Application of BIM application benefit evaluation model based on fuzzy AHP in the whole life cycle of tunnel engineering

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Abstract: Tunnel engineering plays an important role in traffic planning, but it faces many problems in the process of periodic construction because of its large construction scale, long investment and construction time and prominent geological disaster risk. This paper introduces the life-cycle theory and establishes the benefit evaluation model of BIM Technology Application under the guidance of fuzzy AHP. The comprehensive operation rate of the model has been improved by 59.9% under both the construction level and the operation level of the project. And the weight score of some engineering indicators is also more than 90 points, which greatly improves the project management-level and coordination efficiency. This model can effectively provide new application ideas for engineering construction, and establish the benefit evaluation system of BIM application in the whole life cycle.

Keywords: fuzzy AHP technology; BIM technology; applying benefit evaluation model; tunnel engineering; life cycle.

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1 Foreword

The building information model is an engineering data model based on 3D digital technology, which integrates all different types of information generated in different construction stages of the building project, and describes all the relevant data, schemes, processes and other information in each stage of the whole life cycle of the project in a digital way to realise the creation, update and sharing of information (Ashek-Al-Aziz et al., 2020; Tüysüz and Kahraman, 2020; Wang et al., 2021). The design defects and construction quality problems in the traditional municipal tunnel project will increase the overall operation and maintenance cost of the project, and increase the difficulty of sub-project construction and index deployment (Pu and Wang, 2021; Shi and Lv, 2021; Liu et al., 2020a). In view of this, this paper applies BIM application benefit evaluation model to project management, and considers the management of decision-making, implementation, operation and maintenance of the project from the perspective of life-cycle theory, so as to realise the overall coordination and information sharing of construction projects. At the same time, the fuzzy AHP method is used to classify the criteria and benefits of decision-making division of labour, so as to realise its dynamic management, adjustment and optimisation, and strive to improve the overall construction level and quality of tunnel projects and provide reference for similar projects.

2 Construction of benefit evaluation model of BIM application based on fuzzy AHP technology

2.1 Model construction of BIM in tunnel engineering project

Building Information Model (BIM) technology, as a way to digitally express the physical and functional characteristics of a facility, can establish a life-cycle shared database including the stages of design, construction, operation, management and maintenance of an engineering project, thereby improving the efficiency and benefits of the project (Yang et al., 2019). As a control project in the rail transit project, the safety of tunnel construction is the top priority, but the influence of complex hydrogeological conditions greatly limits the implementation of the construction scheme. The uncertainty of the construction environment and the difficulty in controlling the construction process make the construction safety accidents occur frequently, which increases the construction safety hazards and economic losses to a certain extent. At the same time, tunnel engineering has the characteristics of zonal distribution, complex geological conditions and great construction difficulty, which makes it difficult and insufficient in construction, operation, maintenance and management (Song et al., 2019). Therefore, in order to improve the applicability and practicability of tunnel engineering construction and optimise and adjust possible problems, this paper establishes a theoretical model of tunnel engineering construction life cycle based on BIM technology, and the schematic diagram is shown in Figure 1.

The establishment of the theoretical model is to strengthen the dynamic monitoring and management of the construction precision, quality and safety, information integration management and operation and maintenance detection of the general project and sub-projects by surveying the site topography, judging the construction environment and preparing the equipment and materials in the early stage, so as to meet the requirements of the early, middle and late stage of the project construction project and to prevent and control the possible problems in time, so as to achieve the best overall effect, ensure the optimisation and smooth progress of the scheme and complete the overall construction plan.

Figure 1 Establishment of tunnel engineering model based on BIM technology

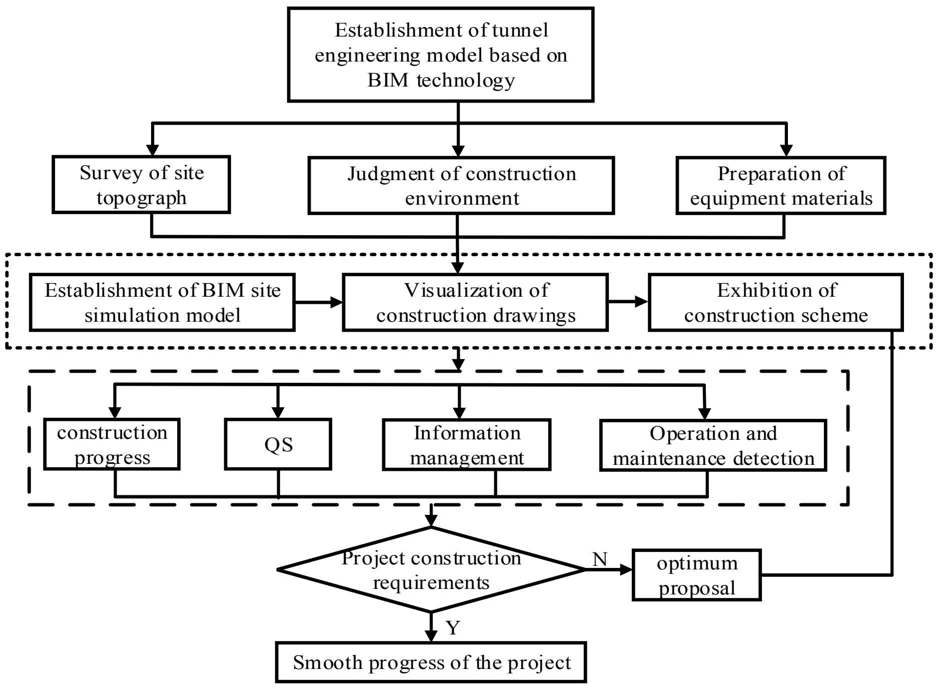
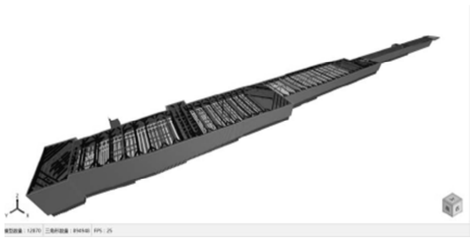


Figure 2 is a partial effect display in the process of model construction. According to the characteristics of tunnel engineering construction, the modelling standards are determined, such as model format, coding mode and attribute fields, etc., and the international unified standard IFC format of BIM is adopted, and the model is created according to the construction drawing by using Autodesk Revit and other software (Liu et al., 2020b). Figure 2(a) shows the partial modelling effect, and the coding rules of the project model are formulated according to the general project, unit project and sub-project to make it realise hierarchical and orderly division, which is convenient for viewing and information searching, etc. The coding mode is shown in Figure 2(b). Geographic Information System (GIS) is a representation means by analysing and storing the collected spatial geographic distribution data of the earth's surface and displaying the terrain and features in the form of digital maps, which can more intuitively display the surrounding working environment and some special geological and geomorphic environments of the project (Chen et al., 2019). By combining BIM with GIS technology, firstly, the data of the surrounding environment and the building itself of the project to be built are collected through GIS technology and displayed in a visual way. Then, the geographic data information is imported into BIM software for processing, so that it has a more objective realistic environment when setting the parameters and structural distribution of the model data, so as to ensure the integration and high efficiency of the project information data, The feasibility of project planning application is improved. The specific performance effect is shown in Figure 2(c).

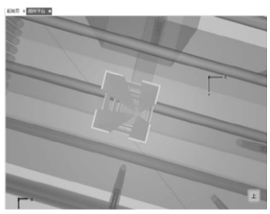
2.2 BIM application benefit evaluation model based on fuzzy hierarchy method

Traditional Analytic Hierarchy Process (AHP) is based on qualitative analysis for quantitative analysis, which systematises the complex thinking process, gradually decomposes and combs the evaluation objectives and finally forms its structural solution into an element system with logical hierarchical structure, and puts forward a set of systematic analysis methods to provide convincing basis for scientific management and rational decision-making. However, it is limited to selecting the better one from the original scheme, and because of the lack of quantitative data, the accuracy and judgment process are more complex (Yang and Chou, 2019; Li et al., 2021a; Bensalah et al., 2019). Therefore, this paper introduces the fuzzy theory, and makes fuzzy treatment on some indicators or judgment basis which are difficult to determine responsibility, thus increasing the diversity of indicator selection and making AHP more flexible in the selection and determination of indicator factors. Fuzzy theory refers to the use of the concept of fuzzy sets to judge uncertain information, so as to discover the connection of the information itself, which is mostly used for medical diagnosis and decision support (Lapina et al., 2020). Figure 3 shows the evaluation of BIM application benefit model under fuzzy analytic hierarchy process.

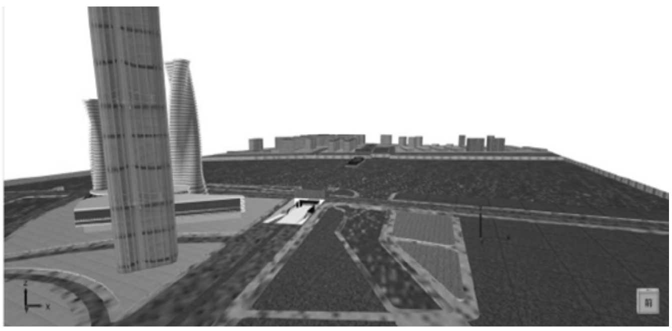
Figure 2 Project model drawing



(a).Partial model presentation



(b).coded system



(c).BIM+GIS

Figure 3 Evaluation of BIM application benefit model based on fuzzy analytic hierarchy process

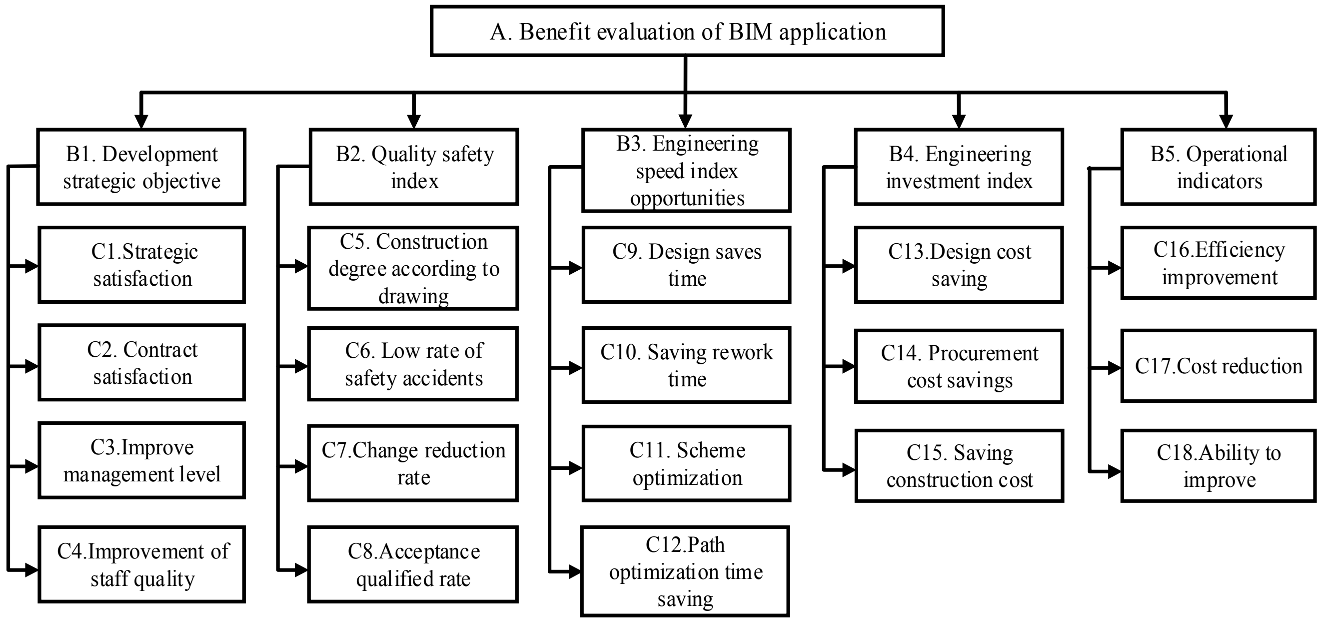


Figure 3 is a structural model of different levels of analysis, which includes the bottom factor layer, the middle criterion layer and the highest goal layer, based on clarifying the final effect of the project. According to the risks and influencing factors in tunnel construction projects, the goal of risk quantification is established as (layer A), the criterion layer of risk occurrence probability and consequence influence degree (layer B), and the risk factors in construction projects (layers C and D, etc.). Then, through the construction of fuzzy complementary judgment matrix P, the importance of the factors is quantitatively compared and the judgment matrix between u_i and u_j are constructed, and the $i, j = 1, 2, ..., n$ importance of the two indicators, ‘v_{ij} and u_j’ are analysed. The feature root method P is used to calculate the weight, and the maximum feature root $\lambda_{\max}$ and corresponding feature vector of the matrix w are obtained. The function is as follows in formula (1):

$$P_w = \lambda_{\max} \cdot w \tag{1}$$

The feature vectors w are normalised to obtain the order of importance of indicators at all levels, that is, the weight coefficient division of indicators. The normalised function is expressed as shown in formula (2):

$$\bar{w} = \frac{w}{\sum_{i=1}^{n} w_i} \tag{2}$$

The matrix is tested for consistency, and the functional expression of consistency index is shown in formula (3):

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{3}$$

In formula (3), the corresponding consistency index CI is the hierarchy of the matrix. At that time $CI = 0$, the consistency analysis P was satisfied, and the value CI was negatively correlated with the consistency degree. The expression of the consistency ratio calculation function is shown in formula (4):

$$CR = \frac{CI}{RI} = \frac{\sum_{i=1}^{n} v_i CI_i}{\sum_{i=1}^{n} RI_i} \tag{4}$$

In formula (4), in order to calculate the consistency ratio CR, RI is an average random consistency index, which can be obtained by looking up the level corresponding to the matrix. When CR is equal to 0.1, the judgment matrix has complete consistency and when it is less than 0.1, the consistency of the judgment matrix is good; otherwise, the indexes in the judgment matrix should be revised until the conditions are met.

3 Application effect analysis of BIM evaluation model

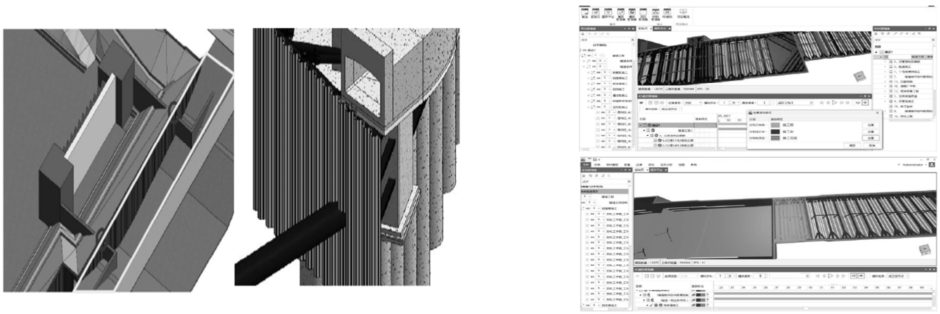
3.1 Example analysis of evaluation model in tunnel engineering

In this paper, a river-crossing tunnel at the junction of two districts in a city is selected. The main line of the tunnel is 1.58 km long, with a total investment of 2.093 billion yuan, a construction period of 4 years (including a trial operation period of one year) and an operation and maintenance period of 10 years. The tunnel construction mainly includes the main structure on the shore, the immersed pipe section structure, the enclosure structure on the shore section (including cofferdam), Embankment protection and repair, ventilation engineering, drainage and firefighting engineering, electrical engineering, monitoring system engineering, etc. (Luciani and Peila, 2019). The whole life cycle includes six stages: decision-making, design, construction, use, maintenance and demolition. The costs generated by each stage are not simply additive, and the progress and effect of the previous stage will affect the formulation of project decision-making in the later stage (Ning et al., 2020). In order to solve the difficulties in the project, all the project participants are comprehensively considered in the benefit evaluation of BIM application, so as to meet the actual needs of the project and give full play to its system integration function. And through the establishment of tunnel health data files, regular and special inspections are carried out for hydrology, design, construction, third party and other data measurement, which is convenient for later maintenance and repair (Moňoková and Vileková, 2020).

In the early stage of planning, design and management of BIM Information Management Centre platform, 3D and visualisation of drawings can intuitively and quickly discover the problems and deficiencies in the design, make timely adjustments, avoid the impact on later construction and reduce the difficulty of later operation and maintenance, and use Navisworks software to carry out collision detection on tunnel models, avoiding nearby water supply, power, communication and gas pipelines, and reducing the collision between design pipelines and existing pipelines, between design structures and between design structures (Zhang, 2021). Figure 4(a) shows the collision detection effect. At the same time, BIM technology is used to carry out four-dimensional simulation of on-site progress plans at all levels, so as to grasp the progress of the plans and facilitate the dynamic optimisation and adjustment, that is, by selecting planning nodes and building models, the models are divided into trees in turn according to the classification levels of family types, families and types, so as to realise the combination of time dimension information with the construction sequence in the construction scheme, realise visual resource allocation and optimise the construction scheme in advance (Yang et al., 2020). Figure 4(b) shows the progress simulation effect. This technology reduces the change and rework caused by collision design conflict in maintenance from 5 to 6% of similar projects to 0.8%, and BIM technology has obvious improvement effect on project design quality.

Figure 5(a) shows the quality inspection of the construction site of the tunnel construction project, and Figure 5(b) shows the tracking effect of the project progress. Through the BIM model engineering calculation combined with the implementation difficulty of the project itself, the accuracy of the construction plan has been improved by 30% and the problems such as unreasonable operation logic and conflict in the original plan implementation process have been avoided, and the optimisation and adjustment of the plan for four times have been realised, with a time saving rate of 6.85%. Unsafe factors of open-air high-altitude operation, manual labour and construction environment will be different with the progress of the project, so the detection of quality problems can make emergency plans for controlling hazards in advance, which can reduce the incidence of safety accidents to a certain extent (Hong et al., 2020). By using BIM technology to add pushpins, the quality and safety problems were rectified in time and the timely rectification rate was 83.59%, which increased the safety rate of all links by over 50% and the overall quality of construction projects by 29%, thus ensuring the smooth progress and completion of the total project.

Figure 4 Project model drawing



(a).Model collision detection

(b).Four-dimensional construction progress simulation

Figure 5 Project model drawing

(a).Quality safety monitoring

(b).Progress tracking

Table 1 shows the statistics of some benefit savings during the completion of the project. The benefit projects include saved technical management personnel expenses (913,400 yuan), administrative expenses (91,500 yuan), equipment rental expenses (732,400 yuan), loan interest expenses (1,295,800 yuan) and rework and modification expenses (123,900 yuan), with a total savings of 3,033,100 yuan. BIM technology has greatly reduced the cost of construction projects during the actual case operation, and the benefits it creates are far greater than the construction costs, which can better realise the integration and utilisation of resources, thus enabling the project construction to implement cost saving and efficiency improvement on the basis of ensuring quality and safety (Li et al., 2021b).

3.2 Benefit evaluation of BIM application based on AHP

In this paper, according to the evaluation index system, the index result diagram is established and the standard factors of the criterion layer and the index layer are assigned according to the importance degree of each index. The employer, general contractor, construction unit, BIM consultant team and relevant experts are invited to form a jury to collect the data results of their views on the importance degree of the index, and the first-class index and the second-class index are set by using the 1–9 scale method. The first-level indicators are development strategy indicators (B1), quality and safety indicators (B2), project progress indicators (B3), project investment indicators (B4) and operation and maintenance indicators (B5). Secondary indicators include strategic development satisfaction (C1), contract satisfaction (C2), improvement of management level (C3), improvement of overall quality (C4), construction degree according to drawings (C5), less rate of safety accidents (C6), change reduction rate (C7), qualified rate of project acceptance (C8), design time saving (C9), rework time reduction (C10), etc., procurement cost saving (C14), construction cost saving (C15), operation and maintenance efficiency improvement (C16), operation and maintenance cost saving (C17) and operation and maintenance capability improvement (C18). According to the jury's opinion and scoring situation, the weight of the index is calculated, and the results are sorted out to get Table 2.

Table 1 Direct benefits saved by BIM application

Serial number	*1*	*2*	*3*	*4*	*5*	*6*
Benefit project	Technical management expense	administrative costs	the equipment rental cost	bandwidth interest	rework costs	total
Price (ten thousand yuan)	91.34	9.15	73.24	129.58	12.39	303.31

Table 2 Weight summary table

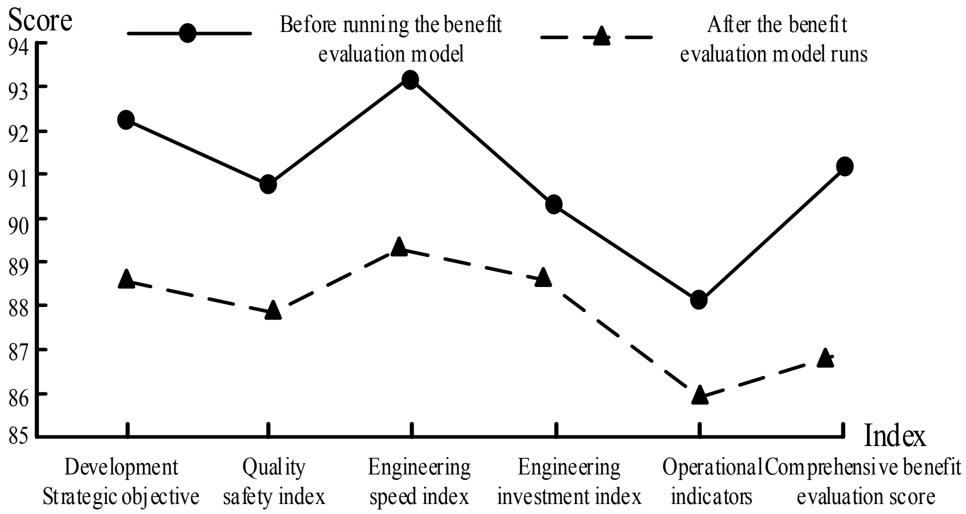
Target layer (A)	*Criterion layer (B_i)*	*weight*	*Indicator layer (C_i)*	*CR*	*Relative-weight*	*Combination weight*
Benefit evaluation of BIM application	B_1	0.054	C_1	0.012	0.465	0.025
			C_2		0.162	0.009
			C_3		0.276	0.014
			C_4		0.097	0.006
	B_2	0.383	C_5	0.018	0.096	0.039
			C_6		0.287	0.12
			C_7		0.185	0.06
			C_8		0.432	0.164
	B_3	0.244	C_9	0.005	0.139	0.036
			C_{10}		0.141	0.034
			C_{11}		0.456	0.112
			C_{12}		0.264	0.062
	B_4	0.212	C_{13}	0.008	0.296	0.062
			C_{14}		0.166	0.034
			C_{15}		0.538	0.116
	B_5	0.107	C_{16}	0.016	0.122	0.012
			C_{17}		0.32	0.033
			C_{18}		0.558	0.062

Table 2 is the calculation result of index weight of tunnel engineering construction project. It can be seen from the table that the consistency test of comparison and analysis between primary indicators B1–B5 and secondary indicators C1–C4, C5–C8, C9–C12, C13–C15, C16–C18 is not greater than 0.1, which meets the requirements of consistency test. Among them, C15 (construction cost saving, 0.538) and C18 (improvement degree of operation and maintenance capability, 0.558) are the biggest influencing factors of the relative weight of the indicator layer, followed by C1 (strategic development satisfaction, 0.465), C11(construction scheme optimisation time saving, 0.456) and C8 (qualified rate of sub-project acceptance, 0.432). For the tunnel construction project, the cost investment and later maintenance are related to the construction efficiency and management level of the whole project, ensuring its safety and technicality, at the same time making it have certain benefits, which can greatly strengthen the quality control of the tunnel project (Marco and Narbaev, 2021). For some tunnel projects built by cooperation between government and enterprises, the construction cost and operation cost can be reduced through the improvement of technical means. With the addition of BIM application benefit model, the time of construction scheme is saved and optimised and the qualified rate of partial projects is increased. BIM technology makes use of it to carry out quality and safety control and problem detection at all stages and links, which makes it optimise, improve and properly adjust the scheme in the construction process. To a certain extent, it realises the technical loss reduction and reduces the possibility of problems in the later construction process.

Using expert evaluation method, the indicators are evaluated and according to the evaluation results, they are divided into five evaluation grades: very significant, significant, not obvious, poor and poor. Then, the data of the evaluation grades of each indicator by experts are statistically sorted out, and the membership degree of indicators and evaluation grades is determined. Determine the weight of evaluation object, carry out fuzzy comprehensive calculation and calculate the benefit evaluation score. In the Figure 6, the change data of benefit score before adopting the model is the average situation obtained by comprehensive investigation according to the tunnel project with similar operation scale, similar operation environment and the same construction, maintenance and operation situation and the cost calculation in the evaluation of the preparatory scheme before the tunnel construction, and it is used as a comparative situation to test the fuzzy evaluation effect of BIM application benefit. The result is shown in Figure 6.

Figure 6 shows the comparison of operating benefit scores of indicators at the criterion level before and after the application of BIM model, in which the abscissa is the classification of indicators and the ordinate is the score value. The solid line in the figure indicates the benefit results after the introduction of BIM technology, in which the comprehensive benefit score from project management is 91.076, of which the project progress score is the highest (93.123), while the development strategy score is 92.162. The quality-level score (90.68) and the project investment-level score (90.17) are all above 90 points, while the operation and maintenance-level score (88.090) is lower than 90 points, but also exceeds 85 points. However, the scores of all aspects without introducing this model are only below 90 points, among which the highest project progress score is only 89.53 points, and its performance in later operation and maintenance is poor. Generally speaking, the application benefit evaluation model constructed by BIM has achieved remarkable results in four aspects: development strategy, quality and safety, project progress and project investment and greatly saved the construction period, while there is room for further improvement in operation and maintenance. On the whole, the benefit of saving the construction period is the most prominent, and the operation and maintenance needs to be further improved, but the overall completion degree is good, and the goals and effects achieved by the project construction are obvious.

Figure 6 Scoring results of operational benefits of criteria layer indicators before and after BIM model application



4 Conclusion

In view of the problems and limitations of traditional project management mode in tunnel engineering construction, the whole life-cycle theory is introduced to establish its BIM technology application benefit evaluation model, and on the basis of this AHP, the fuzzy comprehensive theory method is used to establish its evaluation indexes at different levels and standards under fuzzy AHP, so as to have a better understanding of its application effect. The results show that the rework rate of BIM technical model is reduced from 5-6 to 0.8%, and the accuracy of construction is increased by 30%, the saving rate of construction period is 6.85%, the timely rectification rate is 83.59% and the comprehensive quality level of the project is improved by 29%, which makes the overall project run better. At the same time, when calculating the weight of each index, it is found that the biggest influencing factors of the relative weight of the index layer are C15 (construction cost saving, 0.538) and C18 (improvement degree of operation and maintenance capacity, 0.558). In the fuzzy comprehensive evaluation score, the development strategy (92.162), quality and safety (90.68) and project investment (90.17) all reached more than 90 points, while the poor performance operation and maintenance score (88.090) was also higher than the passing score, indicating that BIM technology has improved all aspects of project construction and some direct benefits generated by BIM reached 3.0331 million yuan. However, further exploration is needed for its later operation and maintenance, which will help to establish a benefit evaluation system of BIM application in the whole life cycle, and provide new ideas and methods for engineering construction.

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