Developing Cost Control Information System in the Complex Project

Sheng Luo, Yujie Lu*, Yong Peng, Yun Le
Department of Construction Management and Real Estate
School of Economics and Management, Tongji University
Shanghai, China
* Corresponding author: lyj0415@gmail.com

***Abstract*—Traditional cost control information system fails to meet the requirements of the complex construction project, since it requires more interoperability with various managerial works and extensive data integration with other information sources. Those imperative challenges require a new cost control module incorporated with the existing Project Management Information System (PMIS). Based on the real case of EXPO 2010 Shanghai construction project, this paper develops a new project cost control information system with three major functions including cost information integration, cost control analysis, and intelligent reporting. To illustrate this system, the study is structured by three steps. First, the logic relationships among different integrated information objectives are discussed and organized in a static structure diagram described by Unified Modeling Language (UML). Then the sequential data workflow is analyzed based on the optimized communication and collaboration behaviors. Finally, various types of cost analysis reports are generated in light of project owner's specific requirements. This research not only proposes a new methodology to study the cost control system in complex project environment but also provides a successful practical toolkit for the real construction projects.**

Keywords-complex project; integrated system; Project Management Information System (PMIS); cost control; cost analysis

I. BACKGROUD

A. The Situation of Investment Integration

In most construction projects in China, the owner's investment control and contract control work under different departments. The owner's engineering management department should be responsible for investment control, including the decomposition of the project according to the cost, arranging the investment plan at every stage of the project, gathering the information of actual completed investment, analyzing the investment control situation. The owner's contract finance department should be responsible for contract management, including contract bidding, determining the contract price, the management of execution of the contract, the change and the claim of the contract, payment of contract. Because of the differences in the organization structure as well as the management target, the department of investment control and the department of contract management work independently in the actual work, lacking of the update and the communication of the investment and contract financial data. Moreover, since their management targets are at different stages, one department's data could not be used by the other, result in the dilemma of the redundancy and the lack of the data.

B. Requirement of Investment Control Integration

In the practice of contract implementation, we can find corporation and communication between investment control and contract management, for instance, determine the actual completed investment according to actual project situation as well as the confirmation of engineering supervisor and price consulting company; the construction unit will determine the payment monthly progress cost according to the contract payment item; by the financial proof management, we can build the relation between the cost and the payment; in the execution of the contract, change occurs frequently, which results in the change of the price, therefore, owners often need to analysis both the traditional investment control and the information of changes in the relating contract management and investment management.

In the single engineering project, since the cost decomposition structure and contract structure are simple, the above requirement of investment integration analysis is easy to meet. However, in the increasing number of the multiple engineering projects, there are multiple corresponding in the investment items and the contract. Take 2010 Shanghai Expo Multiple construction project as an example. Expo Pudong Temporary buildings and mating facilities is one of the single projects, including 159 contracts. Consider from the investment, cost decomposition structure construction including A, B, C three parts' more than 100 single constructions altogether. However, the matching contracts only include AB parts construction contract and C part construction contract, which means that the investment project and the contract are in one-to-many relation. Therefore, without integrated investment analysis, owners cannot apply corresponding contract data and current information when analyzing a single project's investment control. So we need to develop a system which can be applied in investment control and contract management integration.

To address the problems in investment control and contract management integration, the EXPO project management team developed a Investment Control and Contract Management Information Integration (C3A) System. Not only gained a good

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reputation in the practice, this system also passed Shanghai Science Committee's "The Research of Key Technology in Large Multiple Complex Project Systematic Control" check and Shanghai Construction and Traffic Committee's "Shanghai EXPO Engineering Project Investment Control and Contract Management Information Integration System Research" project check. The investment analysis addressed in this paper is a key part in this large project.

C. The Outline of the Research

The research in this paper involves three parts: create investment integration function's target, correlation and property, constructing investment integration analysis model's information target's static structure, analyzing and proposing the sequences of the information targets data exchange and corporation logic, designing the function of investment integration analyzing statement. In order to show the exchange sequence and the generation process of the information flow between those functional factors, we will introduce a class diagram to build the relation and the integral structure of the relating factors and we will use sequence diagram to analyzing the formulation of the function module

II. Literature Review

To the author's knowledge, the existing investment control integration analyzing models are focusing on investment control and progress control, just like Peng Yong [1], Wang Fei [2], Lu Yong [3], Abudayyeh [4], Froese [5], etc. Investment Control is classified by cost decomposition structure while the Progress Control is classified by work decomposition structure. The representative models are as following:

*1) Percent-Allocation Model:*Tekcholz realized that there is a difference in the stage accuracy between work decomposition structure and cost decomposition structure. According to the one-to-many information relation between the cost decomposition factor and the work element, he proposed Percent-Allocation Concept, which is, decomposi- ting a cost decomposition factor into different percentage and allocating these cost information on relating works, finally building a mapping between cost information and project information. *[6]*

2) Matrix Model:Hendrickson constructed a matrix which is consitituted by work decomposition structure and cost decomposition structure. He suggested to use the matrix focuse----work element as the mapping between the work decomposition structure and cost decomposition structure. [7]

3) BOD Model: BOD model is a three dimensional system consitituted by work decomposition structure, cost decom- position structure and design target. It has a similar principal with the Matrix Model, mainly focusing on project designing period. [8]

4) Based on improved work packages of investment control and schedule control information management system model: Sangchul Kim proposed this model in which used schedule control's basic element "activity" as the basic element of improved integrated model control. [9] Activity has two important properties: space and resource. On one hand, by the combination of activity and cost decomposition structure, it will benefit the uniform of the data in both investment control and schedule control. On the other hand, "Activity" collects the actual data by its resource property, which will help to compare the plan investment and actual investment, finally benefits the integration of investment control and schedule control.

5) Project Control Integration System Based on Web:Li proposed this model. It will evaluate the actual investment and progress by 18 resource performance indicators in 4 classes(Labor, Material, Equipment, Subcontractor),which developed by earned value mathod, as well as multi-level evaluation criteria. This model has following advantages: firstly, it used earned value method to flourish the investment compare criteria system; secondly,based on object oriented method, using project control as the core of the information management system model, this model realized the integration of investment control, schedule control and resource by mapping the project control with objects like resource, status, progress, predesesspr, allocation etc. [10]

III. The Static Structure of Investment Integration Analysis

According to the view of information theory, informa- tion integration system' static structure and dynamic logic realized the abstract of the actual work of the integration of investment control and contract control by planning and controlling information flow. Not only will it achieve the transfer and the process of the information of the integration of investment control and contract management, but it will also to realize the properties that not possessed by the original investment control and contract management under isolated condition through creating new function object, attribute and operation in order to better reflect the overall function and goals of investment control and contract management integration.

The objects of investment integration analysis are classified into three levels: project level, contract level and contract control level. The first level is based on the project and the second one is based on the contract. The contract control is an innovative concept, which represents a basic data unit and plays as the independent core object of public information. Therefore, the investment integration analysis static diagram which constituted by three levels is as following.

There are four association classes in the Contract Control Investment Integration Analysis, which are planning investment for contract control (which is tacitly agreed as estimated cost), accumulated actual completed investment up to now, accumulated investment plan up to now and accumulated completed project investment up to now; And there exist a form of aggregation between accumulated investment plan up to now and the monthly investment plan of contract control investment plan, which means accumulated investment plan up to now is the sum of all monthly investment planning up till now of this contract control. Accumulated completed project investment up to now is based upon the cost that current accumulated actually completed project corresponding to estimated costs. Based upon the related categories mentioned above, there are three subsidiaries

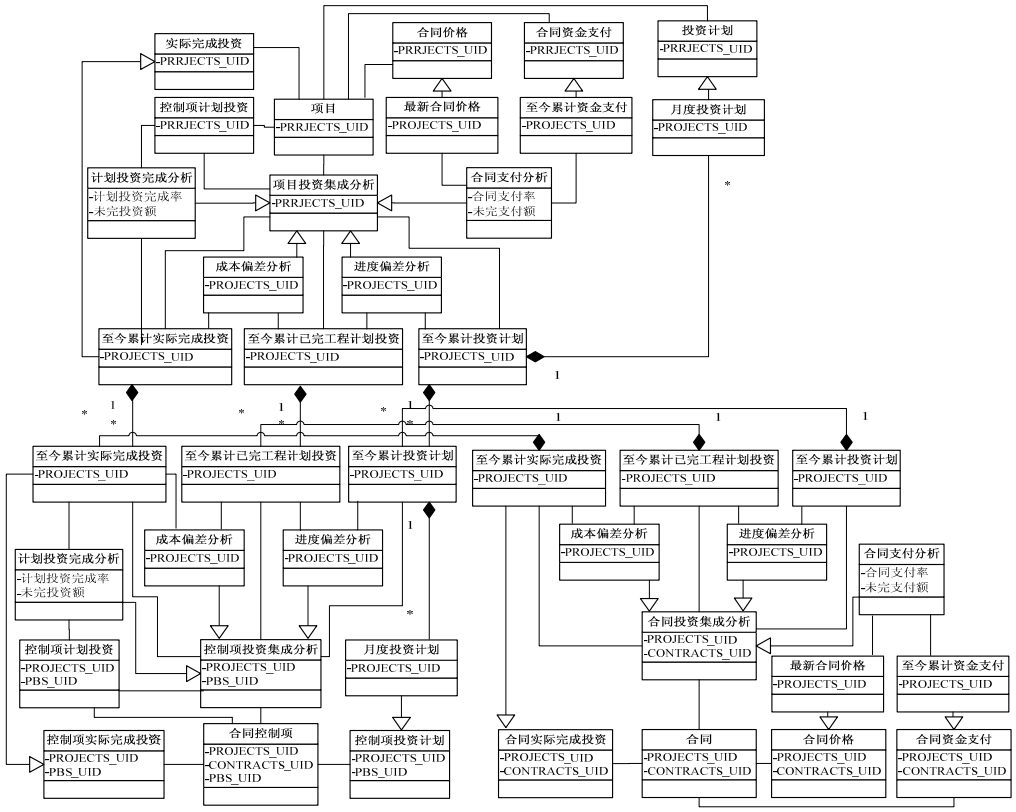

Figure 1. Class Diagram of the investment integration analysis based on UML

categories that contract control investment integration analysis have, they are cost variance analysis, schedule variance analysis and planning investment completed analysis; Cost variance analysis, the result that accumulated completed project investment up to now subtract accumulated actual completed investment up to now, is the reflection of the relation planning and actual cost in front of the same actual completed project amounts. Schedule variance analysis, the result that accumulated completed project investment up to now subtracts accumulated investment planning up to now, is the reflection of the relation between current control actual progress and progress plan. Planning investment completed analysis comprise two properties: planning investment completed rate and unfinished investment amount; planning investment completed rate is the result that accumulated actual completed investment divided by contract control planning investment, unfinished investment amount, the result that contract control planning investment subtract accumulated actual completed investment, is the reflection of the proportion between current accumulated actual completed up to now and entire estimated cost.

There are five related categories in integrated analysis of investment contracts, which are: the latest contract price of contract, accumulated funding up to now of the funding payment category, accumulated actual completed investment up to now, accumulated investment plan up to now and accumulated completed project up to now. Accumulated actual completed investment up to now, accumulated investment plan up to now and accumulated completed project up to now are composed of the aggregation of the related categories corresponding to all the contract control categories. For instance, the accumulated completed investment up to now of the temporary site in Pudong and corresponding facilities Jianan engineering contract is the outcome of the aggregation of whole contract control accumulated completed investment up to now including the Jianan contract. Based upon the related categories mentioned above, there are 3 subsidiary categories that contract investment integrated analysis have, they are cost variance analysis, schedule variance analysis and contract payment analysis. Cost variance analysis, the result accumulated completed project investment up to now subtract accumulated actual completed investment up to now, is the reflection of the relation between planning investments and actual cost in front the same actual completed project amount. Schedule variance analysis, the result that accumulated completed project investment up to now subtract accumulated investment plan up to now, is the reflection of the relation between current contract actual progress and progress plan. Contract payment analysis comprise 2 properties: contract payment rate and unfinished payments; contract payment rate,the result that accumulated funding payment up to now divided by the latest contract price; unfinished payments, the result that the latest contract price subtract accumulated funding payment up to now, is the reflection the proportion between current accumulated funding payment up to now and the latest contract price.

There are 6 related categories in the project investment integrated analysis, which are: the latest contract price of

project, accumulated funding payment of the funding payment category, planning investment (which is tacitly agreed as estimated cost), accumulated actual completed investment up to now, accumulated investment plan up to now and accumulated completed project planning investment up to now. Planning investment, accumulated actual completed investment up to now, accumulated investment planning up to now and accumulated completed project planning up to now are composed of the aggregation of related categories of all contract control. The latest contract price of project is composed of the aggregation of the latest contract price of all the contracts.

Based upon the related categories mentioned above, there are 4 subsidiary comprised by project investment integrated analysis, they are: cost variance analysis, progress variance analysis, planning investment completed analysis and contract payment analysis, the concrete composition and meaning of which are the same as their contract and the same name subsidiary category of contract control.

IV. THE DATA PROCESS FOR INVESTMENT INTEGRATED ANALYSIS

The data process of the investment integrated analysis is composed of three levels, which are: contract control analysis process, contract analysis process, project analysis process.

1) Contract Control Analysis Process.

Firstly, contract control analysis process use the related category data such as accumulated actual completed investment up to now, planning investment cost, monthly investment plan, accumulated actual completed project amount up to now. Secondly, a computation of self-call model conducted by monthly investment plan lead to the generation of accumulated investment plan up to now; based upon the current plan investment cost, accumulated actual completed project amount up to now lead to the generation of accumulated completed project planning investment up to now. Thirdly, contract control investment integrated analysis module activates cost variance analysis subsidiary category through accumulated actual completed investment up to now and accumulated completed project planning investment up to now respectively, activates schedule variance analysis subsidiary through accumulated investment plan up to now and accumulated completed project planning investment up to now, activated planning investment completed analysis subsidiary through accumulated actual completed investment up to now and planning investment. Lastly, a data computation conducted respectively to the subsidiary mentioned above: A. cost variance analysis category send itself a self-call computer instruction, as to make accumulated completed project plan investment up to now subtract accumulated actual completed investment up to now. B. schedule variance analysis category send itself a self-call computer instruction, as to make accumulated completed project plan investment up to now subtract accumulated investment planning progress variance amount up to now. C. planning investment completed analysis send itself a self-call computer instruction, as to make accumulated actual completed investment up to now divided by planning investment achieved planning investment completed rate, to make planning investment subtract accumulated actual completed investment up to now achieved unfinished investment. Here's the diagram for contract control data process. (see Figure 2)

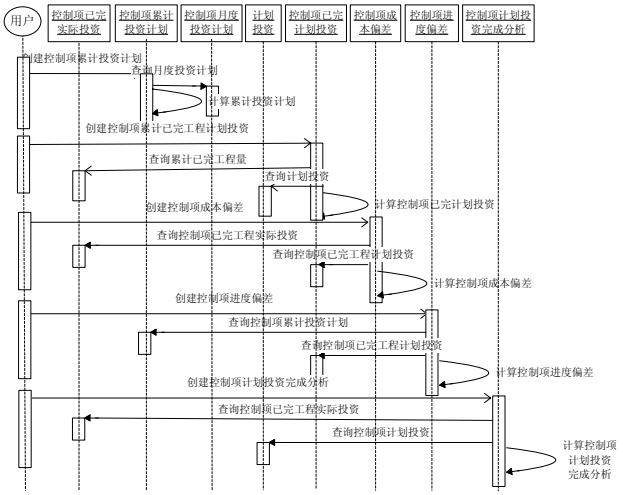

Figure 2. Sequence diagram of the Contract Control Analysis Process

2) Contract Investment Integration Analysis Process.

After the finish of contract control investment integrated analysis process, activation of contract investment integrated analysis module should be done. Its data process of cost variance analysis, schedule variance analysis, planning investment completed analysis subsidiary is familiar with contract control. Besides, module activates the contract payment analysis subsidiary by using the latest contract price and 2 related data of accumulated funding payment up to now. Contract payment analysis subsidiary send itself a self-call computer instruction as to make accumulated funding payment up to now divided by the latest contract price achieved contract support rate, to make the latest contract price subtract accumulated funding payment up to now achieved unfinished payments. Here's the diagramme of process of contract control data, see Figure 3.

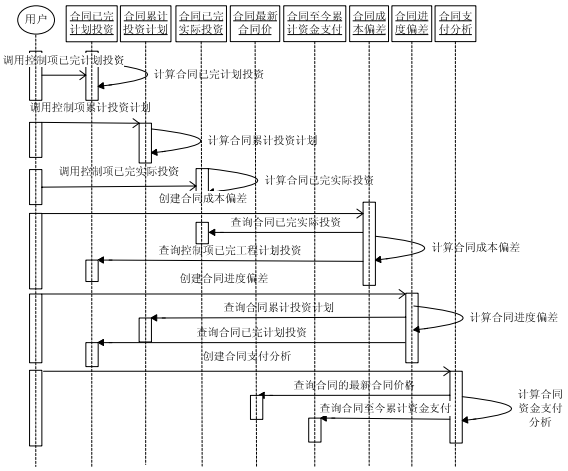

Figure 3. Sequence diagram of the contract investment integration analysis

3) Project Investment Integrated Analysis Process.

After the accomplishment of contract control investment integrated analysis, an activation of project investment integrated analysis module should be conducted. Its data process of cost variance analysis, schedule variance analysis, planning investment completed analysis and contract payment analysis subsidiary is similar with the module mentioned above(see Figure 4) Besides, module activate the planning investment completed analysis subsidiary category of project by using accumulated actual completed investment up to now and 2 related data of planning investment. Planning investment completed analysis subsidiary category send a self-call model computer instruction as to make accumulated actual completed investment up to now divided by planning investment achieved planning investment completed rate, to make planning investment subtract accumulated actual completed investment achieved unfinished payments up to now.

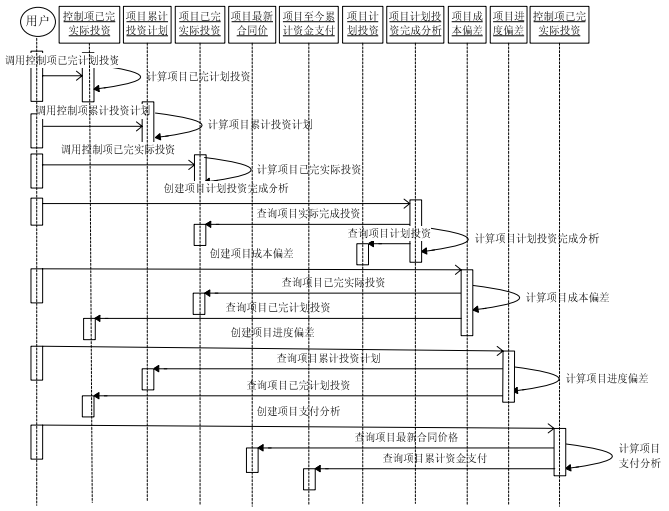

Figure 4. Sequence diagram of the project investment integration analysis

V. DESIGN OF STATEMENT OF THE INVESTMENT INTEGRATION ANALYSIS

Enormous information management works will inevitably result in mass statement files, which are not only the major interactive medium between system and users, but also the powerful tool for users to intuitively manage, compare and analyze data information. Therefore, in the application of the engineering investment integration analysis of Shanghai Expo, the system prototypes has made in-depth analysis on design form, content component and data association, etc. of the statement from longitudinal hierarchy such as program, contract and unit engineering and horizontal function like investment control, contract management, fund management and information exchange in order to satisfy the data demand of users with different levels and purposes in the whole process of investment control and contract management integration. Considering that the Shanghai Expo is still in operation, all the datum have been modified and upgraded.

Table 1. Summary of Shanghai Expo engineering expense cost (in part)

Table 2. Schedule of Shanghai Expo engineering expense cost (in part)

A. Analysis of the expense cost statement

The expense cost statement designed by this system includes the summary of engineering expense cost and schedule of project expense cost of Shanghai Expo. The summary of engineering expense cost of Shanghai Expo (see Figure 1) is to hold and manage the expenditure of funds of all projects and other function information from the overall height of engineering in Shanghai Expo. Therefore, the horizontal elementary unit is project and there is no need to refine to project item or unit engineering level. The contents include the total panned investment of the projects, the newest contract rate, the settlement price and the accumulated cash disbursement hitherto; among them, the accumulated cash disbursement hitherto can be further classified to construction and installation, materials and equipment, survey and design and other engineering cash disbursement based on the cost breakdown structure. In consideration of the complexity of the engineering investment subject, the accumulated cash disbursement hitherto can be divided into Shanghai Expo engineering headquarters disbursement and Shanghai Expo Land Holding Corporation disbursement according to the disbursement subject.

Schedule of project expense cost (see Figure 2) is to conduct data integration and management on expenditure of funds of all contracts belong to the project and other function information from the project level. Therefore, the horizontal elementary unit is contract and the content is to add contract coding and name as well as the unit information of the second party based on the horizontal related information of the summary of expense cost. Therein, the newest contract rate and the total panned investment represent the contract management and investment control information respectively, the

accumulated cash disbursement hitherto and its classified categories stand for the funds management information, and reflect the data integration among horizontal multi-functional information of the contract. The set-up of the project name, numbers and overall bar of contracts belong to the project and respectively accumulating the datum such as the total panned investment of all contracts, the newest contract rate, the settlement price and the accumulated cash disbursement hitherto reflect the data integration relationship between the longitudinal projects of the system and the multi-level of the classified contracts; the performance period of the statement will immediately display the ageing of the system data.

Therefore, the target user and precision of information of the summary of engineering expense cost and schedule of project expense cost of Shanghai Expo is different; the design of the summary of engineering expense cost is conducive to those non-professional users and is especially good for leading and mastering the general situation and classification of expenditure of funds of all projects as well as comparing with the horizontal datum of the planned investment and contract price. While the design of the schedule of project expense cost can help the system management personnel and project management personnel conduct refining funds management and horizontal datum integration management of other functional information aiming at the contract level of every project.

B. Research on the comparative analysis statement of the Investment Budget estimate

The comparative analysis statement of the Investment Budget estimate designed by this system includes table of the comparative analysis of the project Investment Budget estimate and the schedule of the comparative analysis of the project Investment Budget estimate. Table of the comparative analysis of the project Investment Budget estimate (Table 3) is to hold and manage projects and the budge estimate analysis datum of all its investment projects merely from the prospect of the invest control. Its horizontal elementary unit is project and the investment projects divided according to the investment budge estimate structure, in cost of construction and installation, the investment project is the unit engineering; The contents include the budge estimate of the projects and investment projects, the newest contract rate, the estimated final settlement, the estimated exceeding budge estimate value and estimated exceeding budge estimate rate. Take the data in dotted box of the table as example, after entering the estimated final settlement value 50048, it will automatically subtract the budge 41094 from 50048, and then we get the estimated exceeding budge estimate value 8954, and if let 50048 divided by 41094, we can get the estimated exceeding budge estimate rate 21.8%; the introduction of the estimated exceeding budge estimate value and estimated exceeding budge estimate rate reflects the data integration of the estimated final settlement and the budge estimate.

The objective of the schedule of the comparative analysis of the project Investment Budget estimate (Table 4) is to build the integrative project budge estimate analysis data of the investment disintegration structure and the contract disintegration structure. Therefore, the horizontal elementary

单位：万元

序号	投资项名称	概 算	合同价	预计决算	预计超概	超概率
	世博公园项目	41,094.95	26,812.19	50,048.85	8,953.90	21.8%
一	建筑安装费					12.7%
(一)	绿化、土方					-9.2%
(二)	道路广场地坪					-15.2%
(三)	建筑					-33.5%
1	空中花园塔吊					-100.0%
2	小卖部					-100.0%
3	公共盥洗室（A区）	101.20	0.00	39.97	-61.23	-60.5%
4	公共盥洗室（B区）	399.35	0.00	597.60	198.25	49.6%
5	公共配套服务	445.20	0.00	815.60	370.40	83.2%

数据仅供系统演示使用，

并不代表项目真实资料。

Table 3. Table of the comparative analysis of the project Investment Budget estimate (in part)

Table 4. schedule of the comparative analysis of the project Investment Budget estimate (in part)

unit will add contract and contract coding based on the investment projects divided by the investment disintegration structure, and will build the information mapping links between the investment control and contract management through the investment projects' relevance with the contract and the project. Take the land parcel investment projects A02 and A03 in dotted box of the table as example, their budget estimate values constitute the project budget estimate of the region A according to the investment disintegration structure, and their contract prices constitute the price of the construction of the contract according to the contract disintegration structure, consequently, the land parcel investment projects A02 and A03 are the common unit of both the investment disintegration structure and the contract disintegration structure. The schedule of the comparative analysis of the project Investment Budget estimate can build diverse data integration structure between the longitudinal hierarchy such as projects, contract and unit engineering and horizontal function such as investment control and contract management for users.

VI. CONCLUDING REMARKS

Investment integrated analysis made up a realization of the unification of contract control, contract and project multi-level investment integrated analysis internal information in the system through accumulated actual complete investment up to now, accumulated investment plan up to now and accumulated completed project plan up to now; made up a covering of shortage of traditional investment comparison and tracking, made a construction of relation between progress control and cost control through the introduction of cost variance and

progress variance; build up an entire system for investment control, contract management, funding management, which used to be isolated from each other, through the creation of planning investment completed analysis and contract payment analysis object; made up a realization of the whole goal of investment integrated analysis that integrate the project group contract and contract control as one through the information exchanges and coordination existing within each other.

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