

## A Study of Smart Construction and Information Management Models of AEC Projects in China

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**Abstract** — According to the development and needs of civil engineering and construction industry in China, the conception of Smart Construction Theory is explored. Questionnaire survey is used to collect data needed for the analysis, as an effective method in the field of civil engineering. Then the structure of AEC (Architecture, Engineering and Construction) projects information management models was concisely described. Furthermore, Smart Cost Management is proposed. The research considers cost management function to reason by analogy other functions of the model, and gives an implementation example of construction project information management model. The cost management problem is solved with dynamic programming method. The research strengthens and optimizes information management of AEC projects and improves the efficiency and competitiveness of civil engineering and project management in China.

**Keywords** - Smart Construction Theory; AEC projects; civil engineering; cost management

### I. INTRODUCTION

In the field of civil engineering in China, AEC (Architecture, Engineering and Construction) projects information development is an important part of construction industry adoption of Information Technology, IT, [1]. IT is an important part of AEC projects, and the key to improve management level and core competitiveness of construction industry. With rapid development of civil engineering and emerging information technologies in China [2], the amount and complexity of AEC projects information are growing [3], because project scale is much larger and the process of construction project is more complicated than before [4]. Nonetheless, theoretical vacancy and methods obsolete of AEC project information management, and low level of emerging information technologies application result in the problem of “information islands” in the field of civil engineering[5]. Application efficiency of emerging information technologies is low in China, although civil engineering in China has a increasing investment in informationization research and application of emerging information technologies in recent years.

Under the background, many scholars study on “digital construction”, “sensing technology” and “information technology application” of AEC projects for a long time, for example, BIM (Building Information Modeling), BLM (Building Lifecycle Management), ubiquitous computing, 4D visualization, smart city, internet of things etc. To some extent, these studies contribute to development of informationization, information technology, and civil engineering level. But, theoretical vacancy and methods obsolete of AEC projects information management and civil engineering are not fundamentally solved, and information

technology application have a great gap in home and abroad. According to the research status at home and abroad, AEC projects information management model for information management of BLM and based on SCT (Smart Construction Theory) is built. The research provides solutions and suggestions for civil engineering in China, improvement of AEC projects information management model, and further research of SCT.

### II. PROCESS AND METHODS OF EMPIRICAL RESEARCH

The paper use questionnaire survey and expert interview to collect data. Questionnaire is a survey method to collect research material in writing indirectly by issuing a survey questionnaire to investigators.

#### A. Questionnaire Survey

The questionnaire is based on the previous evaluation scale of the model. Since the study is to solve the problem of construction project information management, so the investigation object is mainly from all participants of construction project management, senior management personnel, and other related professional members from scientific research institutions, colleges and universities[6].

The questionnaire is mainly divided into two parts: one part is information about research and person’s basic information; the other part is research content. In the first part, a small amount of multiple choice questions and fills-up topics are set up for objective recording natural conditions of respondents. moreover, in order to minimize differences from familiarity with the information tools, people who have experience in using related information management tools are respondents of questionnaire.

In second part, research content contains two aspects: evaluation of emerging information technologies applied in AEC projects information management, and functional evaluation of AEC projects information management model. There are 51 questions in this part. They are designed by 5 levels Likert Scale, and each topic grades five levels standard from 1 to 5: 1 Very conform, 2 conform, 3 general, 4 not conform, 5 not conform to very much.

*B. Basic Hypothesis of the Model*

Application and integration of a variety of emerging information technologies are technological base of AEC projects information management model; functional design plays an important role in the model; the model can reflect the four main features of Smart Construction Theory, and the model can guide the functions of AEC projects information management platform[7]. Based on these, put forward 11 basic hypothesis related the model are divided into following three levels, as shown in Table I.

TABLE I BASIC HYPOTHESIS RELATED THE MODEL

Hypothesis level	Contents of hypothesis	No.
Application and integration of a variety of emerging information technologies influence on AEC projects information management model	Application of BIM has a significant positive correlation to the model	H11
	Application of internet of things has a significant positive correlation to the model	H12
	Application of ubiquitous computing has a significant positive correlation to the model	H13
	Application of 4D visualization has a significant positive correlation to the model	H14
	Integration of emerging information technologies has a significant positive correlation to the model	H15
Functions system of the model influence on AEC projects information management model	Information management function has a significant positive correlation to the model	H21
	Information management function of BLM has a significant positive correlation to the model	H22
	Effectiveness of information management function has a significant positive correlation to the model	H23
	Needs of information management from different parties have a significant positive correlation to the model	H24
Main features of Smart Construction Theory and functions of the platform influence on the model	Main features of Smart Construction Theory have a significant positive correlation to the model	H31
	Function system of AEC projects information management platform has a significant positive correlation to AEC projects information management model	H32

*C. Data Gathering*

Three methods are used in the survey: paper-based questionnaire, email-based questionnaire and telephone-based questionnaire. The survey work is from May to December, 2012. After seven months survey, totally 396

questionnaires are sent out, and 307 questionnaires are got back. Among them, 254 questionnaires are effective, yet 53 questionnaires are invalid. The recovery rate is 77.53%, and effective rate is 64.14%. Details about the survey is shown in Table II

TABLE II QUESTIONNAIRE DISTRIBUTION AND RECOVERY

Methods	Questionnaires distributed	Questionnaires recycled	Effective	Recovery rate (%)	Effective rate (%)
Paper-based	157	125	101	79.62	64.33
Email-based	175	119	95	68.00	54.29
Phone-based	64	63	58	98.44	90.63
Total	396	307	254	77.53	64.14

*D. Description and Limitation of Sample*

In the process of research, age, educational background, , employer, number of years worked for employer and

regional distribution of the respondents in 254 valid questionnaires are analyzed. Sample characteristics description as a whole are shown in Table III.

TABLE III SAMPLE CHARACTERISTICS DESCRIPTION

Characteristic	Classify	Number of samples	Rate (%)
Age	Under the age of 30	46	18.11
	30 to 39 years old	62	24.41
	40 to 49 years old	68	26.77
	50 to 59 years old	59	23.23
	More than 60 years	19	7.50
Educational background	College degree	78	30.71
	Bachelor degree	92	36.22
	Master degree	44	17.32
	PhD degree	26	10.24
	Other	14	5.50
Employer	Owner	38	14.96
	Designer	41	16.14
	Supervisor	32	12.60
	Contractor	51	20.08
	Supplier of materials	23	9.06
	Scientific institutions	54	21.26
	Other	15	5.91
Number of years worked for employer	Less than 5 years	39	15.35
	5 to 10 years	67	26.38
	10 to 20 years	75	29.53
	20 to 30 years	62	24.41
	More than 30 years	11	4.33
Regional distribution	Harbin City	52	20.47
	Mudanjiang City	39	15.35
	Jilin City	33	12.99
	Hefei City	30	11.81
	Xi'an City	25	9.84
	Tianjin City	24	9.45
	Beijing City	18	7.09
	Nanjing City	13	5.12
	Shanghai City	12	4.72
Guangzhou City	8	3.15	

In Table 3, collected samples are in line with research need, and sample size meet representativeness. However, due to the limitation, such as research ability, time and money, randomness of the samples is insufficient. On regional distribution, a large number of samples is in the three northeast provinces, but small number of samples is in other provinces and sample size is less than expected. In some extent, these may cause lacking generalization of research conclusion.

### III. AEC PROJECTS INFORMATION MANAGEMENT MODEL

#### A. Smart Construction Theory

Smart Construction Theory can be defined as a bran-new engineering management theory for BLM, which build smart environment of the project construction and operation, and improve and manage effectively all the processes of engineering project in life cycle through technical innovation and management innovation. It takes BIM, internet of things, ubiquitous computing, 4D visualization and other advanced network and information technology as implementation tools, and to meet the requirements of smart project function

and the individuality purpose of the different parties as aims [8].

According to the above definition, supportive system of Smart Construction Theory is from three aspects at least: Smart City provides concept support for Smart Construction Theory [9], and meanwhile Smart Construction is an important part and the way of implementation of Smart City; AEC projects management, BLM, Lean Construction [10] and Sustainable Construction provide theory basis for Smart Construction Theory; lots of technology such as BIM, internet of things, ubiquitous computing and 4D visualization provide technical support.

The core idea of Smart Construction Theory is to make full use of advanced information and network technologies, to integrate every link of BLM, to achieve smart response to the personalized needs of different parties, to provide convenience for parties of different stages, to realize sustainable development of Smart Construction from the point of view of economic and environmental protection.

#### B. AEC Projects Information Management Model

The whole life of AEC projects is filled with all kinds of information. (Fig. 1).

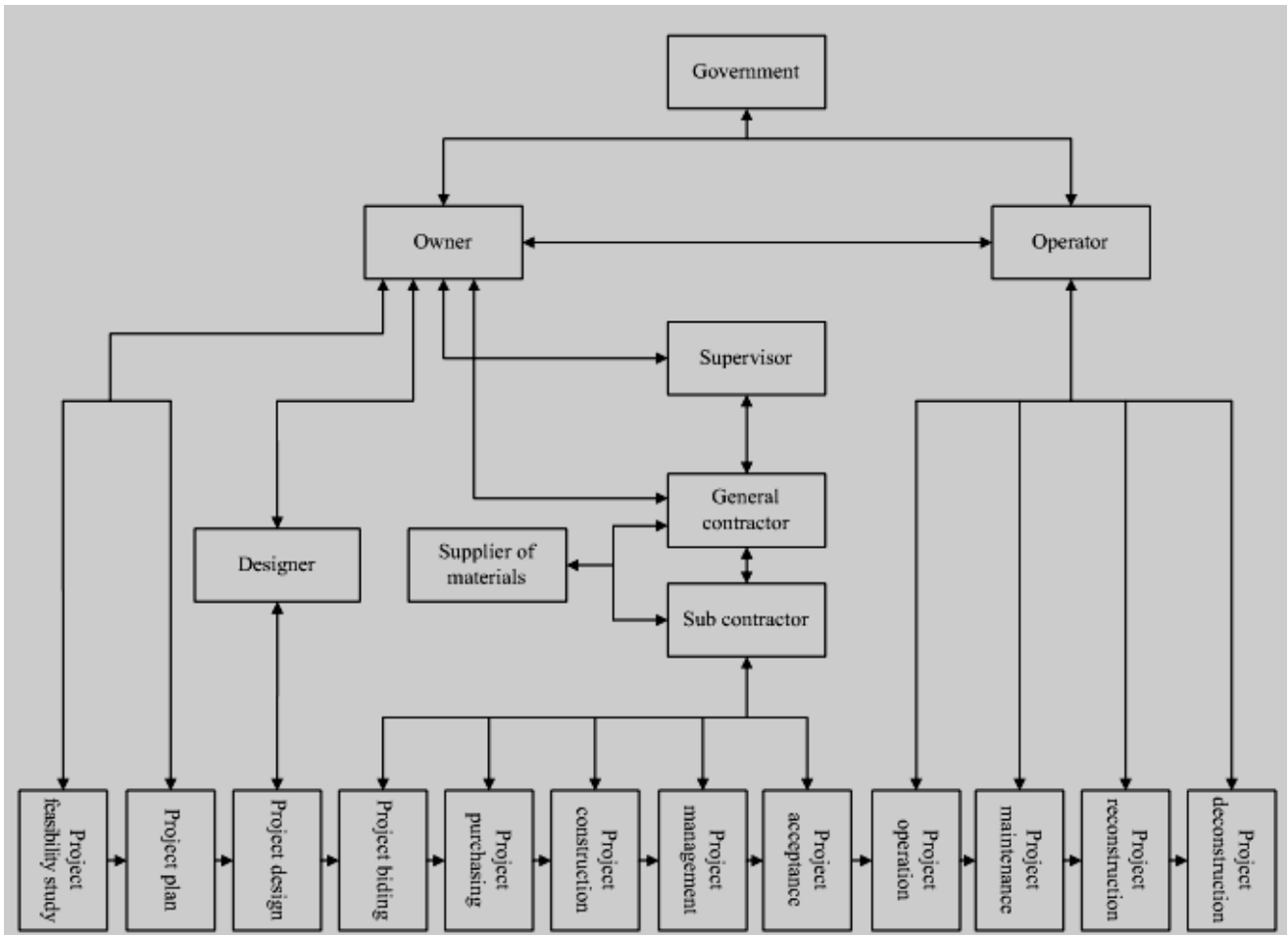


Figure. 1. Information Flow in the Whole Life Cycle of AEC Projects.

BLM of AEC projects contains 12 processes: project feasibility study, project plan, project design, project biding, project purchasing, project construction, project management, project acceptance, project operation, project maintenance, project reconstruction and project deconstruction. Meanwhile, there are 8 participants in the figure: government, owner, operator, supervisor, designer, supplier of materials, general contractor and sub contractor.

The modelling process of the research is mainly top-down, and divided into six steps: feasibility study, demand

analysis, model design, model building, model test and model implement. The 6 steps are gradually in-depth, detailed and cycling. According to the above analysis, AEC projects information management model includes all kinds of products and process information of life-cycle project management. It forms dynamically in construction. Architecture and main body of model includes application layer, network layer, platform layer and data layer which structure a framework (Figure. 2).

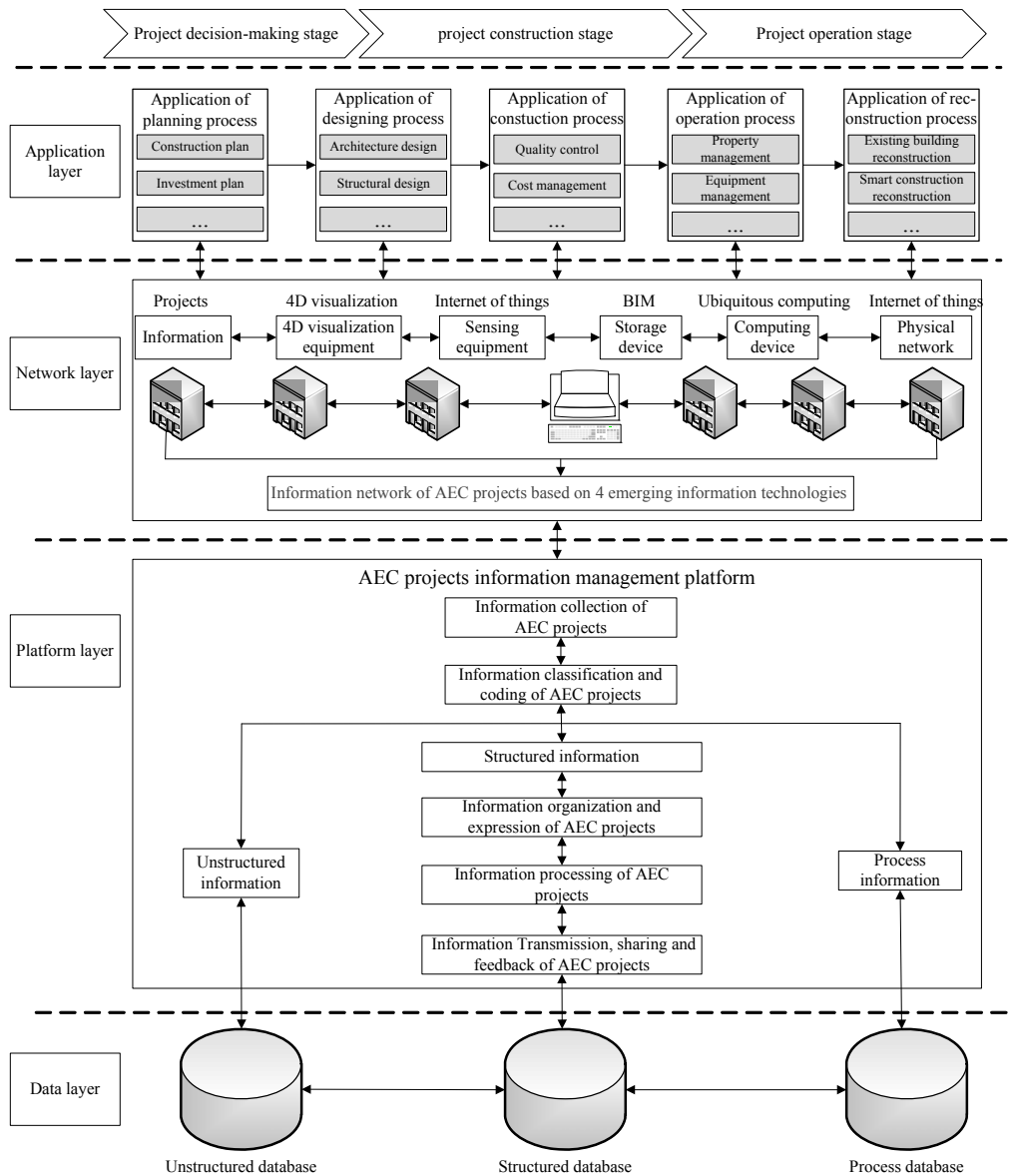


Figure. 2. Basic Framework of AEC Projects Information Management Model

1. Application Layer. Application layer is composed by various application software that serve different stages of projects. They are planning analysis software, structure design software, construction management software and property management software, etc. In application layer, AEC projects information management model is responsible for accumulating, integrating, expanding and applying information. Through integrating application software, son models of Smart Construction Information Modeling are shaped up.

2. Network Layer. Network layer gather all kinds of engineering information from internet space by Internet of things. Thus, the distributed users can share and deliver information of AEC projects information management model online. Network layer is foundation of application and

sharing of model. Users can manage information on the network conveniently, and cost is reduced very much.

3. Platform Layer. Platform layer is AEC projects information management platform, and it's functions are structured information management, unstructured information management and process information management. The platform can realize the fusion between engineering information and the model, support constructive process of model and keep original work patterns of most professional systems and users.

4. Data Layer. Structured information is stored by database under IFC standard. Unstructured information is stored and managed by document management system and database. Process information is stored by relevant process database temporarily.

IV. REALIZATION OF AEC PROJECTS INFORMATION MANAGEMENT MODEL: COST MANAGEMENT FUNCTION AS AN EXAMPLE

A. Smart Cost Management

The paper researches on realization of AEC projects information management model: cost management function as an example, and Smart Cost Management is proposed. Compared with traditional cost management methods, research background, concept and range of Smart Cost Management are analysed. By summarizing advantages, organization and operation of Smart Cost Management, lots of smart cost information management methods are put forward, including extraction mechanism, integration, parametric modeling, and dynamic programming model of smart cost information. The research is based on the model and emerging information technologies integration platform, takes cost management function to reason by analogy other functions of the model, and is an implementation example of the model.

The differences between Smart Cost Management and traditional construction project cost management are including (1) From the perspective of information management, (2) The whole life cycle cost management, (3) Meet demands of the parties of AEC projects, and (4) Realize the dynamic cost management.

AEC projects information management model based on Smart Construction Theory has incomparable advantages. They are building components by using the parametric modeling method, automatic quantities calculation based on parameters, greatly enhancing information level and efficiency of cost management: (1) To improve the accuracy of the calculation of quantities, (2) Reasonable arrangement of resources plan, to speed up the project schedule, (3) Control design change, (4) Support multiple AEC projects contrast, (5) Historical data saving and sharing, (6) increase cost control capability of the parties, and (7) Conducive to the implementation of Smart Construction Theory.

B. Unilateral Smart Cost Information Dynamic Programming Model

Under Smart Construction Theory, combining AEC projects information management model and emerging information technologies integration platform, Smart Cost Management can work well. Since design change can timely manifest in the 3D drawings and data by the model, combining emerging information technologies integration platform, quantities change information can be automatic calculated by advantage of the pervasive computing technology, and the change of the life cycle cost information is offered. The overall scheme of AEC project is optimized. Plans and related information are transferred to all relevant

parties by Internet of things technology, and optimize the each participant cost plan. Due to Smart Cost Management conforms to the dynamic programming principle and no after effect principle, the cost management problem can be solved with dynamic programming method.

The basic assumptions are (1) Aimed at the optimal construction project life cycle cost, (2) Individual participant as management main body, (3) The feasibility of the AEC project, and (4) Multiple alternatives exist. According to the research needs, the whole life cycle of the AEC projects are divided into four main processes: decision-making, design, construction and operation. Assuming the variables for four processes  $k(k = 1, 2, 3, 4)$  (Figure. 3).

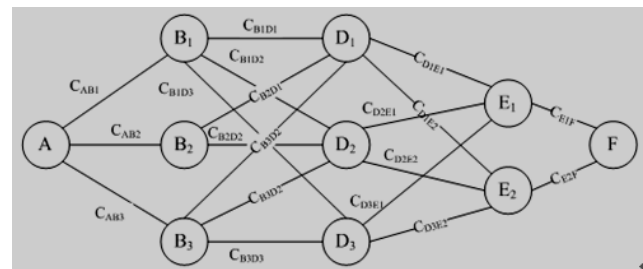


Figure. 3. Cost Dynamic Programming Model

In Fig. 3, Points A, B, D, E, F are nodes between the processes of AEC project. B1, B2, B3 said the three routing from A to B; D1, D2 and D3 said three path from B to D; E1 and E2 said the three paths from D to E. Assuming that  $S_k$  is objective condition impact on cost, such as Social and economic environment, natural conditions, etc. Thus,  $S_1 = \{A\}$ ,  $S_2 = \{B_1, B_2, B_3\}$ ,  $S_3 = \{D_1, D_2, D_3\}$ ,  $S_4 = \{E_1, E_2\}$ ,  $S_5 = \{F\}$ .  $U_k(S_k)$  is decision variable, on behalf of cost information management method and alternative plans of the process  $k$ .  $U_k(S_k)$  is from  $D_k(S_k)$ , so  $U_k(S_k) \in D_k(S_k)$ . optional path by Starting from B1 is (D1, D2, D3), so  $D_2(B_1) = \{D_1, D_2, D_3\}$ . If  $D_3$  is chose,  $U_2(B_1) = D_3$ .

Equation  $S_{k+1} = C_k(S_k, U_k)$  can represent the change of AEC projects status.  $V_j(S_j, U_j)$  is each process index function. Among them,  $j = 1, 2, 3, 4$  are decision-making cost, design cost, construction cost and operation maintenance cost.  $V_{1,4}(S_1, U_1, S_2, U_2, \dots, S_5)$  is the whole life cycle index function of AEC projects.  $S_k$  is state variable of process  $k$ , and  $f_k(S_k)$  is index function when  $S_k$  is optimal. Thus, Smart cost management recursive model is as shown in Figure. 4.

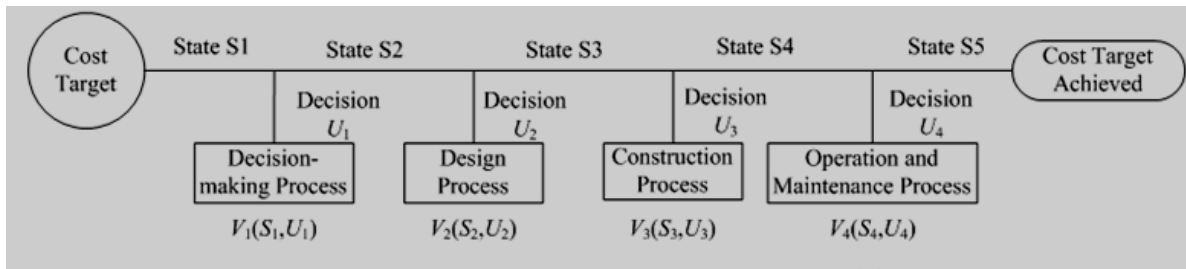


Figure 4. Smart Cost Management recursive model.

Basic equation of Smart Cost Management recursive model is:

$$\begin{cases} f_k(S_k) = \min\{C_k(S_k, U_k) + f_{k+1}(S_{k+1})\}, k = 5, 4, 3, 2, 1 \\ f_5(S_5) = 0 \end{cases}$$

By formula, the essence of Smart Cost Management is most short circuit problem. Because the cycle of AEC projects is long, the time value of money must be considered, especially in using stage of projects.

C. Model Adjustment.

When project design change occurs, plan of Smart Cost Management should be changed accordingly, and need to adjust smart cost information dynamic programming model. There are three main consideration changes: change of time points, change of cost value and generation of new alternatives. Completed work of AEC project has sunk cost, and change of time point said how to achieve the optimal cost management without considering sunk cost in past. The selected scheme has a certain degree of path dependence. When cost value changes, need to add new paths. When new alternatives, need to build the model of solution path. Accordingly, model adjusted and increase new path E3 (Figure. 5).

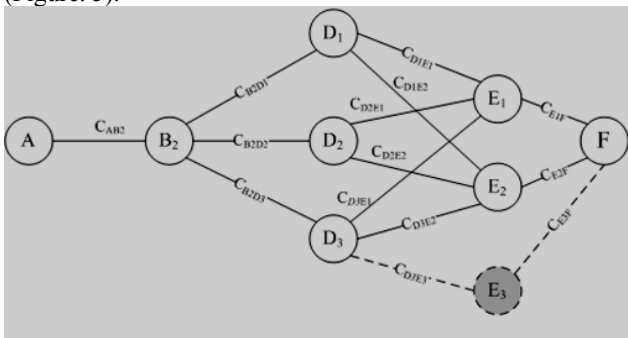


Figure 5. Adjustment of Cost Dynamic Programming Model

V. CONCLUSION

In sum, the paper breaks through the present academics research perspective in the field of civil engineering, and has not only scientific and reasonable research processes but also effective research results. Smart Construction Theory is proposed in the paper. Through literature research, the paper analyzes idea origin, theoretical basis and technical support of Smart Construction Theory, and puts forward the

connotation of it. Combined actual situation of civil engineering in China with Smart Construction Theory, the paper builds AEC projects information management model. The paper researches on realization of the model - cost management function as an example, and Smart Cost Management is proposed. Compared with the traditional cost management methods, research background, concept and range of Smart Cost Management are analysed. By summarizing advantages, organization and operation of Smart Cost Management, smart cost management methods are put forward, including extraction mechanism, integration, parametric modelling, and dynamic programming model of smart cost information.

The process and results provide a new theoretical guidance and realizing approach to study civil engineering problems, especially AEC projects information management problem. Meanwhile, subsequent research on Smart Construction Theory based on the model has support of empirical data. The results prove that study of AEC projects information management model is necessary and valuable, improvement of practicability and functionality of the model require development of integration of 4 emerging information technologies, functions system of the model, and main features of Smart Construction Theory and functions of the platform influence on the model. Furthermore, information management function, information management function of BLM, effectiveness of information management function, and needs of information management from different parties are critical. In addition, research on Smart Construction Theory and the model will be effectively direct effect, and avoid unnecessary waste and loss for development of civil engineering in China.

At present, the research is still in infancy stage, no matter Smart Construction Theory or AEC projects information management model need to improve and deepen content and depth constantly. Although the research is theoretical and practical, it also has a few limitations, due to subjective and objective conditions. In addition, there are many researches to work on civil engineering problems and AEC projects information management problem in China, and subsequent research work will be more innovative and challenging.

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