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Optimisation of the Construction Plan of Assembled Concrete Structures in Other Courtyard Buildings Based on Grey Clustering

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ABSTRACT: The assembled concrete structure is a common construction solution in the current building industry, and it is debatable how to further improve the construction efficiency of the pointed claw assembled concrete structure. The study proposes a grey clustering method based on the improved OWA operator as a means to obtain more effective construction evaluation indicators. In performance tests, it was shown that the grey clustering method under the OWA operator optimisation is more capable of computing features for large amounts of data than traditional grey clustering, with an execution time of less than 200s. In the application tests of the construction scheme, the study showed that the proposed optimisation scheme has a more effective safety evaluation, shorter construction period and lower resource consumption. These results show that the use of grey clustering is effective in optimising the construction of assembled concrete structures, and that the optimised solutions show better reduction in construction time and resource utilisation than traditional construction solutions, so that the rational use of grey clustering in assembled buildings will help the construction industry to achieve greater efficiency in construction.

KEYWORDS: Grey clustering; Assembled buildings; Concrete structures; Construction solutions

1 INTRODUCTION

With the continuous development of the construction industry, assembled buildings have gradually become the main solution in the current construction industry, which is more economically efficient than traditional construction solutions, due to its short construction period and low labour requirements. It is more economically efficient than traditional construction solutions, due to its shorter construction period and lower labour requirements. In recent years, the use of assembled buildings has resulted in lower environmental pollution, in line with the national strategy for sustainable development (Knyziak 2019). In the construction of assembled buildings, concrete structures are favoured by many construction units because they are prefabricated structures that require only assembly and docking during construction, which significantly improves construction efficiency. At the same time, Bataglin F S et al. put forward a control model for planning and controlling the delivery and assembly of prefabricated structures in order to reduce the construction period and cost of prefabricated buildings. In the model, the collaboration and integration between on-site installation and logistics of prefabricated structures are emphasized. Finally, the empirical study shows that it can effectively achieve the integration of structural components (Bataglin F S et al. 2020). However, it is undeniable that the development of assembled concrete structures is still restricted due to the immaturity of the construction market, and that the construction safety situation is still severe in terms of its construction status, so it is crucial to optimise the construction programme for assembled concrete structures (Vassiliades et al. 2022; Sotiropoulos et al. 2020). In order to improve the efficiency of the construction of assembled concrete structures, some studies have proposed the use of fuzzy evaluation to analyse the safety risks in the construction process and propose avoidance solutions, while others have proposed the use of cluster analysis to obtain the construction risks of assembled concrete structures and conduct safety assessments (Ullah et al. 2020). A grey clustering approach is proposed to evaluate the safety risks in the construction of assembled concrete structures in a more comprehensive manner and to propose construction optimisation solutions to improve the development of the construction industry in China.

2 RELATED WORKS

The construction industry is an important industry in various countries, and the proposition of prefabricated buildings has attracted the attention of a large number of scholars. Bortolini et al. propose a control model for planning and controlling the delivery and assembly of assembled structures, but this model is based on BIM 4D modelling support and enables planning and control at different levels, further improving the coordination between production and logistics of assembled building structures, which is of great importance for the development of assembled buildings. The development of assembled buildings is of great significance (Bortolini et al. 2019). Zhang et al. analysed the seismic performance of steel structures under different connection forms in order to improve the application of steel structures in the construction of assembled buildings and verified each other through experiments and numerical analysis. The final results show that the spacing of intermediate bolts can have a great impact on the load bearing capacity of the structure, so the connection forms of steel structures need to be paid attention to in the construction of assembled buildings (Zhang et al. 2019). Tumminia et al. analysed the energy consumption and environmental impact of assembled buildings, combined with steady-state simulations to analyse the CO2 emissions of assembled buildings, and concluded that the environmental impact of assembled buildings during construction and end-of-life is low (Tumminia et al. 2018). Xia et al. proposed a coordination model for assembled buildings to address the design, production, and construction problems of assembled buildings. An evaluation system was developed to assess the construction progress and risks of assembled buildings (Xia et al. 2022).

Grey clustering analysis is an evaluation method, and with the development of society, the application area of grey clustering is increasing. Zhao et al. proposed a prediction model of PV water pumping system performance ratio based on grey clustering, in which the risk factors affecting the performance level of PV water pumping system were summarised, and a second curvilinear neural network structure was designed in this way, and finally the model performance was analysed using test samples. The results showed that the prediction model based on grey clustering has high accuracy and efficiency (Zhao et al. 2019). Liu proposed a grey correlation analysis clustering method and applied it to the extraction of panel hidden data, which started from three dimensions of the spatio-temporal characteristics of the panel data and introduced the idea of three-way decision making, and finally applied the method to the high-tech industry for empirical analysis, the results showed that the research proposed method can objectively determine the clustering thresholds and achieve the extraction of hidden data with validity and rationality (Liu et al. 2019). Zanon et al. combined various methods such as grey clustering to construct a model that can analyse the relationship between supply chain performance and organisational culture, which overcomes the complexity of natural subjectivity in relationship evaluation, and finally companies in different industries were studied for empirical analysis, showing that the proposed model can effectively identify the key elements of company culture and performance (Zanon et al. 2021). In the medical field, Mirzaei et al. introduced cluster analysis in brain magnetic resonance imaging, applied it to the processing and analysis of brain images, and analysed the clustering effect of cluster analysis in different brain regions (Mirzaei & Adeli 2018). Xu et al. combined grey clustering evaluation method and hierarchical analysis method to construct a dynamic safety warning mechanism in human-machine environment, which effectively realises the integrated human-machine-environment risk assessment mechanism with the risk assessment performance of grey clustering. The mechanism effectively realized the integrated human-machine-environment risk analysis with the risk assessment performance of grey clustering, and finally verified the effectiveness of the early warning mechanism in the experimental analysis (Xu & Wang 2020).

In summary, the proposal of assembled buildings has received a great deal of attention from scholars, and there has been more research on their assembled structures and construction solutions. In addition, the application of grey clustering method is widely researched and has been involved in several fields, but from the current research it can be known that few studies have used the more excellent evaluation ability of grey clustering to evaluate the construction of assembled buildings. To this end, the study applies grey clustering analysis to the evaluation of the construction of assembled concrete structures in other buildings in order to improve the current construction efficiency of assembled buildings, thereby suggesting construction optimisation solutions and thus enhancing the development capabilities of China's construction industry.

There are two innovations in the research. First, the gray clustering model is used to evaluate the safety of building construction. Compared with the existing evaluation methods on the market, the results of the gray clustering algorithm in the evaluation are more intuitive. For the construction industry, the results can provide reference for the construction of prefabricated concrete structures at the first time. Secondly, ordered weighted averaging (OWA) operator is introduced in the study to optimize the weight calculation of gray clustering. Compared with traditional methods, it can more accurately calculate the influence degree of influence factors of prefabricated buildings.

3 OPTIMIZATION OF BUILDING ASSEMBLY CONSTRUCTION BASED ON IMPROVED GREY CLUSTERING

3.1 *Data mining analysis based on the Apriori algorithm*

In the construction optimization of building assembly concrete structures, the study proposes the use of construction scheme optimization based on grey clustering, the main role of grey clustering is to calculate the weight of the indicators in the construction scheme (Lindsey et al. 2018). Apriori algorithm is an algorithm that searches for frequent items in a data set to analyse the correlation of data in the database by finding out the frequent items in the data set to generate strong association rules (Zhang et al. 2019), the algorithm flow is shown in Figure 1.

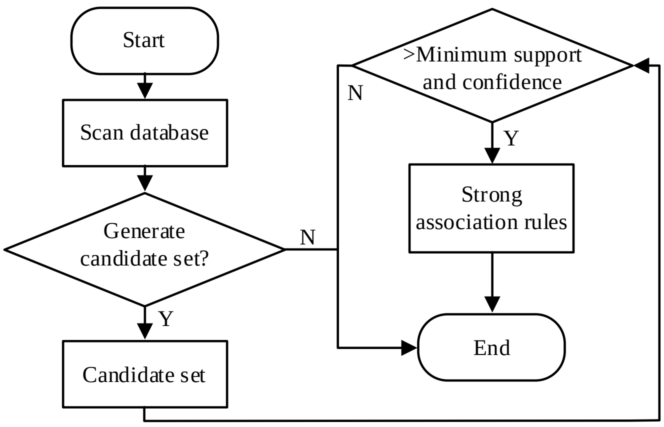

Figure 1. Apriori algorithm flow.

In Figure 1 it is shown that during the calculation of the Apriori algorithm, firstly all the data in the database needs to be scanned and during the scanning process the set of candidate items is determined. Secondly, based on the minimum support and confidence determined, it is determined whether the support and confidence in the search of the dataset is greater than the minimum support and confidence, if it is greater, a strong association rule is generated and the calculation is terminated; if it is less, it is terminated directly.

The purpose of generating strong association rules is to uncover the implied relationships between different indicators. The determination of the confidence level is also extremely important in the process of generating strong association rules, and the minimum confidence level is usually set by the user or expert. In the process of experts and users setting the confidence level , its value size determines the resultant risk factor correlation in the dataset search, the higher the confidence level, the stronger the correlation, the confidence level was set to 0.7 in the study to avoid invalid rules generated by too high or too low confidence level.

3.2 *Grey clustering based on the optimization of OWA operators*

Grey clustering is a method used to study uncertain systems, to analyse and evaluate the validity of indicators by means of weighting, and to use known information to determine the operating rules of the system. In the optimisation of the construction of assembled concrete structures, the advantages of grey clustering, such as real-time monitoring and real-time feedback, have made it increasingly popular in the construction industry (Guan et al. 2020; Li & Wei 2018). In order to optimise the construction of assembled concrete structures, a grey clustering-based construction evaluation scheme is therefore proposed. The grey clustering was used to evaluate the construction of the building assembled concrete structure, and the sample matrix of grey clustering is shown in equation (1).

$$D = d_{ij} = \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1m} \\ d_{21} & d_{22} & \cdots & d_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ d_{n1} & d_{n2} & \cdots & d_{nm} \end{bmatrix} \tag{1}$$

In equation (1), i is the clustering object with values from 1 to n, and j is the clustering indicator with values from 0 to m.

However, the traditional grey clustering is subjective, so it needs to be improved objectively to ensure that the construction solutions under grey clustering are more scientific and rational. In optimisation evaluation, weight evaluation is mainly used to achieve a more comprehensive importance classification. From the known studies, it is known that the more commonly used algorithms include Vague set theory, OWA operator and grey clustering, where the OWA operator can better eliminate the subjective ideas in the calculation process compared to most weight analysis algorithms (Flores-Sosa et al. 2021; Barman & Patra 2019). In this study, the OWA operator is combined with grey clustering to reduce the influence of subjective factors on the calculation of weights in the grey clustering process in order to effectively evaluate the construction of assembled concrete structures.

The OWA operator is evaluated objectively by directly calculating the final result of all the data in the dataset using a weighted average method, where there are outliers and co-values, both of which are defined in equation (2).

$$\begin{cases} D=-\sum_{i=1}^{n} w_i \ln w_i \\ O=\dfrac{1}{n-1}\sum_{i=1}^{n}(n-i)w_i \end{cases} \tag{2}$$

In equation (2), D denotes the deviation; O denotes the co-values; w_i denotes the weight value of the i th indicator; n denotes the total number of data in the dataset. OWA Sunzi is calculated to yield a position vector, which needs to be recalculated for its weight operator, and the calculation formula is shown in equation (3).

$$v_i=\frac{C_{n-1}^{i-1}}{\sum_{i=1}^{n} C_{n-1}^{i-1}} \tag{3}$$

In equation (3), C_{n-1}^{i-1} represents the number of combinations of $n-1$ numbers.

3.3 *Optimisation of assembly building construction based on grey clustering*

The construction of concrete structures for assembled buildings is a construction scheme commonly used in the current construction industry. In order to optimise its construction effect, the study uses the Apriori algorithm for evaluation index search and the grey clustering method for index weight calculation as a way to develop an optimised construction scheme. The main elements in construction optimisation include safety evaluation optimisation, construction process optimisation, dynamic evaluation of construction safety and construction schedule Optimisation is shown in Figure 2.

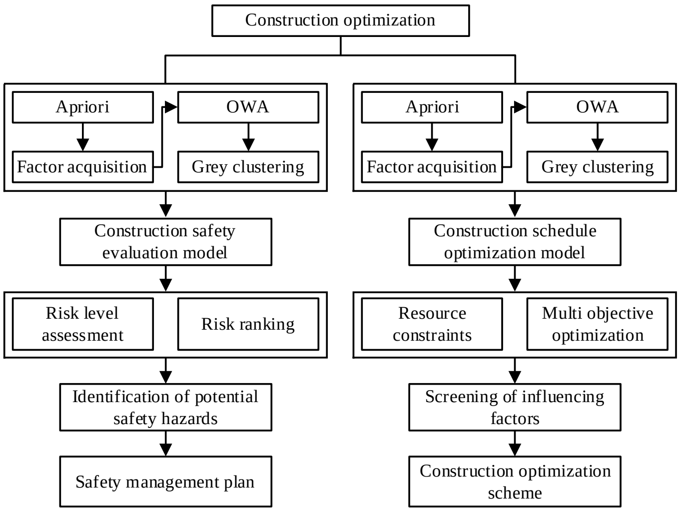

Figure 2. Dynamic evaluation of construction safety and optimization of construction schedule.

Figure 2 shows that in the safety evaluation, firstly the Apriori algorithm is used to obtain the important influencing factors for the safety evaluation, including personnel level, personnel safety awareness, construction specifications, material performance, mechanical equipment quality, safety management awareness, concrete pouring technology, component connection technology, natural environment, transportation environment, construction lighting, etc. Secondly, grey clustering based on OWA operator optimization is used to evaluate the weight of influencing factors. The safety evaluation model of assembly building construction is constructed through weight evaluation. In the model evaluation, the risk of the current construction state needs to be graded, the safety hazards are identified and searched through the ranking of risk factors, and finally the corresponding solutions are formulated. In the construction schedule optimisation, the same Apriori algorithm and grey clustering of OWA operator optimisation are used to obtain the influence factors and weight evaluation respectively, in order to construct the construction schedule optimisation model, which includes resource constraints in construction and multi-objective optimisation in the construction schedule optimisation. Finally, the factors affecting the construction progress are identified, including the system of the construction unit, funds, material supply, construction design, construction management, etc. Develop a more efficient method statement. In the safety evaluation and construction schedule optimization evaluation of prefabricated building construction, the calculation method for risk identification of influencing factors is shown in Formula (4).

$$\beta^j=\eta_j(100-x_j) \tag{4}$$

In equation (4), x_j represents the observed value of the j influence; η_j represents the weight of the j influence in the integrated clustering.

The practicality and superiority of the improved grey clustering method was analysed in the safety evaluation and in the construction schedule optimisation model construction process, with the aim of selecting a system of uncertainty in the safety evaluation, a comparison of the individual uncertainty systems is shown in Table 1.

Table 1. Comparison of uncertain systems.

/	Fuzzy mathematics	Probability statistics	Rough collection	Grey theory
Research object	Cognitive uncertainty	Random uncertainty	Boundary uncertainty	Poor information uncertainty
Base set	Fuzzy set	Cantor	Approximate set	Grey number set
Method basis	Mapping	Mapping	Divide	Information coverage
Ways and means	Cut set	Frequency count	Upper and lower approximation	Grey sequence operator
Focus on	Extension	Connotation	Connotation	Connotation
Characteristic	Experience	Large sample	Information sheet	Small sample

The differences between the systems shown in Table 1 lie in the selection and processing of the data. Due to the slow development of assembled buildings in China and the fact that they are still at a preliminary stage, most of the information is incomplete when evaluating safety and optimising construction schedules. Therefore, it is reasonable to choose grey clustering for the evaluation of safety and construction schedule optimisation in assembled buildings, which are by nature "small samples and poor information".

4 DATA ANALYSIS

4.1 *Algorithm performance analysis*

The research utilises the Apriori algorithm for data mining, so to verify its effectiveness, the effectiveness of the Apriori algorithm in data mining is first analysed and comparative experiments are constructed, with the comparative algorithms including decision tree algorithms and logistic regression models. This research was written in python language in the context of Windows 8 running system to verify the effectiveness of Apriori algorithm. Firstly, the study compared the data mining effectiveness of Apriori algorithm with other 2 classical models decision tree algorithm and logistic regression model, and used PR curve as the evaluation index of the model. PR curve is an evaluation method that integrates the accuracy and recall rate of the model, in which not only can reflect the accuracy change of the model, but also can reflect the recall rate, and the experimental results are shown in Figure 3.

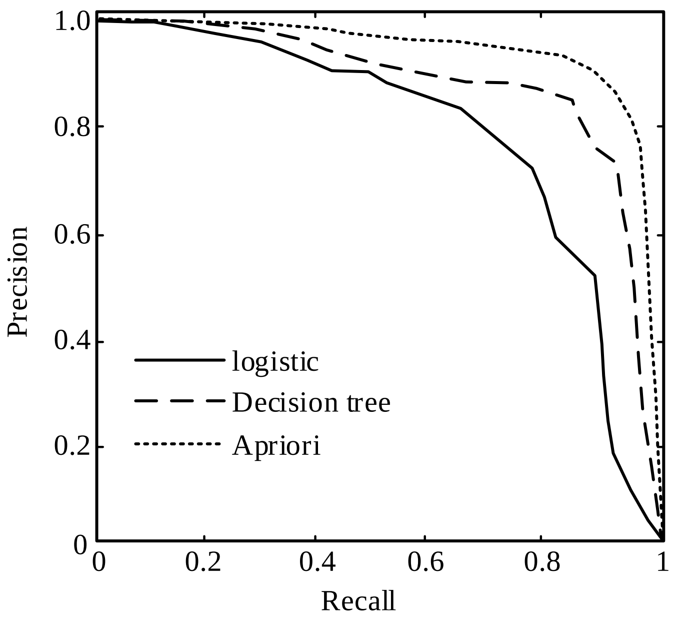

Figure 3. PR curve of different models.

As can be seen in Figure 3, the PR curve of the logistic regression model is closer to the lower right corner than the decision tree algorithm model and the Apriori algorithm, and the accuracy of the logistic regression model is 0.7543 and 0.7389, respectively, as can be seen from the curve expression. The PR curve of the Apriori algorithm is 0.9268, while the PR curve of the Apriori algorithm is 0.8435. The Apriori algorithm is closer to the upper right-hand corner of the PR curve, which means that the Apriori algorithm performs better. The reason is that the Apriori algorithm proposed by the research uses layer by layer search, so the recall rate in data search is higher.

Next, the efficiency of the Apriori algorithm task execution used in the study was analysed, and the execution times of the Apriori algorithm, decision tree algorithm and logistic regression model in the data mining process, with different numbers of nodes, are shown in Figure 4.

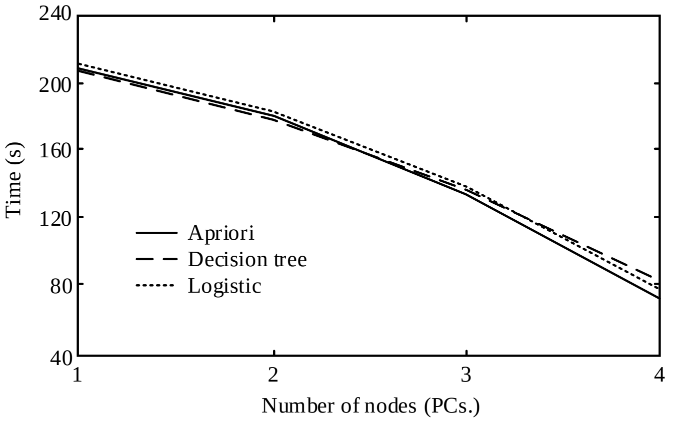

Figure 4. Execution time difference of algorithms.

As can be seen in Figure 4, the execution time of the association rules in data mining reaches 208s when the number of nodes of the Apriori algorithm is 1. As the number of nodes of the Apriori algorithm increases, the execution time of the association rules in performing data mining decreases gradually, and finally decreases to 70s when the number of nodes reaches 4. It can also be seen that the execution time of the decision tree algorithm and the logistic regression model in the execution task, the execution time when the number of nodes is 1 is 207s and 210s respectively, and when the number of nodes reaches 4 the execution time is 77s and 75s respectively. the above results show that the Apriori algorithm is consistent with the decision tree algorithm and logistic regression model in terms of execution time variation, but it can still be seen that Apriori algorithm has a slightly faster execution time variation. Therefore, the number of nodes of the Apriori algorithm affects its efficiency in data mining, and in practice the number of nodes of the Apriori algorithm should be set reasonably to ensure the efficiency of the algorithm in data mining while reducing its internal consumption. Furthermore, the execution effect of the grey clustering method based on OWA operator optimisation after Apriori algorithm data mining is analysed and verified by comparing the running time of the optimised grey clustering method and the traditional grey clustering method in a dataset with the same amount of data, as shown in Figure 5.

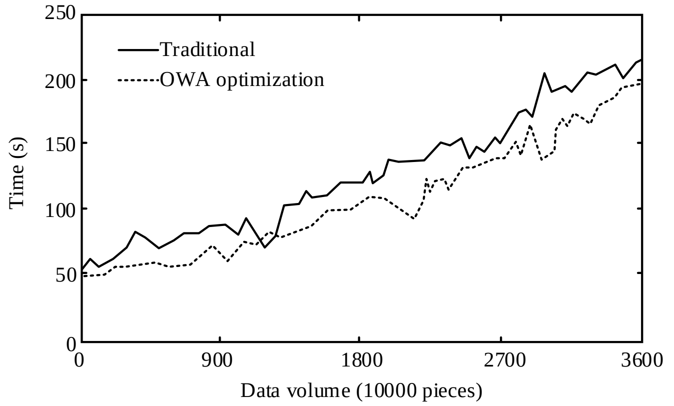

Figure 5. Comparison of calculation time in different data scales.

As can be seen from Figure 5, the runtime of the traditional grey clustering method is significantly lower than that of the OWA-optimised grey clustering method for the same amount of data. The reason for these results is that the traditional grey clustering method does not filter out the weak or unrelated data in the weight calculation, while the OWA optimized grey clustering method is able to filter the candidate set and keep the data with strong association rules, thus taking longer time to run. The above results also show that the OWA operator-optimised grey clustering method is able to perform data mining on a large number of datasets for a long period of time with an increasing amount of data, and has longevity in practice. Finally, the convergence of the optimised grey clustering was evaluated using the change in fitness value, as shown in Figure 6.

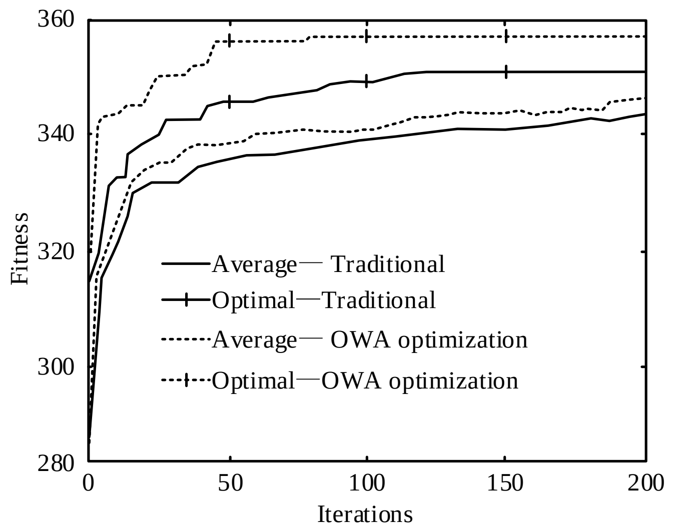

Figure 6. Fitness value change.

As can be seen from Figure 6, the change in the fitness value of the optimized grey clustering shows that the average fitness value starts to gradually converge to the maximum value after the number of iterations reaches 100, and the optimal fitness value gradually converges to the maximum value after the number of iterations reaches 60. The number of iterations required for the traditional grey clustering to reach the maximum value is 110 and 80, respectively, which is significantly higher than that of the optimised grey clustering method, indicating that the OWA operator proposed in the study has better convergence. The research shows that the optimized grey clustering algorithm can calculate the influence weight of relevant influencing factors more quickly in the calculation process, so its calculation and learning iterations are less, and its convergence is improved.

4.2 *Analysis of the construction effect of building assembled concrete structures*

In order to verify the effectiveness of the construction optimisation of the building assembled concrete structure proposed by the research, the study takes a building alias as the research object and uses grey clustering after OWA optimisation to carry out construction optimisation of the assembled concrete structure and evaluate the construction safety and construction schedule under the optimisation scheme. Firstly, the safety evaluation under the optimisation scheme is analysed, as shown in Figure 7.

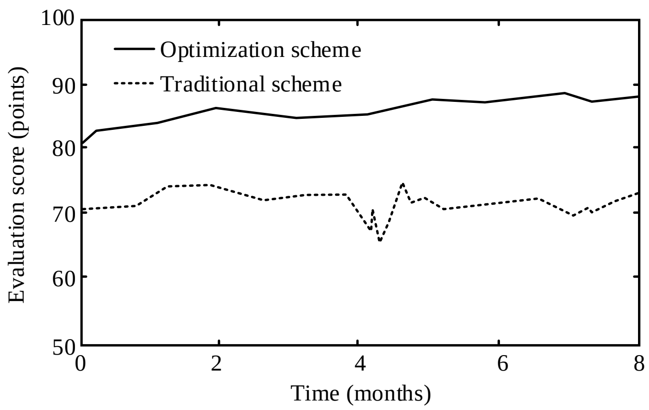

Figure 7. Safety evaluation.

As can be seen from Figure 7, the safety evaluation of the optimised solution is always at a high level, while the safety evaluation score of the traditional construction solution decreases to a certain extent during the mid-construction phase. The above results show that the optimised solution is able to avoid safety accidents through its ability to identify safety risks, thus enabling its safety evaluation to remain at a high value for a long time. Next, the difference in duration between the traditional and optimised solutions is analysed in Figure 8.

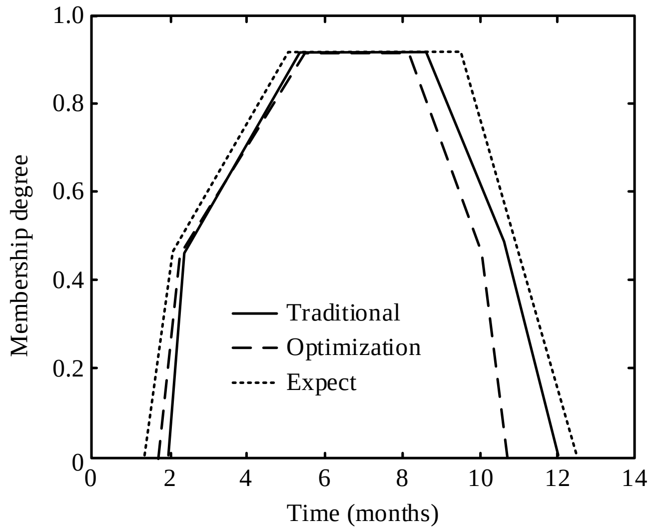

Figure 8. Duration difference under different schemes.

As can be seen in Figure 8, the difference between the traditional and expected construction time for the other house assembly building is not significant, while the optimised construction solution has a shorter construction time compared to the traditional solution, and the assembly building can be completed in less than 11 months. The final analysis of the resource consumption of the different solutions during construction is shown in Figure 9.

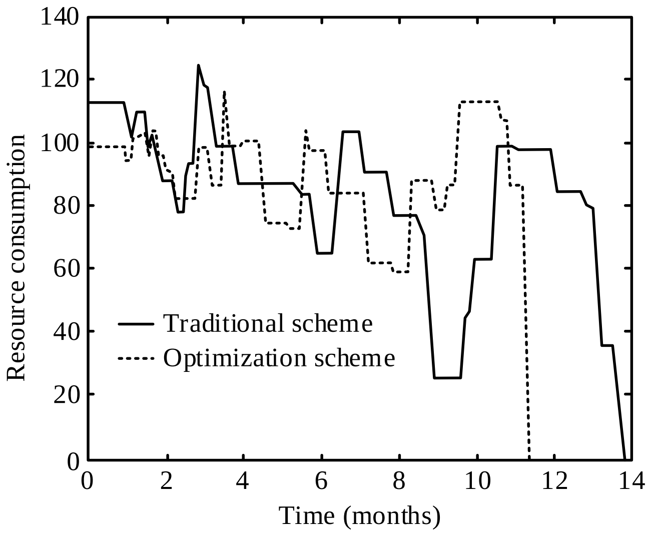

Figure 9. Comparison of resource consumption of different schemes.

As can be seen in Figure 9, the traditional assembly construction solution generates a long-term consumption of resources during the construction phase and still generates a more significant consumption of resources in the time after construction is completed. The optimised construction solution, on the other hand, has a consistent consumption of resources with the traditional construction solution in the early stages and shows a sharp decline in its consumption of resources once the time has reached 11 months, i.e. after construction is completed. A comparison of the overall resource consumption of the two schemes shows that the total resource consumption of the optimised scheme is significantly lower than that of the traditional scheme.

5 CONCLUSION

The advantages of modern adaptability have contributed greatly to its development, but there are still some problems to be solved in the current construction performance. In order to improve the efficiency of the construction of assembled concrete structures, the Apriori algorithm is used for data mining and the grey clustering based on OWA is used to calculate the weights of the data in order to construct a safety evaluation scheme and to construct a construction optimisation scheme. The algorithm performance analysis and the application of the scheme show that the Apriori algorithm has a more consistent processing capability with other commonly used algorithms, and the improved grey clustering method based on OWA has a better capability than the traditional grey clustering in data processing, as shown in the calculation of the weights of multiple data features, where the maximum execution time is still within 200s, while the execution time of the traditional grey clustering is greater than 200s. The number of iterations required to obtain the optimal adaptation value for the improved OWA-based grey clustering method is only 60, which is significantly lower than traditional grey clustering. In the application, it was shown that the safety evaluation proposed by the research can guarantee a high safety level in the long term compared to the traditional safety evaluation scheme, while the construction period of the building assembly construction was significantly shortened compared to the expected duration with the optimized construction scheme. The above results show that grey clustering can effectively improve the efficiency of building assembly structure construction and further reduce the resource consumption of assembly construction, which is of great significance to the development of the construction industry. However, it can be seen from the research results that as China's prefabricated buildings are still in the initial stage, there are certain limitations in the amount of data when selecting safety evaluation indicators. Therefore, more data need to be mined in the follow-up work to modify and adjust the indicator system.

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