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Heterogeneous resource scheduling algorithm based on bim project schedule modeling

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Abstract. To improve analysis precision of heterogeneous resource scheduling algorithm based on project schedule, a kind of heterogeneous resource scheduling algorithm based on BIM-DAG project schedule modeling is put forward. Firstly, project schedule prediction model is defined and model evaluation index of project schedule and BIM quantitative evaluation model are established by adopting refined project cost; secondly, optimal algorithm frame for directed acyclic graph and heterogeneous resource system model of construction schedule is established and effective optimism to BIM quantitative evaluation model and model evaluation index is realized; finally, effectiveness of algorithm has been verified by empirical analysis and the algorithm has guiding significance to actual project schedule.

Key words. Project schedule, Heterogeneous resource, Undirected graphical model, BIM algorithm, Quantitative evaluation.

1. Introduction

Construction industry is an important pillar industry for national economic development. Since thirty years after Reform and Opening-up, fixed-asset investment in China has presented strong growth in general and fixed-asset investment amount nearly accounts for one third of GDP. In 2012, fixed-asset investment in China was RMB 37467.6 billion, increased by 20.3070 compared with last year; herein, output value of construction industry was RMB13530.3 billion with year-on-year growth of 16.2070. In recent ten years, fixed-asset investment in China and construction industry have completed output value change trend. China has become one of the biggest construction markets in the world and urbanization rate of China will 55% by 2020 and will exceed 76% by 2052 with fast development of construction industry.

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The development of metropolitan, urban agglomeration, urban belt and central city, indicates rapid development of China's urbanization process, but also indicates the broader market space of construction industry.

Project construction is important to economic development and whether project construction target can be realized on schedule is key point to decide economic benefit and social benefit of project and to promote increase of national economy and maintain long-term prosperity and stability of national economy. In modern project management, how to formulate reasonable construction plan, master construction schedule accurately and optimize and use various construction resources to shorten duration, reduce cost, improve quality, produce safely and construct civilly has become consensus of construction managers. Project management requirement is more and more defined and requirement for main control target, such as construction schedule is more and more strict. Construction schedule is one of the key indexes for project management, which influences investment benefit of project directly; if project schedule target can be controlled better, project quality will be improved, project cost will be reduced and efficiency and effect of other target factors will be improved. Otherwise, project target will lose efficiency, dispute will be caused thereby and it even will lead to unfavorable influence on economic benefit and social benefit of project. During execution process of project schedule, actual duration of various sub-divisional works may be inconsistent with planned duration and change of various influence factors and organization measures will usually delay duration and increase cost during project execution with progress of project, which requires us to adjust and correct duration plan proposed and prepare actual schedule for project promptly.

This Paper analyzes current situation of domestic and foreign research, deepens actual investigation and research for project, borrows and absorbs the latest research results, such as schedule management theory, project reliability theory, computer model and BIM technology application, etc. by collecting domestic and foreign literatures and carries out research by adopting method of system analysis and logical deduction and combination of qualitative analysis and quantitative research.

2. Definition for defined project cost

2.1. Definition description

Refined management for cost is to carry out refined management to various project phases to realize intensive stage management for cost. For all stages of project implementation, resource shall be optimized and configured to effectively avoid "three excesses" phenomenon. Management link of refined project cost mainly includes five stages: design, decision, construction, bidding and tendering and completion and cost management and relevant subjects involved in the five stages are shown in Fig.1.

Refined project cost is premise for confirmation and control of reasonable cost. To realize reasonable evaluation for investment, it shall be ensured that it is within total cost control limit. Especially in cost evaluation stage of design, it shall be

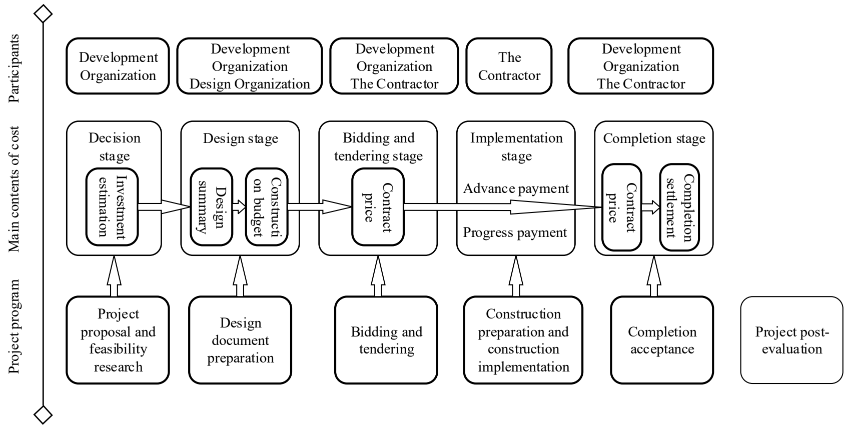

Fig. 1. Project cost management for green building

ensured that the cost evaluation value is more reasonable than cost evaluation value in investment stage and it is influenced by cost evaluation in investment stage. For cost evaluation in design stage of construction drawing, refined evaluation shall be carried out according to design thought and material of construction drawing. For green construction cost management, it is critical to dispose cost for bidding and tendering between Development Organization and the Contractor for cost evaluation. For management for schedule of process construction project and prepayment capital events, two key links of practical construction and earlier-stage design of scheme shall be combined. For final settlement and settlement management of green construction project, it not only requires summarizing practical project cost, but also controlling cost in all project stages.

2.2. BIM quantitative evaluation model

Table 1. BIM-tally correspondence

S/N	Material names	Model family names	Volume
1	FA_ concrete-fine stone concrete	100+150	74.168
2	FA_ concrete-rebar	100+150	18.532
3	FA_ concrete-fine stone concrete	100+200	19.918
4	FA_ concrete-rebar	100+200	5.974
5	FA_ concrete-rebar	150	0.218
6	FA_ concrete-rebar	FW-150	118.156
7	FA_ concrete-rebar	JT-150	15.142
8	FA_ concrete-rebar	SH-150	290.128

It takes cost management process of construction project in science & research building of certain domestic college and analyzes cost by taking cost management process of construction work as research object. After confirming cost evaluation interval, model relationship between green construction material and BIM elements shall be established and specific green construction material types are shown in Table 1.

After confirming green construction material of concrete rebar, cost influence of green construction material on green construction project can be calculated. It mainly involves the following three stages: (1) project construction stage. During project development progress, influence factors of various green construction costs shall be ranked by size; because during development stage of green construction, proportion of consumption for primary energy and non-regenerated energy to total construction cost is larger than 80%, rebar and concrete-fine stone soil with lower cost are selected, which is favorable to reduce process cost of the whole project. (2) Project maintenance and operation stage. The stage shall strengthen recycle and reuse of raw material, such as waste water during project development process and shall further reduce project cost. (3) Recycle stage of green construction material. The process mainly involves recycle and utilization of waster steel and waste material of floor slab is recycled reasonably to construct green construction, which is significant to reduce project cost.

2.3. Model evaluation index

Main evaluation indexes for project development project cost are: three major indexes of technology, environment and cost. Peculiarity correlation model between indexes and sub-system can be established according to foresaid factors characteristics and hierarchical structure evaluation model of complex factor cost management for project can be established and the model can be divided into three groups of different layers: (1) comprehensive influence parameters for environment; (2) economic index, project index and environment index; (3) specific evaluation index as shown in Table 2.

Table 2. Cost evaluation index for development project

Target layer	Second-level index	Third –level index
Comprehensive environment	Project property D_1	Surface area of components I_1
Influence coefficient Z		Volume of components I_2
	Economic index D_2	Material price of components I_3
		Environment treatment investment I_4
	Environment index D_3	Primary energy demand I_5
		Non-regenerated energy consumptionI_6
		Renewable energy sources I_7

Complete cost evaluation process generally involves three stages of production, operation development and maintenance and influence of 8-group unit components on cost evaluation during production process is evaluated based on 8-group unit components of floor slab shown in Table 1. Solution result of relevant index involves economic indexes, namely, environment treatment investment and development material price and the two factors are set as variables and rest indexes are calculated by utilizing BIM model.

3. Directed acyclic graph and heterogeneous resource system model of construction schedule

3.1. Integral optimal process frame

This Paper exports road construction schedule data and relevant resource group data and transforms them to directed acyclic graph (DAG) model and heterogeneous resource system model by utilizing BIM database and then optimizes target problem by adopting MCEFT Algorithm and integral optimal process frame is shown as Fig.2. Herein, optimization for construction schedule shall firstly conform to existing schedule data and resource group data in BIM database and ADG model and heterogeneous resource model shall be established manually (this Paper focuses on feasibility research on schedule subcontract and scheduling and optimization and automatic establishment schedule technology is only taken as future combination and extension direction, which is not described in detail herein.) The Chapter mainly describes establishment of the two kinds of models and mathematical modeling for construction schedule subcontract and scheduling.

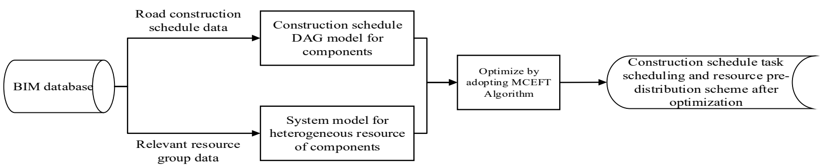

Fig. 2. Integral optimization process frame

3.2. Construction schedule DAG model

In this Paper, road construction schedule source data of construction project are exported from BIM database and schedule consists of a series of construction task and there is constraint relationship between these tasks. Corresponding construction schedule DAG model includes two kinds of basic elements: node and edge, which can be represented by DAG$=(T,E)$. Herein, all task nodes are represented by $T=\left(t_1,t_2,\cdots,t_{|T|}\right)$, which includes 4 kinds of starting node, termination node, practical task node and virtual time node. Starting node represents starting of the whole construction project and there is no precursor node, starting time for starting node is set as 0 to avoid losing generality; termination node represents end of the whole project and there is no successive node; Practical task node corresponds with a series of construction task in construction schedule source data; Virtual time node is introduced mainly here; when there is time leisure between nearby tasks executed by two sequences (the time leisure is usually maintained during formulation of practical project schedule); namely, it shall be established between the two task nodes and a virtual time node is added to supplement the time leisure and virtual time node will not occupy any practical resource group. Edge of DAG model represents constraint relationship between task nodes and the constraint relationship corresponds with task execution sequence during construction process. It can be represented by $E = \left\{ \left(e_{s,e}\right)_i | i = 1, 2, \cdots, |E| \right\}$, where, $\left(e_{s,e}\right)_i$ is a edge of task node t_s and t_e.

3.3. Heterogeneous resource system model

Heterogeneous resource system model of road construction schedule shall be established manually according to relevant resource group data and model demonstration is shown as Table 3. The model represents execution time of all task nodes of construction schedule DAG model under different resource group distribution conditions and heterogeneous resource system model can demonstrated by Table 3.

Table 3. Heterogeneous resource system model (Unit: 10 days)

Construction work	$r1$	$r2$	$r3$	...
$t1$	6	7	8	...
$t2$	10	13	16	...
$t3$	11	14	17	...
$t4$	9	7	11	...
$t5$	4	6	5	...
$t6$	8	7	4	...
$t7$	5	11	6	...
$t8$	13	7	9	...
$t9$	9	12	5	...
$t10$	10	8	14	...

Vertical coordinate $t_i \in \left(t_1, t_2, \cdots, t_{|T|}\right)$ corresponds with a task node of construction schedule; horizontal coordinate $r_i \in R \left\{ r_i | i = 1, 2, \cdots, |R| \right\}$ represents a resource group in resource group set R in system. An element with coordinate (t_i, t_j) in heterogeneous resource system model can be represented by $EcCost_{rj}(t_i)$, which means execution time of task node t_i under distribution resource group r_j (if t_i is starting node or termination node or virtual node, it is calculated as $r_j = 0$). When a resource group is used to execute a task, only when task is completed, the resource group can distribute next task (namely, task is executed independently and resource group is non-preemptive). $AveW(t_i)$ means average execution expenditure of node t_i and it can be calculated by the following formula:

$$AveW(t_i) = \sum_{k=1}^{|R|} \left(EcCost_{rj}(t_i) / |R| \right). \tag{1}$$

In consideration of several quantitative methods of heterogeneous degree of heterogeneous model, this Paper has designed parameter in experiment stage—time redundancy to quantize heterogeneous degree of model.

3.4. Scheduling mathematic modeling of construction schedule

After completing construction schedule DAG model and heterogeneous resource system model establishment, realization of construction schedule subcontract and target problem of scheduling under the model is to solve integral execution time of construction schedule according to existing task scheduling sequence (all tasks sequences of the sequence have scheduling class from high to low and meet topotaxy in DAG model). It is assumed that DAG model includes $|T|$ task nodes and heterogeneous resource system includes $|R|$ resource group. Task scheduling sequence is $\left(t_1, t_2, \cdots, t_{|T|}\right)$ and $s = \left(r_1, r_2, \cdots, r_{|T|}\right)$ is resource group distribution sequence solution of all tasks and its elements are respectively resource groups distributed in $\left(t_1, t_2, \cdots, t_{|T|}\right)$. It is supposed that current task node with the highest scheduling class is t_i and its distribution resource group is r_j and then corresponding earliest starting time is shown in formula (2):

$$T_{EFTime}\left(t_i, r_j\right) = \max\left\{T_{avail}\left(r_j\right), T_{ready}\left(t_i\right)\right\}. \tag{2}$$

Where, $T_{avail}\left(r_j\right)$ represents time for resource group r_j to execute task and $T_{ready}\left(t_i\right)$ represents ready time of t_i, which can be calculated respectively according to Formula (3) and Formula (4).

$$T_{avail}\left(r_j\right) = \max_{tk \in exec(r_j)}\left\{T_{AFTime}\left(t_k\right)\right\}. \tag{3}$$

$$T_{ready}\left(t_i\right) = \max_{tk \in pred(t_i)}\left\{T_{AFTime}\left(t_k\right)\right\}. \tag{4}$$

Where, $exec\left(r_j\right)$ represents task set executed by resource group r_j and $T_{AFTime}\left(t_k\right)$ represents practical execution completion time of t_k and $pred\left(t_i\right)$ represents all precursor node set of t_i. Under condition of distribution resource group r_j, if t_i is treated in non-preemptive method, earliest completion time of t_i can be represented as Formula (5):

$$T_{EFTime}\left(t_i, r_j\right) = T_{EFTime}\left(t_i, r_j\right) + EcCost_{rj}\left(t_i\right). \tag{5}$$

Where, $EcCost_{rj}\left(t_i\right)$ represents time expenditure of task t_i by adopting resource group r_j. Under condition of distribution resource group r_j, if node t_i is executed completely, value of $T_{EFTime}\left(t_i, r_j\right)$ is given to $T_{AFTime}\left(t_i\right)$. Integral completion time of construction schedule is equal to completion time of t_{Exit}, as shown in Formula (6):

$$makespan = \max_{t_i \in T}\left\{T_{AFTime}\left(t_i\right)\right\} = T_{AFTime}\left(t_{Exit}\right). \tag{6}$$

4. Empirical analysis

A project department is responsible for construction task of residence building project of external-brick and internal-formwork cast-in-place concrete structure in earlier period and duration is to be determined; the building is 5-layer structure with ground area 2600m2 and underground parking area 668 m2 and shock strength is 8 degree; Internal wall is 13cm cast-in-place reinforced concrete slab and external wall is 37cm brick wall and internal partition wall is 4cm thickness precast concrete slab. Indirect expense rate of the unit structure is RMB 9000, which is confirmed by Construction Organization according to objective condition and historical data and by adopting combination of quantitative and qualitative methods. According to detailed statement or quantity list generated by BIM, construction procedure of the second-floor cell structure of residence building is confirmed by adopting virtual construction software in WBS and BIM, as shown in Table 4.

Table 4. Details on construction procedure of the second-floor cell structure

Work code	Normal continuous time/day	The shortest duration time/day	Direct expense rate/thousand Yuan	
	i	D_i^0	$D_i^{\min}$	μ_i
External wall brick	A=1	5	1	5
Erect rebar network	B=2	6	3	4
Erect vertical formwork	C=3	6	2	7.6
Erect gate and embedded parts for water and electricity	D=4	7	5	30
Erect reverse formwork	E=5	5	2	10
Adjust partition plate	F=6	5	2	15
Cast concrete	G=7	9	5	12
Internal decoration	H=8	2	1	20
Reinforcement for balcony and floorslab	I=9	5	1	9

According to Table 1, construction organization network plan chart is drawn by adopting double codes network plan technology (as shown in Fig.3).

The reason why the cell structure sets the shortest time is that it considers objective factors, construction technology and construction quality, etc.; on the premise of ensuring construction quality of the cell structure construction quality, it cost-duration is optimized: (1) calculation duration and key route shall be confirmed. Key route is ①-③-④-⑥-⑦ and calculation duration is 26 days. (2) Duration time of key work can be compressed on compressing key route and expense can be optimized. Specific result is shown in Table 5.

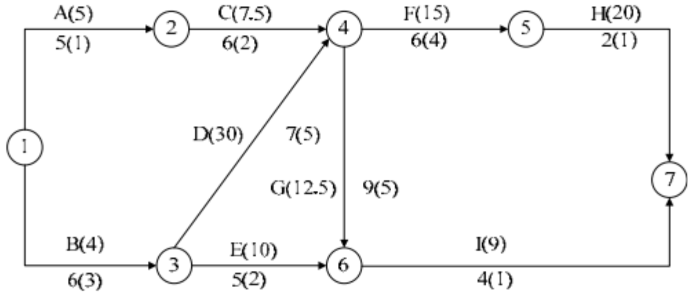

Fig. 3. Network plan chart for construction organization of the unit structure

Table 5. Summary table for construction schedule—cost optimization

	The number of times for compression			
	1	2	3	4
Code for compressed work	B	I	A,B	-
Direct or combined expense rate/(thousand Yuan/day)	4	9	9	-
Expense rate difference/ (thousand Yuan/day)	-5	0	0	-
Shortened time/day	2	3	1	-
value added for expense/thousand Yuan	-10	0	0	-
Total work duration/day	24	21	20	-

5. Conclusion

At present, domestic and foreign research range about project schedule forecast, project reliability and BIM technology is wide and these researches have provided theoretic support for scientific management and effective execution of construction schedule, while further research is required for many problems. For example, (1) construction schedule forecast control depends on mathematical model and computer algorithm; substitutive characteristics for executing network plan are ignored for simplification of assumption condition and model use is complex and practical application effect is dissatisfactory. Therefore, construction schedule forecast control model conforming to practical work shall be founded out. (2) Because of complexity of construction of construction work, it is hard to forecast short-term work progress and quantitative analysis on uncertainty of construction schedule during execution process of work cannot be carried out and multiple factors and complex condition change during practical construction process cannot be reflected truly and refined management requirement for modern work cannot be satisfied. Therefore, research aiming at visualization, informatization, randomness and controllability simulated in construction process has great research significance on complex forecast duration model. (3) In BIM 4D/SD platform construction schedule control, practical schedule generally depends on personal experience and key information flow and lacks real-time effective progress feedback. Although there is relevant construction management software, up to now, there has been no report on introducing BIM technology to construction progress research. It is necessary to further research BIM technology and theory method of construction schedule forecast and control management.

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