Study on Multi-Objective Dynamic Optimization Method for Architectural Engineering Based on BIM

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Abstract. At present, there are still many problems in the construction industry, such as low production efficiency, extensive production mode, high energy consumption, relatively backward technology and management mode. In this paper, we take use of BIM to establish a unified multi-dimensional optimization information model with multiple target of duration, cost and quality. And then, we propose a multi-objective mathematical model to improve the adaptive genetic algorithm. It helps to comprehensively realize the management and control of the three major objectives in engineering construction, and promotes the popularization and application of BIM technology in the construction industry.

1. Introduction
As a pillar industry of China's economy, the construction industry has been developing at a high speed. With the progress of science and technology, people's pursuit of architecture is becoming more and more complex, and the requirements for the functional quality of the building are becoming more and more comprehensive. Therefore, the construction process of construction projects has become more complex, and the amount of information obtained and transmitted between the various construction subjects is also very large. The existing project management techniques and methods are difficult to meet the complex requirements of construction management in the construction industry. The construction site management is very extensive, and there is serious waste of funds and resources. In short, multi-objective management and control in the construction process is difficult to achieve high efficiency.

Building information modelling (BIM) is to use information technology to build multi-dimensional building information model, and share the information in the model. Its main goal is to transfer information smoothly and comprehensively in the process of design, construction and operation management of construction projects, finally achieve the goal of life cycle information. In this paper, BIM technology is introduced into the three major objectives of project: duration, cost and quality management, to develop the multi-objective information optimization model and target integration management in the process of project construction. This study provides new ideas and methods for multi-target information integrated management, and provides a unified model for sharing and exchanging BIM data among different information management systems, and helps to promote the application of BIM technology in the whole life cycle of buildings.

2. Construction of Multi-objective optimization model
Duration, cost and quality as the three main control objectives of the project, are related to the success of the entire project. In order to ensure the implementation of the project, the construction unit must use scientific methods to reasonably control the three major objectives of the project. The first thing is to
 quantify the three major goals, and establish multi-objective equilibrium optimization mathematical model for engineering projects. Based on this, we establish a multi-objective information optimization model for construction based on BIM and IFC.

2.1. Duration model
In the construction project management, progress management is often the issue that managers are most concerned about. Based on network plan, the duration of the project is equal to the sum of the actual duration of all active operations on the critical path in the network plan. Because of the different operation methods and mechanical selection methods, the actual duration of the process will vary.

This article assumes that each process has a minimum duration, normal duration and maximum duration, and then the duration model is established as follow:

\[
\begin{align*}
\min T_c &= \sum_{i,j \in I} t_{ij} \\
S.T. \quad &\sum_{i,j \in I, \tau \in I} t_{ij} \leq T_r \\
& t_{ij}^{L} \leq t_{ij} \leq t_{ij}^{U}
\end{align*}
\]

In the formula, \(I\) represents the collection of all lines in a network plan; \(I_{\alpha}\) is collection of processes on key lines; \(t_{ij}\) is actual duration of the process \(ij\); \(t_{ij}^{L}\) is shortest duration of the process \(ij\); \(t_{ij}^{U}\) is the longest duration of the process \(ij\); \(T_c\) is calculation period; \(T_r\) is required duration.

2.2. Cost-duration model
The cost of engineering construction is divided into direct cost and indirect cost. The former includes the costs of labor, materials, machinery, etc. directly used to complete the engineering tasks. Generally, direct costs increase as process duration shortens, and within a certain range, direct costs are inversely proportional to process duration.

The relationship between direct costs and process duration is shown as Fig.1.

![Fig.1 Relationship model between direct costs and process duration](image)

The indirect costs include the costs of management staff such as salary, procurement, office work, labor protection, and travel expenses that are not directly used to complete the project. Indirect costs decrease as the duration decreases, as shown in Fig.2.
Therefore, the relationship between total cost and process duration is shown as Fig. 3.

According to the theory of diminishing marginal utility in economics, to introduce a marginal cost increase factor \( r_{ij} \) into the cost-duration model, value of which is determined by factors such as construction environment, process, labor force, etc. When these factors are conducive to the smooth construction of the project, the value of \( r_{ij} \) is low; on the contrary, its value is high. According to the above discussion, the process time-cost model is expressed as a power function relationship, and taking period reward system into account, and then establish the cost-duration model as follow:

\[
\min C = \sum c_{ij} + r_{ij} \left( t_{ij}^n - t_{ij} \right)^2 + g \times T_c + \alpha \left( T_c - T_r \right)
\]

\[
S.T. \quad -t_i + t_j - t_{ij} \geq 0
\]

\[
\alpha = \begin{cases} 
\alpha_1 & T_c - T_r \geq 0 \\
\alpha_2 & T_c - T_r \leq 0 
\end{cases}
\]

In the formula, \( c_{ij} \) is the direct completion cost of the process under normal conditions; \( r_{ij} \) is marginal cost increase factor; \( t_{ij}^n \) is the normal duration of the process \( ij \); \( t_{ij} \) is the actual duration of the process \( ij \); \( t_i \) is the start time of the event \( i \).

2.3. Quality-duration model

The quality of the project depends on the quality of each process during the construction process, which are the most fundamental link in the formation of project quality. Process quality forms with process time, that is, different completion times result in varying degrees of process quality. With the compression of working hours, the quality of work completed will be affected. It is generally assumed that the construction factors are not changed, the quality of each process changes approximately linearly.
with the time of completion. With the compression of work duration, the quality of the process is also relatively low.

The relationship between the completion time and the quality of the process is approximately shown as Fig.4.

![Fig.4 Relationship model between completion time and process quality](image)

In order to quantify it more reasonably, we introduce system reliability, to establish the quality-duration model.

The system reliability model has the following classification: series, parallel, mixing, voting, etc. Among them, series systems and parallel systems are the most basic structural types.

Series system is a series structure composed of t subsystems. Only when all subsystems do not fail, but this system would work. In other words, failure of any subsystem will result in failure of the system.

Assume Xi (i=1,2,…,t) represents the i-th subsystem, the reliability is expressed as Ri, then the reliability of series system is as follow:

$$R = \prod_{i=1}^{t} R_i$$  \hspace{1cm} (3)

Parallel system refers to a parallel structure consisting of t subsystems. The system is ineffective only when all subsystems are in a fault state. If one of the subsystems is in a normal state, the system will not fail.

Assume Xi (i=1,2,…,t) represents the i-th subsystem, the reliability is expressed as Ri, then the reliability of parallel system is as follow:

$$R = 1 - \prod_{i=1}^{t} (1 - R_i)$$  \hspace{1cm} (4)

Assume that all construction factors will not change, for any process ij, with the shortest duration $t_{ij}^l$ and the longest duration $t_{ij}^u$, the reliability $R_{ij}$ of each process is positively related to $t_{ij}$. When process duration exceeds $t_{ij}^u$, no matter how much delay will not bring about the improvement of quality.

We use working procedure reliability to represent process quality, to obtain the process quality reliability - duration relationship model, as shown in Fig.5.
We can see from Fig.5 that, when the duration of the process is shortest, the process reliability is the worst. With increasing duration, the process reliability also increases. When the duration reaches the maximum, the quality reliability no longer increases. According to this, we establish the engineering quality - duration model as follow:

\[
\max Q = \prod_{i=1}^{n} R_{ij} \prod_{j=1}^{n} \left[ 1 - \prod_{h=1}^{r_{ij}} \left( 1 - R_{jh} \right) \right]
\]

By integrating the above single-target model, We can draw a multi-objective equilibrium optimization mathematical model as follow

\[
\begin{align*}
\min F(x) &= \{ f_1(x), f_2(x), -f_3(x) \} \\
\min f_1(x) &= \min T_c = \sum_{i \in I} t_{ij} \\
\min f_2(x) &= \min C = \sum C_{ij} + r_{ij} (t_{ij}^s - t_{ij})^2 + g \times T_c + \alpha (T_c - T_r) \\
\max f_3(x) &= \max Q = \prod_{i=1}^{n} R_{ij} \prod_{j=1}^{n} \left[ 1 - \prod_{h=1}^{r_{ij}} \left( 1 - R_{jh} \right) \right]
\end{align*}
\]

\[
S.T. \\
\sum_{i \in I, j \in I} t_{ij} \leq T_r \\
t_{ij}^l \leq t_{ij} \leq t_{ij}^u \\
-t_j + t_j - t_{ij} \geq 0 \\
\alpha = \begin{bmatrix} \alpha_1 & T_c - T_r \geq 0 \\ \alpha_2 & T_c - T_r \leq 0 \end{bmatrix}
\]

\[
C_c \leq C_p, Q_c \geq Q_p
\]

Multi-objective equilibrium optimization mathematical model above is a synthesis of duration model, cost-duration model and quality-duration model. The smaller the value of the multi-objective function, the better the optimization will be.

3. Multi-objective optimization solution

Most of modern multi-objective optimization problems are solved by intelligent methods. Modern intelligent solutions include genetic algorithm, ant colony algorithm, simulated annealing algorithm, particle swarm optimization algorithm, neural network and so on. In this paper, an improved genetic algorithm is proposed to solve the above multi-objective optimization problems.
Genetic algorithm is a global optimization probability search algorithm based on simulating the evolution process of biological world. The cross probability $P_c$ and mutation probability $P_m$ in traditional genetic algorithm are empirical values, and, which are invariable. The fixed mutation probability makes the group gradually converge after several iterations. Inbreeding is formed and it thus directly affects the performance of the offspring. So M.Srinivas proposed an adaptive genetic algorithm. In this algorithm, the algorithm is in each iteration will set the $P_c$ and $P_m$ value adaptively according to the individual fitness value. This adaptive genetic algorithm has better efficiency and global optimality.

However, the adaptive genetic algorithm also has some limitations, one of which is that it is easy to have premature convergence or premature convergence. In order to solve this problem, we propose an improved adaptive genetic algorithm: judge whether there is an immature convergence trend based on the custom discriminant, and use macro control and micro processing to set crossover probability $P_c$ and mutation probability $P_m$, so that get rid of the unripe convergence of the algorithm. The probability is described as follow:

$$P_c = \begin{cases} 0, & \frac{f_{\text{max}} - f_{\text{avg}}}{f_{\text{avg}} - f_{\text{min}}} + \lambda \leq 0, \quad f_{\text{max}} - f_{\text{avg}} < 1, \quad M_1 > M_2 \\ \frac{f_{\text{max}} - f_{\text{avg}}}{f_{\text{avg}} - f_{\text{min}}} + \lambda, & \frac{f_{\text{max}} - f_{\text{avg}}}{f_{\text{avg}} - f_{\text{min}}} < 0, \quad f_{\text{max}} - f_{\text{avg}} < 1, \quad M_1 > M_2 \\ \frac{P_c - P_c}{f_{\text{avg}} - f_{\text{min}}}, & \text{other} \end{cases} \quad (7)$$

$$P_m = \begin{cases} 0, & \frac{f_{\text{max}} - f_{\text{avg}}}{f_{\text{avg}} - f_{\text{min}}} + \lambda \leq 0, \quad f_{\text{max}} - f_{\text{avg}} < 1, \quad M_1 > M_2 \\ \frac{f_{\text{max}} - f_{\text{avg}}}{f_{\text{avg}} - f_{\text{min}}} + \lambda, & \frac{f_{\text{max}} - f_{\text{avg}}}{f_{\text{avg}} - f_{\text{min}}} < 0, \quad f_{\text{max}} - f_{\text{avg}} < 1, \quad M_1 > M_2 \\ \frac{P_m - P_m}{f_{\text{avg}} - f_{\text{min}}}, & \text{other} \end{cases} \quad (8)$$

The algorithm flow is shown as Fig.6.

![Fig.6 Multi-objective optimization solution algorithm flow](image)

**4. Conclusion**

This article firstly analyses the relationship among project duration, cost, and quality, and then establishes the duration model. Then, through introducing the theory of diminishing marginal utility, cost-duration model is established that takes into account the marginal cost increase factor. And then, we introduce the system reliability theory into the establishment of quality-duration model, to make a detailed analysis of the relationship between process quality reliability and process duration. At last, we
use the improved AGA algorithm to solve the multi-objective mathematical model, and introduce the operation steps of the improved AGA algorithm.

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