility was less than 2h were mainly concentrated in Wuhan, and the accessibility of human tourist attractions was better than that of natural tourist attractions. The road traffic accessibility of tourist attractions in Ezhou, Huangshi, Huanggang, Xiaogan, Xianning, Qianjiang, Xiantao and Tianmen mainly was between 1.5h and 3h. The multiplicative difference between some of the tourist attractions and traveler origin in WUA reached more than three triples, representing a significant regional difference in traffic accessibility. In addition, some areas had poor accessibility between tourist attractions and traveler origin in WUA, such as the Dabie Mountains in the northeast region of WUA.

https://doi.org/10.17993/3ctecno.2023.v12n3e45.388-409

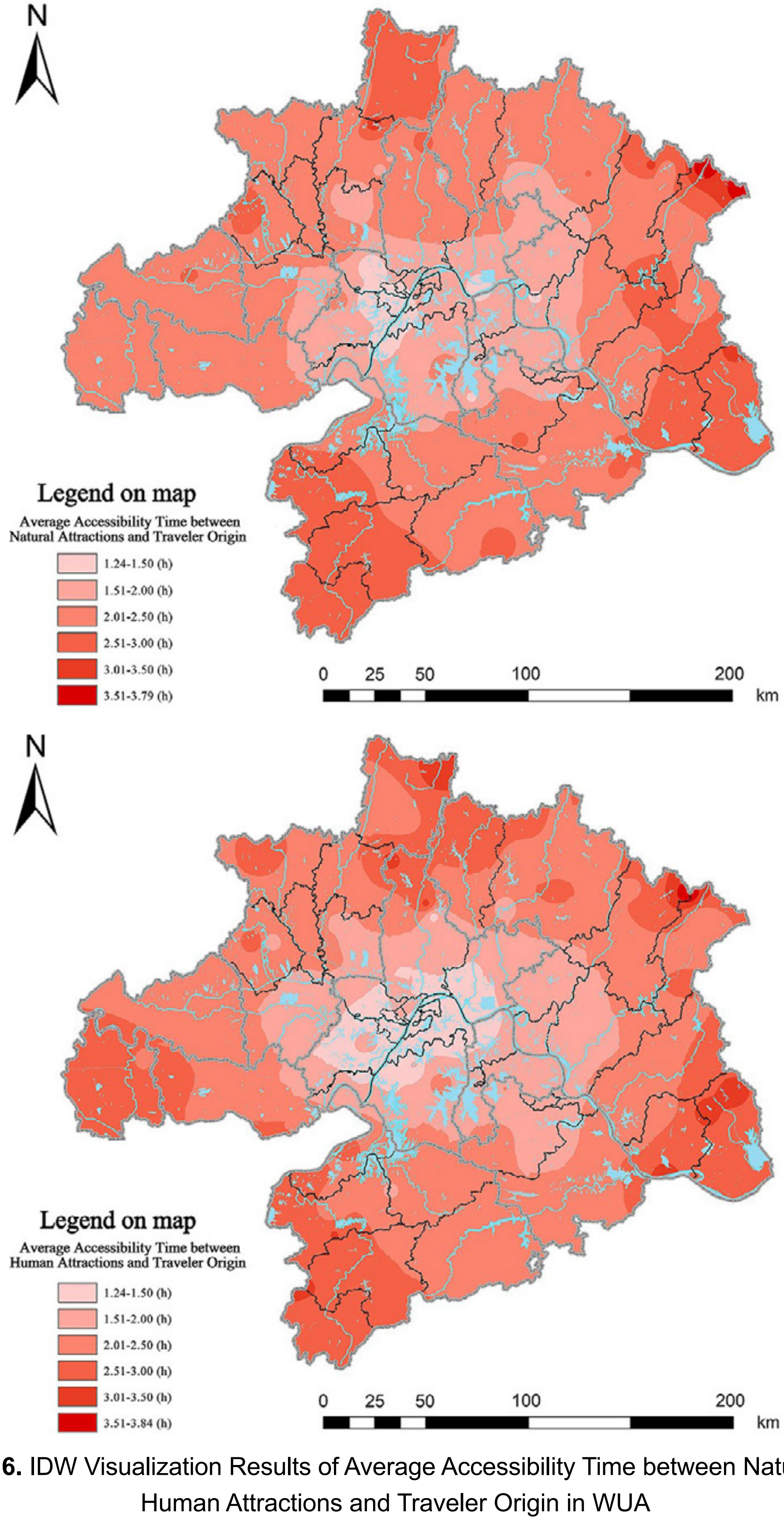


Figure 6. IDW Visualization Results of Average Accessibility Time between Natural and Human Attractions and Traveler Origin in WUA

https://doi.org/10.17993/3ctecno.2023.v12n3e45.388-409

3.2.2. ROAD TRAFFIC ACCESSIBILITY ANALYSIS BETWEEN DIFFERENT TOURIST ATTRACTIONS

The mathematical expression (5) was used to measure the average access time between different tourist attractions (Table 4). The average accessibility time between different tourist attractions ranged from 1.45h to 3.62h, with an average of 2.27h.

Table 4. Statistical Results of Average Traffic Accessibility Time between Different Tourist Attractions in WUA

Road Traffic Accessibility Time	Between Natural Attractions (A-level)	Between Human Attractions (A-level)	Between All Different Attractions (A-level)
$0.0 \leq T \leq 1.5$	0 (0%)	2 (1.67%)	2 (0.93%)
$1.5 < T \leq 2.0$	17 (18.09%)	44 (36.67%)	61 (28.51%)
$2.0 < T \leq 2.5$	46 (48.94%)	38 (31.67%)	84 (39.26%)
$2.5 < T \leq 3.0$	25 (26.59%)	25 (20.83%)	50 (23.36%)
$3.0 < T \leq 3.5$	5 (5.32%)	10 (8.33%)	15 (7.01%)
$3.5 < T$	1 (1.06%)	1 (0.83%)	2 (0.93%)
Total	94 (100%)	120 (100%)	214 (100%)

The road traffic accessibility among all different tourist attractions showed a circle structure with Wuhan as the core with evident centrality (Figure 7). Wuhan and Ezhou had higher road traffic accessibility than other regions in WUA, and the tourist attractions with poorer road traffic accessibility were mainly located in the western part of WUA and the southwestern part of WUA. Its insufficient road traffic accessibility was due to fewer nearby tourist attractions and its more remote location. The average access time with the best traffic accessibility was 2.5 times higher than the worst, showing a noticeable difference in regional accessibility.

https://doi.org/10.17993/3ctecno.2023.v12n3e45.388-409

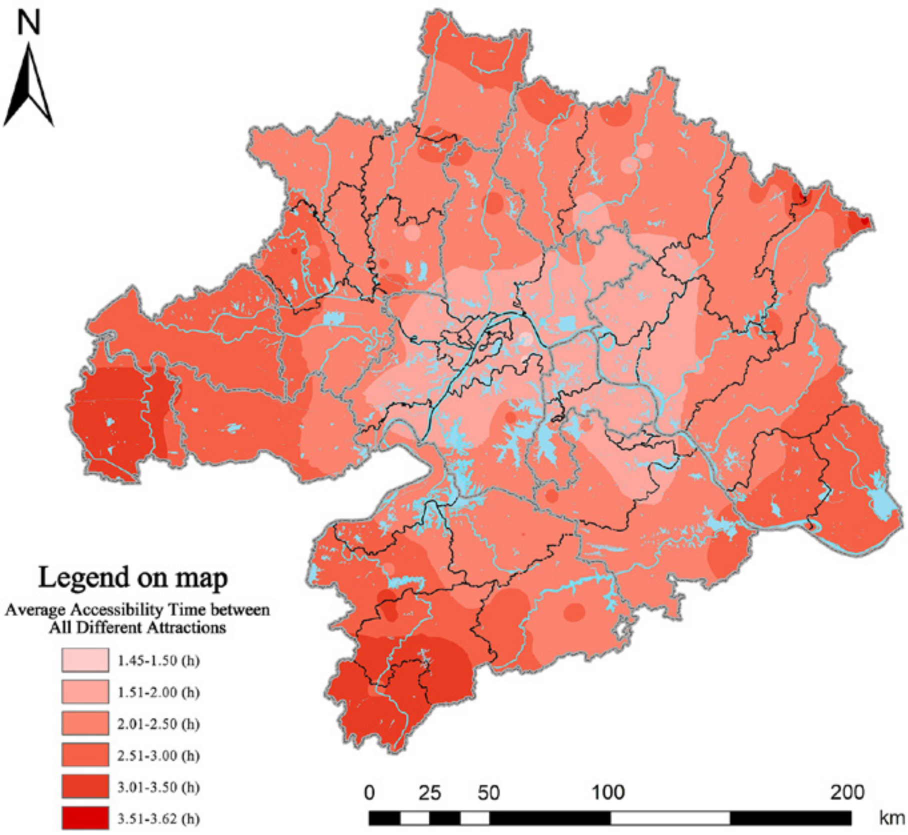
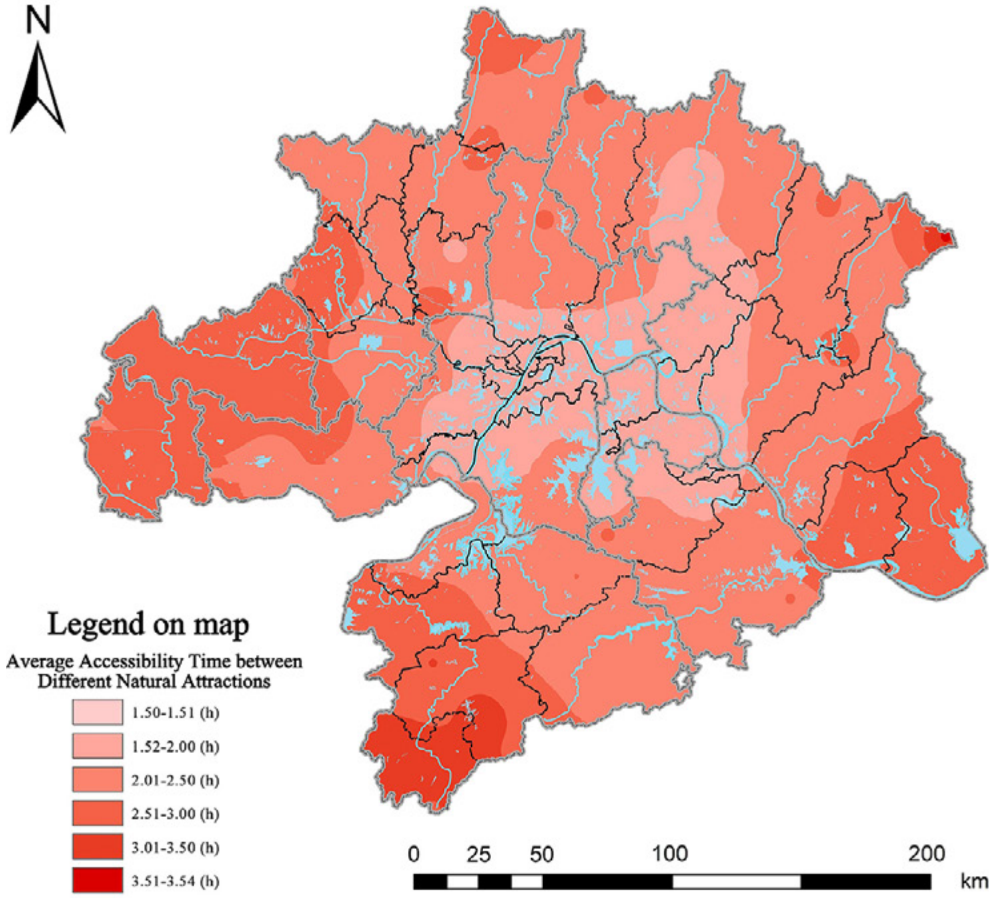


Figure 7. IDW Visualization Results of Average Accessibility Time between All Different Attractions in WUA

The spatial pattern for road traffic accessibility of natural tourist attractions gradually surrounded Wuhan and Ezhou to the periphery. The average access time of natural tourist attractions ranged from 1.50h to 3.54h, with an average value of 2.34h. The road traffic accessibility of human tourist attractions surrounded in a gradient from Wuhan and Ezhou to the surrounding areas, and the road traffic accessibility in the central part of WUA was significantly higher than in the surrounding areas. The average access time for human tourist attractions ranged from 1.45h to 3.65h, with an average value of 2.23h. The results indicated that the road traffic accessibility between different human tourist attractions was better than between different natural tourist attractions (Figure 8). Because the distribution of human tourist attractions was relatively concentrated, mainly in areas with excellent historical development and dense road networks. However, the distribution of natural tourist attractions was more dispersed, mainly in hilly and mountainous regions of WUA endowed with natural resources but not easily reachable.

https://doi.org/10.17993/3ctecno.2023.v12n3e45.388-409



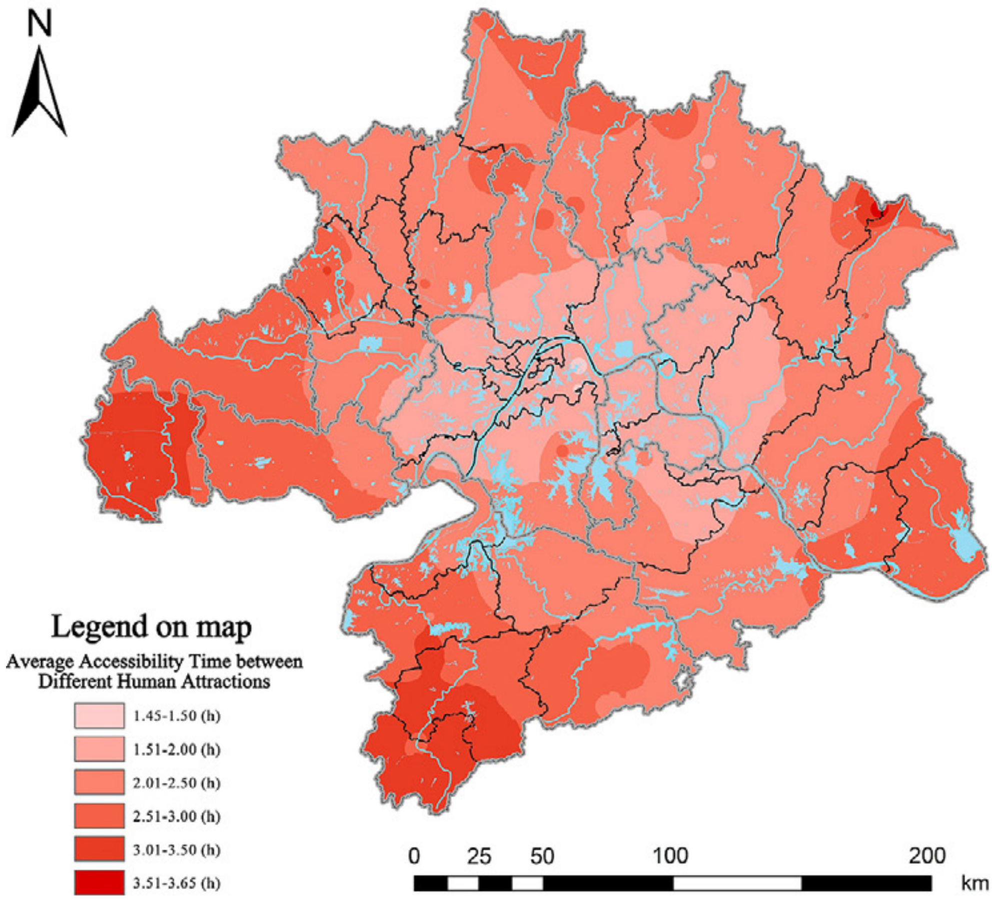


Figure 8. IDW Visualization Results of Average Accessibility Time between Different Natural Attractions and Average Accessibility Time between Different Human Attractions in WUA

https://doi.org/10.17993/3ctecno.2023.v12n3e45.388-409

4. CONCLUSIONS

4.1. CONCLUSION

In the context of regional travel of short distances becoming more common, this paper used a combination of mathematical statistics and spatial analysis to explore the spatial structure distribution and to measure the road traffic accessibility of the A-level tourist attractions within WUA. The spatial distribution of tourist attractions in WUA showed a core-periphery structure in general. Different spatial distribution patterns of tourist attractions both indicated clustering. The spatial clustering of human tourist attractions was the highest, and the spatial clustering of the natural tourist attractions was the lowest. The accessibility of WUA's tourist attractions and traveler origin generally showed a core-periphery structure with Wuhan as the core. The accessibility between different tourist attractions of WUA showed a core-periphery structure with Wuhan and Ezhou as the core. The results exhibited significant centrality and regional differences in road traffic accessibility. The road traffic accessibility of human tourist attractions was better than that of natural tourist attractions.

The spatial distribution and road traffic accessibility of tourist attractions in WUA showed a circle structure centered on Wuhan, aligning with the general regional development rule. However, considering the coordinated development of the region, the A-level tourist attractions resources in western areas of WUA were inadequate, and the accessibility of the north-south direction in WUA was weaker than that of the east-west direction in WUA. Human tourist attractions were mainly concentrated in urban areas with high connectivity and intensive road networks. But natural tourist attractions were separated from traveler origin and other attractions in WUA. Most were in mountainous and hilly areas with poor accessibility, which could attract more tourists with better road networks and traffic infrastructure.

4.2. LIMITATION AND PROSPECT

In the background of the popularity of short-distance travel after COVID-19, this paper empirically analyzed the accessibility of A-level tourist attractions in WUA by means of the road traffic accessibility evaluation model. Due to the lack of consideration of some intra-city road data (the standards and levels of intra-city road data in different cities within WUA were not uniform), the results of tourist attractions accessibility calculations might differ from the actual accessibility level to a certain extent. In addition, the road accessibility measurement assumed a uniform road speed without considering factors such as the degree of mountainous terrain, traffic congestion and subjective choice of travel routes, and it was hoped that some scholars could make a breakthrough for the limitation problem in the future.

https://doi.org/10.17993/3ctecno.2023.v12n3e45.388-409

5. DATA AVAILABILITY

All the data for this study is available upon request to the author.

6. CONFLICT OF INTEREST

The authors declare that the research has no financial or personal relationships with other people or organizations that can interfere with it.

REFERENCES

(1) Liu, M., & Hao, W. (2020). Spatial Distribution and Its influencing Factors of National A-Level Tourist Attractions in Shanxi Province. Acta Geographica Sinica, 75(4), 878-888. https://doi.org/10.11821/dlxb202004015

(2) Li, W., Hu, J., Zhou, R., Cheng, S., & Feng, J. (2014). Analysis of the Tourism Spatial System Structure of Wuhan. Human Geography, 29(1), 141-145. http://doi.org/10.13959/j.issn.1003-2398.2014.01.023

(3) Li, P., Yu, H., & Wang, Y. (2018). Spatial Agglomeration Characteristics of from 3A-Class to 5A-Class Scenic Spots in China. Scientia Geographica Sinica, 38(11), 1883-1891. https://doi.org/10.13249/j.cnki.sgs.2018.11.016

(4) Tóth, G., & Dávid, L. (2010). Tourism and Accessibility: An Integrated Approach. Applied Geography, 30(4), 666-677. https://doi.org/10.1016/j.apgeog.2010.01.008

(5) Kastenholz, E., Eusébio, C., Figueiredo, E., & Lima, J. (2012). Accessibility as Competitive Advantage of a Tourism Destination: The Case of Lousã. In K. F. Hyde, C. Ryan, & A. G. Woodside (Eds.), Field Guide to Case Study Research in Tourism, Hospitality and Leisure: Advances in Culture, Tourism and Hospitality Research (369-385). Emerald Group Publishing Limited, Bingley. http://doi.org/10.1108/S1871-3173(2012)0000006023

(6) Masson, S., & Petiot, R. (2009). Can the High Speed Rail Reinforce Tourism Attractiveness? The Case of the High Speed Rail between Perpignan (France) and Barcelona (Spain). Technovation, 29(9), 611-617. https://doi.org/10.1016/j.technovation.2009.05.013

(7) Dredge, D. (1999). Destination Place Planning and Design. Annals of Tourism Research, 26(4), 772-791. https://doi.org/10.1016/S0160-7383(99)00007-9

(8) Luo, L. (2023). Analyzing Accessibility of Car Campgrounds through Road Network Structure Software in Beijing. Computers and Electrical Engineering, 109, 108716. https://doi.org/10.1016/j.compeleceng.2023.108716

(9) Tao, H., He, Y., Ran, F., Jiang, X., & Zhang, P. (2023). Spatial Structure and Geographical Characteristics of Tourist Towns in the Wuling Mountain Area. Journal of Resources and Ecology, 14(3), 644-655. https://doi.org/10.5814/j.issn.1674-764x.2023.03.018

(10) Zhu, H., & Chen, X. (2008) Space Distribution Structure of A-grade Scenic Spot in China. Scientia Geographica Sinica, 28(5), 607-615. http://geoscien.neigae.ac.cn/CN/Y2008/V28/I5/607

(11) Dupuy, G., & Stransky, V. (1996). Cities and Highway Networks in Europe. Journal of Transport Geography, 4(2), 107-121. https://doi.org/10.1016/0966-6923(96)00004-X

(12) Ding, Q., Zhu, Li., & Luo, J. (2016). Analysing Spatial Accessibility to Residential Care Facilities in Wuhan. Human Geography, 31(2), 36-42. https://doi.org/10.13959/j.issn.1003-2398.2016.02.007

(13) Sun, X., Xu, M., Lau, Y., Kanrak, M., & Ng, A. K. Y. (2023). Cruise Shore Excursion Planning Based on Accessibility of Scenic Spots. Research in Transportation Business & Management, 49, 101007. https://doi.org/10.1016/j.rtbm.2023.101007

(14) Zolotarev, S., Kusakina, O., Ryazantsev, I., Yushchenko, I., & Ivashova, V. (2023). Transport Accessibility Assessment of Rural Tourism Facilities. E3S Web of Conferences, 376, 04005. https://doi.org/10.1051/e3sconf/202337604005

(15) Dumitrașcu, A. V., Teodorescu, C., & Cioclu, A. (2023). Accessibility and Tourist Satisfaction-Influencing Factors for Tourism in Dobrogea, Romania. Sustainability, 15(9), 7525. https://doi.org/10.3390/su15097525

(16) Rahmafitria, F., Dirgahayani, P., Putro, H. P. H., Rosyidie, A., & Hudalah, D. (2023). Tourism Accessibility in Protected Islands: The Case of the Komodo National Park, Indonesia. Tourism Review, 78(3), 966-985. http://doi.org/10.1108/TR-03-2022-0110

(17) Feng, X. (2023). Coupling and Coordinated Development of Traffic Accessibility and Regional Tourism Economy. Research in Transportation Business & Management, 49, 101010. https://doi.org/10.1016/j.rtbm.2023.101010

(18) Cao, F., Huang, Z., Wu, J., Xu, M., & Zhou, W. (2012). The Relationship between Tourism Efficiency Measure and Location Accessibility of Chinese National Scenic Areas. Acta Geographica Sinica, 67(12), 1686-1697. https://doi.org/10.11821/xb201212010

(19) Bevilacqua, E., & Casti, E. (1989). The Structure and Impact of International Tourism in the Veneto Region, Italy. GeoJournal, 19, 285-287. https://doi.org/10.1007/BF00454573

(20) Chen, J., Liu, D., & Xie, S. (2013) Evolution of the Spatial Structure of the Scenic Spots in Wuhan. Tropical Geography, 33(3), 349-355. http://www.rddl.com.cn/CN/Y2013/V33/I3/349

(21) Liu, Z., Li, H., Shi, C., Wang, X., & Zhang, H. (2010). The Response of Short Term Tourist Flows to Spatial Structure of Regional Tourism: A Case Study of Tourist Flows of Yunnan in Golden Weeks. Acta Geographica Sinica, 65(12), 1624-1632. https://doi.org/10.11821/xb201012017

(22) Srisawat, P., Zhang, W., Sukpatch, K., & Wichitphongsa, W. (2023). Tourist Behavior and Sustainable Tourism Policy Planning in the COVID-19 Era: Insights from Thailand. Sustainability, 15(7), 5724. https://doi.org/10.3390/su15075724

(23) Feng, Y., Yu, W., & Lei, R. (2017). Spatial Distribution Features and Controlling Factors of Traditional Villages in Guangdong Province. Scientia Geographica Sinica, 37(2), 236-243. https://doi.org/10.13249/j.cnki.sgs.2017.02.009

(24) Li, M., Ouyang, W., & Zhang, D. (2022). Spatial Distribution Characteristics and Influencing Factors of Traditional Villages in Guangxi Zhuang Autonomous Region. Sustainability, 15(1), 632. https://doi.org/10.3390/su15010632

(25) Scott, L. M., & Janikas, M. V. (2010). Spatial Statistics in ArcGIS. In M. M. Fischer & A. Getis (Eds.), Handbook of Applied Spatial Analysis: Software Tools, Methods and Applications (27-41). Springer Berlin Heidelberg. http://doi.org/10.1007/978-3-642-03647-7_2

(26) Hart, T., & Zandbergen, P. (2014). Kernel Density Estimation and Hotspot Mapping: Examining the Influence of Interpolation Method, Grid Cell Size, and Bandwidth on Crime Forecasting. Policing: An International Journal, 37(2), 305-323. http://doi.org/10.1108/PIJPSM-04-2013-0039

(27) Liu, Y., Luo, J., Sun, J., Tian, Y., Cui, J, & Zeng, J. (2021). Spatial Structure Characteristics Analysis of Tourism Supply and Demand in Hubei Province in 2018. Human Geography, 36(2), 175-183. http://doi.org/10.13959/j.issn.1003-2398.2021.02.021

(28) Scott, D. W. (2012). Multivariate Density Estimation and Visualization. In J. E. Gentle, W. K. Härdle, & Y. Mori (Eds.), Handbook of Computational Statistics: Concepts and Methods (549-569). Springer Berlin Heidelberg. http://doi.org/10.1007/978-3-642-21551-3_19

(29) Wang, W., Yang, Q., Gan, X., Zhao, X., Zhang, J., & Yang, H. (2022). Spatial Distribution Pattern and Influencing Factors of Homestays in Chongqing, China. Applied Sciences, 12(17), 8832. https://doi.org/10.3390/app12178832

(30) Xu, J., Wang, H., Liao, W., & Fong, C. S. (2023). From Closure to Gradual Release of EGS Industry: Empirical Evidence from the Spatial Evolution and Causal Mechanism in the Main Town Area of Wuhan, China. 3C Empresa. Investigación y pensamiento crítico, 12(2), 15-37. https://doi.org/10.17993/3cemp.2023.120252.15-37

(31) Pan, J., & Cong, Y. (2012). Spatial Accessibility of Scenic Spot at 4A Level and Above in China. Scientia Geographica Sinica, 32(11), 1321-1327. http://geoscien.neigae.ac.cn/EN/Y2012/V32/I11/1321

(32) Sun, J., Tian, Y., Cui, J., Luo, J., Zeng, J., & Han, Y. (2017). Identification of Tourism Spatial Structure and Measurement of Tourism Spatial Accessibility in Hubei Province. Economic Geography, (04), 208-217. http://doi.org/10.15957/j.cnki.jjdl.2017.04.026

(33) Yang, X., Gu, C., & Wang, Q. (2007). Urban Tourism Flow Network Structure Construction in Nanjing. Acta Geographica Sinica, 62(6), 609-620. https://doi.org/10.11821/xb200706006

(34) Yang, X., Feng, L., & Zhang, K. (2013). The Impact of Transportation on Accessibility of Tourism Scenic Region of Cross-Border Tourism Region: A Case Study of Dabieshan Mountain. Scientia Geographica Sinica, 33(6), 693-702. http://geoscien.neigae.ac.cn/EN/10.13249/j.cnki.sgs.2013.06.693

(35) Liao, Z., & Zhang, L. (2021). Spatial Distribution Evolution and Accessibility of A-level Scenic Spots in Guangdong Province from the Perspective of Quantitative Geography. Plos One, 16(11), e0257400. https://doi.org/10.1371/journal.pone.0257400

3C tecnología
Glosas de innovacion aplicadas a la pyme