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RESEARCH ON THE EARNED VALUE MANAGEMENT SYSTEM APPLIED IN CONSULTANCY PROJECT PERFORMANCE

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Key words: performance measurement, Earned Value Management (EVM), project control, consultants.

ABSTRACT

Performance analyses of consultancy firms usually include man-hour analyses, schedule analyses and budget analyses. During the project management process, the project scope change makes it difficult for the management to control the project and predict the future trends. This research has developed a project performance measurement model based on the concepts of CAPP (Continuous Assessment of Project Performance) and PMBOK (Project Management Body of Knowledge), created by the Construction Industry Institute and PMI (Project Management Institute). Through data collection, analysis, and summary, this study establishes a historical database, reviews existing records, and selects major and significant performance evaluation indicators from the project data, as well as building of relevant models. Through an established Web-based project performance measurement system to identify the project implementation performance trend, it allows participants in various stages of the construction engineering life cycle to exchange and share engineering performance information and experience.

I. INTRODUCTION

The scale of today's construction projects has been growing with increasing capital investment, and project durations have become relatively longer. Many risks, such as rising wages, poor cooperation of subcontractors, and price fluctuations of building materials, may occur during the construction period, delaying the project duration and affecting payment. Both construction and the consulting industries depend mainly on the experience of the project management personnel, and are difficult to form objective and systematic control methods and models (Crosbie et al., 2011). Construction companies have implemented a number of performance measurement frameworks, such as key performance indicators (KPIs), the balanced scorecard, and the European Foundation for Quality Management (EFQM). Each looks at the performance measurement from a different perspective and either overlaps with or complements the others (Kagioglou et al., 2001; Bassioni et al., 2004). Although there are small changes in the construction industry through a structured performance measurement system (PMS) with appropriate management information systems (MIS), there are significant improvements such as successfully addressing all stakeholder requirements and focusing on critical areas for improvement as well as bringing cultural changes (Nudurupati et al., 2007). Regardless of whether the owner of the project was to Design-Bid-Build (DBB) or Design-Build (DB) or Build-Operate-Transfer (BOT), the consultant will be facing the problem of cost management performance. Most consultancy firms in Taiwan use computer systems which are only powerful enough to analyze initial stage budgets. During the bidding stages, consultancy firms would carry out related analysis including analyses of man-hour, schedule and budget as well as design-related tasks. The actual project scope would change significantly due to different owners and contractors. The systems are not equipped to react to changes at each construction stage or to use the Earned Value Management (EVM) method to predict the construction project's Estimate at Completion (EAC). Because there are too many items that need to be considered during the project management process, project control has to depend on the experience of the managing personnel during the project control process (Abba, 1997; Abba, 2000; Cox et al., 2003; Hillson, 2004; PMI, 2004), and the constantly changing project scope makes the management difficult to

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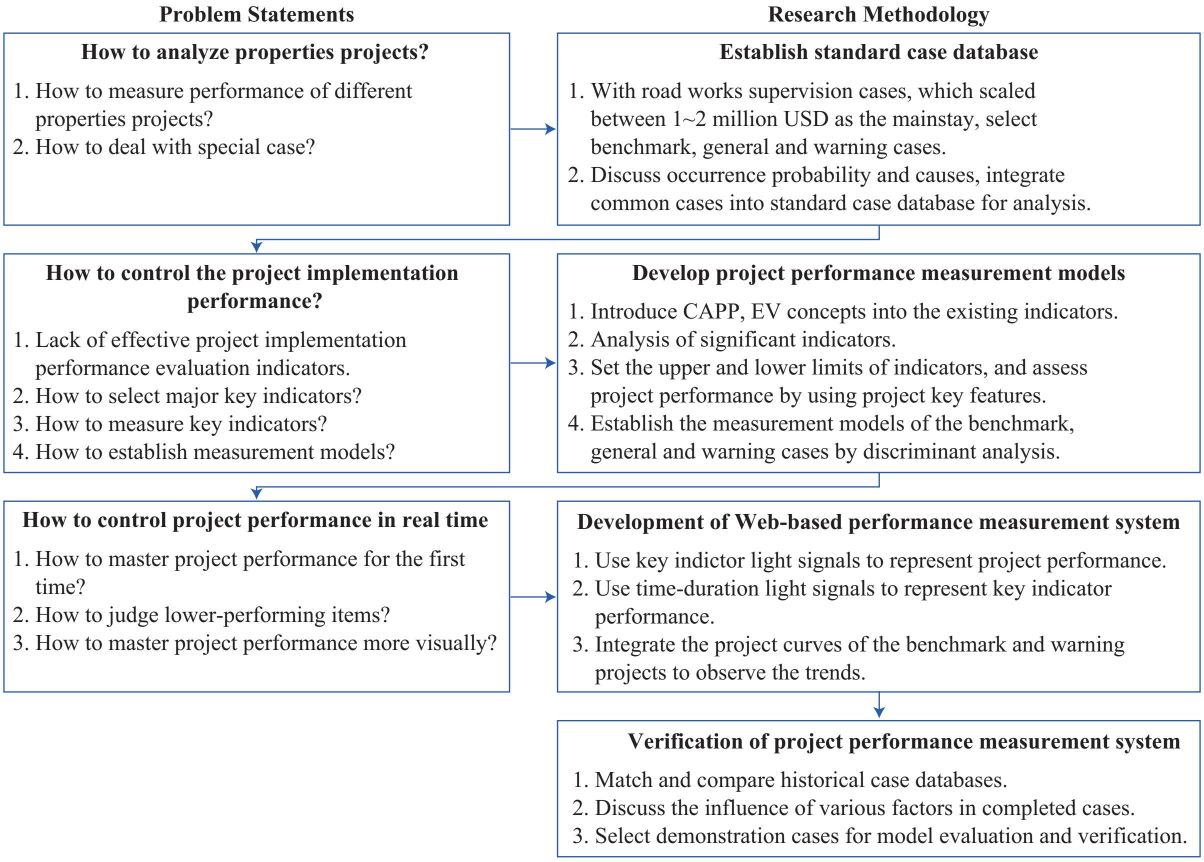


Problem Statements

How to analyze properties projects?

1. How to measure performance of different properties projects?
2. How to deal with special case?

How to control the project implementation performance?

1. Lack of effective project implementation performance evaluation indicators.
2. How to select major key indicators?
3. How to measure key indicators?
4. How to establish measurement models?

How to control project performance in real time

1. How to master project performance for the first time?
2. How to judge lower-performing items?
3. How to master project performance more visually?

Research Methodology

Establish standard case database

1. With road works supervision cases, which scaled between 1~2 million USD as the mainstay, select benchmark, general and warning cases.
2. Discuss occurrence probability and causes, integrate common cases into standard case database for analysis.

Develop project performance measurement models

1. Introduce CAPP, EV concepts into the existing indicators.
2. Analysis of significant indicators.
3. Set the upper and lower limits of indicators, and assess project performance by using project key features.
4. Establish the measurement models of the benchmark, general and warning cases by discriminant analysis.

Development of Web-based performance measurement system

1. Use key indictor light signals to represent project performance.
2. Use time-duration light signals to represent key indicator performance.
3. Integrate the project curves of the benchmark and warning projects to observe the trends.

Verification of project performance measurement system

1. Match and compare historical case databases.
2. Discuss the influence of various factors in completed cases.
3. Select demonstration cases for model evaluation and verification.

Fig. 1. Objectives for project performance measurement system.

control the project and predict the trend. A considerable number of basic data are used during the process to ensure smooth implementation; however, it is difficult to identify and locate such files in practice due to a lack of systematization. It often costs a considerable amount of labor, and it is not possible to predict the status of the project effectively when summarizing such files for reference by managers at all levels. On the other hand, the main resource of the engineering consultancy industry is manpower during the project operation process, so project performance must be based on the actual status of the project operation. This research analyzes the project performance measurement theories developed by the Construction Industry Institute (CII) (Lawrence, 1995; Russell et al., 1997), and collects and analyzes the data of completed projects from consultancy firms in Taiwan to identify the differences on those projects of both success and failure by describing the control and management curves using implementation performance indicators. Thus, project management personnel can refer to previous projects via control and management curves for application in ongoing projects. Via an established Web-based performance evaluation information system, they use an integrated database for distributed sharing to store and manage the standardized project performance records in order to exchange and share all project performance information. The objectives for the project performance measurement system are shown in Fig. 1.

The main purposes of this research are stated below. The first step is to collect historical performance records of engineering projects in order to discuss the performance of engineering consultancy through a case study of a major construction consultancy firm in Taiwan. Through data collection, analysis, and summary, this study establishes a historical database, reviews existing records, and selects major and significant performance evaluation indicators from the project data, as well as building on relevant models. Secondly, it aims to establish a performance control system to allow participants in various stages of the construction engineering life cycle to exchange and share engineering performance information and experience. Because the data collection and performance measurements from our model are time-consuming work, a system needs to be developed. However, due to the different locations of construction sites, we adopted a Web-based system to measure performance in order to achieve real-time control targets. This study has established a Web-based project performance measurement system and has set the upper and lower limits of the performance control conditions according to the project performance measurement models to identify the project implementation performance by using control light signals and added benchmarks as well as warning case curves to determine the project performance trend.

II. LITERATURE REVIEW

There are many ways to measure performance of projects. For example, Robinson et al. (2005) adopted the excellence model and the balanced scorecard to facilitate a structured approach to implement continuous improvement strategies; Skibniewski and Ghosh (2009) defined different types of KPIs and identified that a KPI has two dimensions: knowledge specificity and time specificity; Horta et al. (2009) used Web benchmarking systems, used widely in the construction industry (CI), which are designed to provide results based on key performance indicators; Cheng et al. (2010) present a Web-based visualized architecture for historical cases to help project managers to control project costs better. Performance measurement can be divided into two levels: "organization" and "customers" (Consultants, 2008). A multi-criteria model for evaluating the performance of engineering consultants is presented (Thomas Ng and Chow, 2004) and a fuzzy gap analysis model is proposed to improve the practice of Consultant Performance Evaluation (CPE) (Chow and Thomas Ng, 2007). Financial indicators and reporting tools are the core instruments used for enterprise survival (Jussupova-Mariethoz and Probst, 2007).

There are some limitations to the above measurement approach. Infrastructure projects frequently experience scheduling problems and cost overruns during the construction phase, and it is necessary to exploit modern technology to boost monitoring capability, scheduling accuracy, and cost estimates in construction engineering (Chou et al., 2010). The studies in construction management concluded that traditional performance measurement of Value Management (VM) studies focusing on cost reduction is insufficient (Yu et al., 2007). Construction firms typically focus only on budget planning during the initial project stage, which ignores engineering cost changes, information updates, and cost management during construction (Cheng et al., 2010). The current approach has the following limitations: (1) the comparison is only as good as the estimated values for cost and scheduling; (2) there is no certainty or ability to predict the probability of achieving a successful outcome; and (3) normally only a few key variables are monitored.

III. METHODOLODGY

In order to measure project performance without the above limitations, this research uses a construction supervision case as an example, integrates the concept of CII and EVM, and adopts a prediction model using the discriminant analysis method to develop a real-time project cost and schedule performance measurement system with predictive capability. The main purposes of discriminant analysis are as follows (Aldrich and Nelson, 1994; Lawrence, 1995; Davis and Sampson, 2002; Menches and Hanna, 2006; Shin and Eubank, 2011): (1) to determine the linear combination of discriminant variables in order to maximize the ratio of variance between groups against the variance within the group, and each linear combination is independent from previously obtained linear combinations; (2) to test whether the focuses of various groups are different; (3) to identify the variable with the strongest discriminant capabilities; and (4) to assign new subjects to a certain group according to the predicted values of the new subjects.

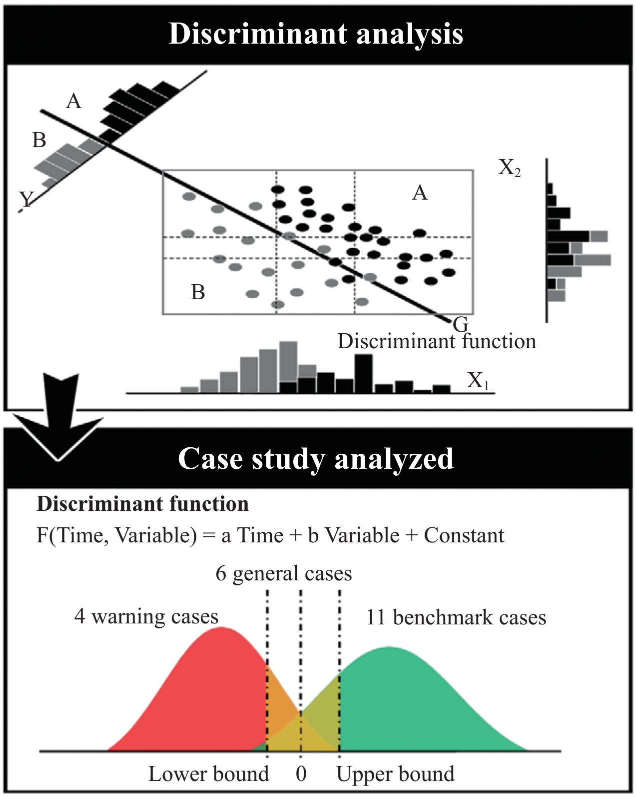


Fig. 2. Diagram for discriminant analysis (modified from John C. Davis, 2002).

The mainly analytical process of this study could be divided into selections of performance indicators and establishment and measurements of models. In the phase of performance indicator selection, EVM, CAPP, and the existing indicators have been selected by thorough in-depth interviews. In the establishment of models phase, this research aims to simplify classification of the cases. The measurement models have been established based on the discriminant analysis result and integrated selected indicators. After that, the control range based on the historical data of selected indicators could be established. Thus the control range could predict the trends of projects.

The concept of Fisher's discriminant function can be illustrated by geometric diagrams, as shown in Fig. 2, depicting the two variables X1 and X2 and two groups A and B. The solid and hollow represent two different attributes of data, which located on the coordinate axes of X1 and X2, the two groups A and B overlap slightly. Variables X1 and X2 are moderately positively correlated. G represents the straight line from the regression of the distribution of groups A and B in the space of X1 and X2, and Y is a straight line vertical and crosses line G.

Table 1. List of interview subjects and number of interviews.

Department	Position	Expertise	Working years	Number of interviews
Construction Management	Vice General Manager	Policy management, Resources integration management, Operational performance management	>30	2
	Director	Human Resource Management, Service Quality Management	>30	2
	Manager	Schedule management, Cost management, Contractor management	26	2
	Assistant Manager	Contractor management, Operational coordination, Construction site integration	21	4
Performance Management	Vice General Manager	Business strategy, Financial management	>30	2
	Director	Customer relationship management, Business potential analysis	22	2
	Manager	Operating performance analysis, Operating trend forecasting	21	4
	Supervisor	System analysis, data processing	18	4

The classification results for A and B can be obtained by projecting all the points of the number distribution of groups A and B onto the straight line Y. On this occasion, the overlapping part of the two groups' number distributions will be smaller than the scope of projection of any straight line. The straight line Y represents the discriminant function. Any value on the line is converted from the two variables X1 and X2. Point B is called the discriminant index, which divides the Y value into two parts as the basis for distinguishing groups A and B (Yu, 2011). The Fisher discriminant analysis seeks to find a projection axis such that the Fisher criterion is maximized after the projection of samples. The between-class matrix S_b and within-class scatter matrix S_w are defined by (Huang et al., 2012):

$$S_b = \frac{1}{n}\sum_{i=1}^{c} n_i(\mu_i - \mu)(\mu_i - \mu)^T \quad (1)$$

$$S_w = \frac{1}{n}\sum_{i=1}^{c}\sum_{j=1}^{li}(x_{ij} - \mu_i)(x_{ij} - \mu_i)^T \quad (2)$$

where x_{ij} denotes the j-th training sample in class i, n_i is the number of training samples in class i, μ_i is the mean of the training samples in class i, and μ is the mean of all samples. It is easy to show that S_b and S_w are both non-negative definite matrices and satisfy $S_t = S_w + S_b$, where S_t is the total scatter matrix. The Fisher criterion is defined by

$$J_F(V) = \arg\max \frac{trace(v^T S_b v)}{trace(v^T S_w v)} \quad (3)$$

The stationary points of $J_F(v)$ are the generalized eigenvectors $v1$, $v2$, …, vd of $S_b v = \lambda S_w v$ corresponding to the d largest eigenvalues.

IV. ESTABLISHMENT OF PROJECT IMPLEMENTATION PERFORMANCE INDICATORS

This research adopts in-depth interviews to select parts of performance indicators from the supervision department of an engineering consultancy firm. It was set up 38 years ago; owns 2,000 engineers with business services include engineering planning, engineering design, project management, and supervision. Detailed information on the interviews is shown in Table 1.

This study selected some performance management terms related to supervision from the existing management system of the engineering consultancy firm that is appropriate for this company. The 62 terms included cost management (15 items), time management (21 items), human resources management (6 items), integration management (4 items), and operating indicators (16 items), and were classified into five major categories. Coupled with the 76 indicators of the three levels of CAPP and 17 EV indicators taken from Wu (2007), there was a total of 155 performance control indicators, from which the repeated items were then merged or deleted. After in-depth interviews, this study selected the cost management (9 items; Table 2), time management (13 items; Table 3), and human resources management (2 items; Table 4) measurement indicators from the existing indicators of the engineering consultancy firm as being applicable to the performance evaluation management system. There was considerable convergence of the views of interviewees, who were all senior personnel, so it was easy to achieve results of "information saturation." Measurement indicators were selected, merged, or deleted when more than six interviewees agreed.

Regarding the CAPP and EV indicators, after much discussion, some inappropriate indicators were removed for the following reasons:

(1) indicators were not for consultancy firms (owner actual

Table 2. Cost management indicators in Consultancy firms.

Cost management indicators	
Construction cost	Construction cost in contract
Contract amount	Design and consulting services expenses
Project budget	= contract amount – expected profit
Recognition revenue	Revenue after accounting recognized
Cash revenue	Revenue of cash
Actual expenses	Cumulative actual expenses
Subcontracting expenses	Expenses for outsourcing service
Actual cost	Cumulative actual cost
Actual budget rate	Project actual budget rate = Actual cost / contract amount

Table 3. Time management indicators in Consultancy firms.

Time management indicators	
Planned project schedule % complete	The ratio of expected project schedule by host engineer
Actual project schedule % complete	The ratio of actual project schedule
Recognition schedule % complete	Project recognition schedule = (recognition revenue / project budget) * 100%
Planned project cost % complete	The ratio of expected project cost
Actual project cost % complete	= (actual cost / contract amount) *100%
Planned payout request % complete	The ratio of expected payout request
Actual payout request % complete	= (payout request / project budget) *100%
Project collection % complete	The ratio of project collection = (collection expenses / project budget) *100%
Date	Calculates the cumulative progress of time
Planned project principal term cost % complete	The ratio of principal term labor cost
Actual project principal term cost % complete	= (cumulative salaries / contract amount of salaries) * 100%
Planned project secondary term cost % complete	The ratio of secondary term labor cost, e.g. expenses for paperwork, business trips, taxes, insurance
Actual project secondary term cost % complete	= (Cumulative actual project secondary term cost / contract amount actual project secondary term cost) *100%

Table 4. Human resource management indicators in Consultancy firms.

Human resource management indicators	
Actual man-hours	Cumulative actual man-hours
Planned man-hours	= Planned man-months *180 hours

costs, owner payment requests, contractor actual costs); (2) no records were available in the original system (number of changed orders, expected cost of changed orders, incidental costs); (3) indicators cannot be quantified (employee turnover, actual building drawings, agenda recognized by influential owner); (4) indicators were difficult to calculate (redo costs attributed to site conditions, redo costs attributed to designer); (5) indicator definitions were too vague (the amount of information required).

Under these conditions, most indicators were deleted for those not belonging to the supervision unit, followed by those without records in the original system, those could not be quantified, those were hard to be calculated, and for those whose definition were too vague. This study selected suitable CAPP indicators as shown in Table 5. With respect to the EV management indicators, indicators were removed mainly because this study was focused on construction supervision projects. Hence, some indicators applied during the construction process such as Budget at Completion (BAC), Estimate to Complete (ETC), and Estimate at Completion (EAC) were deleted. The indicators that remained after filtering are shown in Table 6.

The results of the expert interviews showed that payments differed between owners, so the engineering consultancy

Table 5. Suitable CAPP indicators.

Phase One CAPP	
Actual designer project cost	Actual designer effort hours
Phase Two CAPP	
Actual design % complete	Cost of remaining change orders
Actual project cost % complete	Quantity of remaining change orders
Cost of subcontractor project commitment	Schedule impact of variance/trends
Recordable incident rate	Impact of pending change orders
Quantity of change orders	
Phase Three CAPP	
Designer planned effort hours	Planned project cost % complete
Planned design % complete	Actual overtime work
Planned designer cost	

Table 6. Suitable EVM indicators (PMI, 2004).

Abbreviation	Indicators	Abbreviation	Indicators
PV	Planned Value	VAC	Variance at completion
EV	Earned Value	PV^C	Cumulative PV
AC	Actual Cost	EV^C	Cumulative EV
CV	Cost Variance	AC^C	Cumulative AC
SV	Schedule Variance	CPI^C	Cumulative CPI
CPI	Cost performance index	SPI^C	Cumulative SPI
SPI	Schedule performance index	%Done	Percent complete

industry requires more detailed indicators regarding project performance measurement to facilitate dynamic management. Therefore, this study categorized traditional EV into project EV, recognition EV, and payout request EV as defined below:

(1) Project EV: internally worked schedule-based EV, namely the amount obtained by multiplying the service fee by the expected schedule of the project. A higher project EV means the efficiency of the internally worked EV will be better.

(2) Payout request EV: EV based on the progress recognized by the owner, namely the value of the payment agreed by the owner. There is a difference between the cost of the actual implementation and the payment agreed by owners in the engineering consultancy industry.

(3) Recognition EV: EV based on the actual progress recognized by the accountants. In principle it is the same as project EV; however, in the case of large inconsistencies between the actual progress and the planned progress, where the ratio of actual and planned progress has been unable to accurately reflect the project performance, Recognition EV can provide a relatively accurate project performance indicator.

After defining the EV, the CPI (Cost Performance Indicator) and SPI (Schedule Performance Indicator) are divided into three categories, including the planned CPI, recognized CPI, payout request CPI, cost SPI, recognized SPI, and payout request SPI. In addition, since delay in the expected schedule is common in the case of construction supervision, the PV (Planned Value) will be discussed in planned cases based on the start time and planned completion time.

V. CASE STUDY AND VERIFICATION

1. Case Information

Considering real cases of construction supervision projects, this study analyzed and studied various performance indicators, summarized the case developmental trend and project performance trend, and established a standard case database. It's difficult to collect complete data for projects. Twenty-one cases have been collected for building measurement models. Then 11 benchmark cases and four warning cases have been sorted out based on detailed comparisons and in-depth interviews with the participating experts. Finally, the results of models have been verified with robust comparison between measurement models and in-depth interviews. The collected cases were categorized according to project size, measured by total service fees of 5 million, 10 million, 20 million, 50 million, 100 million and 200 million NTD (1 USD = 30 NTD).

In the process of analysis and research, some cases were found to have particularities. The four types of particularity were summarized as follows:

(1) The total service fee was increased during the project implementation process.

The incidence of such cases was not low. Since the project schedule should be rearranged after the rise in the total service fee and the original project EV data were not modified, a negative slope of the project EV curve may occur as a result. The number of negative slopes was the number of rises of service fees; they were included in the standard case database as warning cases.

(2) The project was finished but the payout request was not completed.

Due to disputes between the constructor and the owner, the completion acceptance was delayed in a small number of cases. Hence, the request for the balance due was not completed. Such cases can be referred to as abnormal warnings; they were included in the standard case database as benchmark cases.

(3) The project's total budget was larger than the total service fee.

The budget of a normal project is rarely lower than the total service fee with a fixed percentage of profits. However, some projects were strategic cases for the company, and may have budgets larger than the total service fee at the start. Such projects would definitely lose money according to the present performance; the service fee PV curve was more than 100%. Since these cases were strategic projects, they were excluded from the research scope of this study.

(4) Progress was made in the early stage of the project without incurring an actual cost.

Because some projects were too small in size, their costs may be absorbed by other cases of greater size. Hence, such cases were referred to as abnormal warnings in the system. Since such cases were rare, to avoid an impact on the analysis of generally common cases, they were not included in the standard database.

2. Key Time Points

The scheduled indicators in this research can be divided into three different types: project schedule, project work schedule, and project invoice cost. (1) Project schedule is based on budget. (2) Regarding project work schedule, this research used the project work schedule to represent the different man-hour cost for projects. The man-hour cost is different for every project. It's based on the level of project manager and engineers. (3) In addition, this research used project invoice cost to represent the different invoice progress for projects. Because the payment mechanism of every owner is different, it would impact the invoice progress of projects.

Some combined indicators were defined as follows: Project planned SPI (P_pSPI) is the percentage completion of the actual project schedule over the percentage completion of the planned project schedule; Project work SPI (P_wSPI) is the percentage completion of the actual project work schedule over the percentage completion of the planned project work schedule; Project invoice SPI (P_iSPI) is the percentage completion of the actual project invoice schedule over the percentage completion of the planned project invoice schedule; Project planned CPI (P_pCPI) is the percentage completion of the actual project cost over the percentage completion of the planned project cost; Project work CPI (P_wCPI) is the percentage completion of the actual project work cost over the percentage completion of the planned project work cost; Project invoice CPI (P_iCPI) is the percentage completion of the actual project invoice cost over the percentage completion of the planned project invoice cost; Project recognition CPI (P_rCPI) is the percentage completion of the actual project recognition over the percentage completion of the planned project recognition.

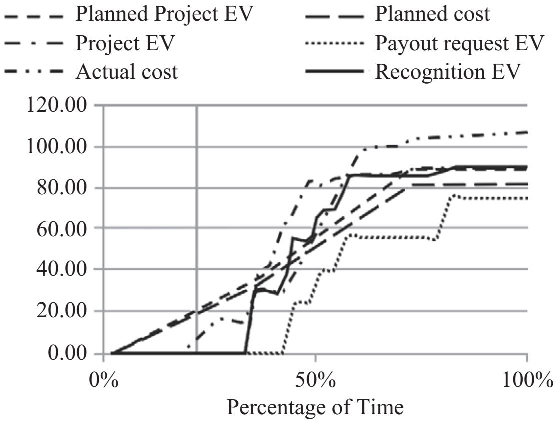


Fig. 3. Indicators of risky case (1).

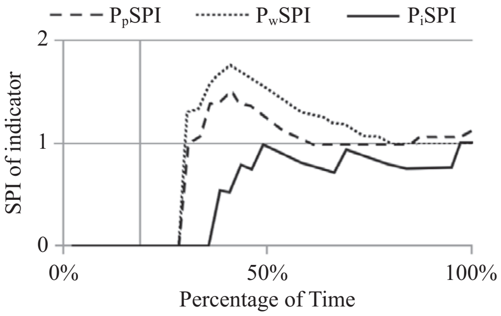


Fig. 4. SPI values comparison of risky case.

The observation of the performance of the project implementation curve demonstrated that two key scheduling points should be particularly noted and controlled:

(1) Twenty percent of the expected schedule: if the Recognition EV has lagged behind the Project EV, the project may be a loss (Fig. 3); when the Actual cost is greater than the Project EV, it is probably a loss; if the project SPI and working SPI begins to separate at around the point of 20% (Fig. 4), the project has the possibility of a loss.

(2) Fifty percent of the expected schedule: if the Recognition EV has lagged behind the Project EV, the project may be a loss (Fig. 5); comparing the Recognition EV with the actual Payout request EV, if the gap is more than the upper limit of the limitation (30%), it may result in a loss (Fig. 5); if the gap between the Planned cost and the Actual cost (AC) is small and without divergence, the project will increase to losses.

Table 7. The difference between benchmarking case and risky case.

Indicators	Benchmarking case	Risky case
Project & payout request EV	Overlap mostly	Separate, close in the end
Project EV & AC	No contact, Project EV > AC	Contact, AC > Project EV in the beginning
Expected cost % complete & AC	Divergent mostly	Convergent mostly
SPI	>1.0 mostly	<1.0 mostly
P_pSPI & P_wSPI	Close	Separate
CPI	>1.0 mostly	<1.0 mostly
P_pCPI & P_rCPI	Close	Separate

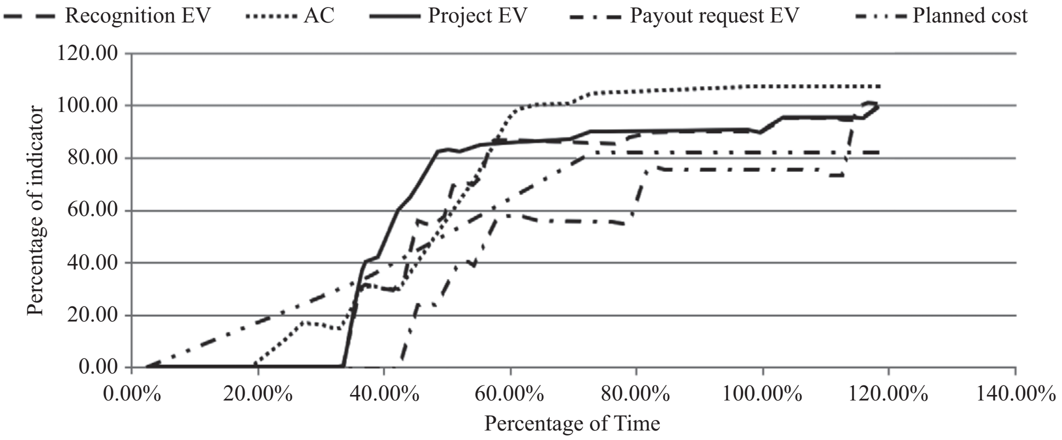


Fig. 5. Indicators of risky case (2).

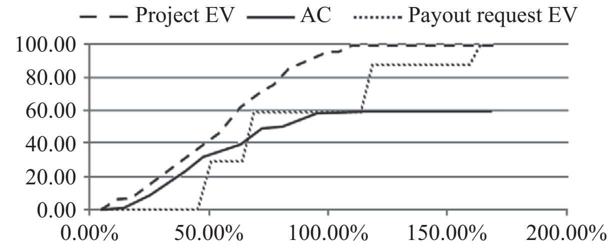


Fig. 6. Indicators of benchmarking case.

(Fig. 5); if the project EV reported by engineers' reaches 80% (Fig. 5), it may lead to losses.

Following the observations regarding individual research indicators, this study analyzed the performance of the benchmark. The warning cases at key time points in terms of various indicators are shown in Table 7.

By integrating the performance differences and key point concepts as illustrated in the previous two sections, this study summarized the characteristics of the benchmark and warning cases to predict the project's tendency as a benchmark or warning case.

(1) Warning cases (Fig. 5): the recognition EV cannot catch up with the project EV at the 20% schedule and 50% schedule; the distance between the Recognition EV and the Payout request EV remains at the upper limit of 30%; at the 20% schedule after the AC (Actual cost), the Project EV curve and the AC curve intersect; the Project EV curve and the AC curve intersect twice; the Payout request EV and AC do not intersect after the 20% schedule; in the early stages of the project, AC is larger than the Project EV.

(2) Benchmark cases (Fig. 6): the Project EV and AC are held at a certain distance in a divergent state without intersecting; the Payout request EV and AC are in a tangential relationship or intersect with each other.

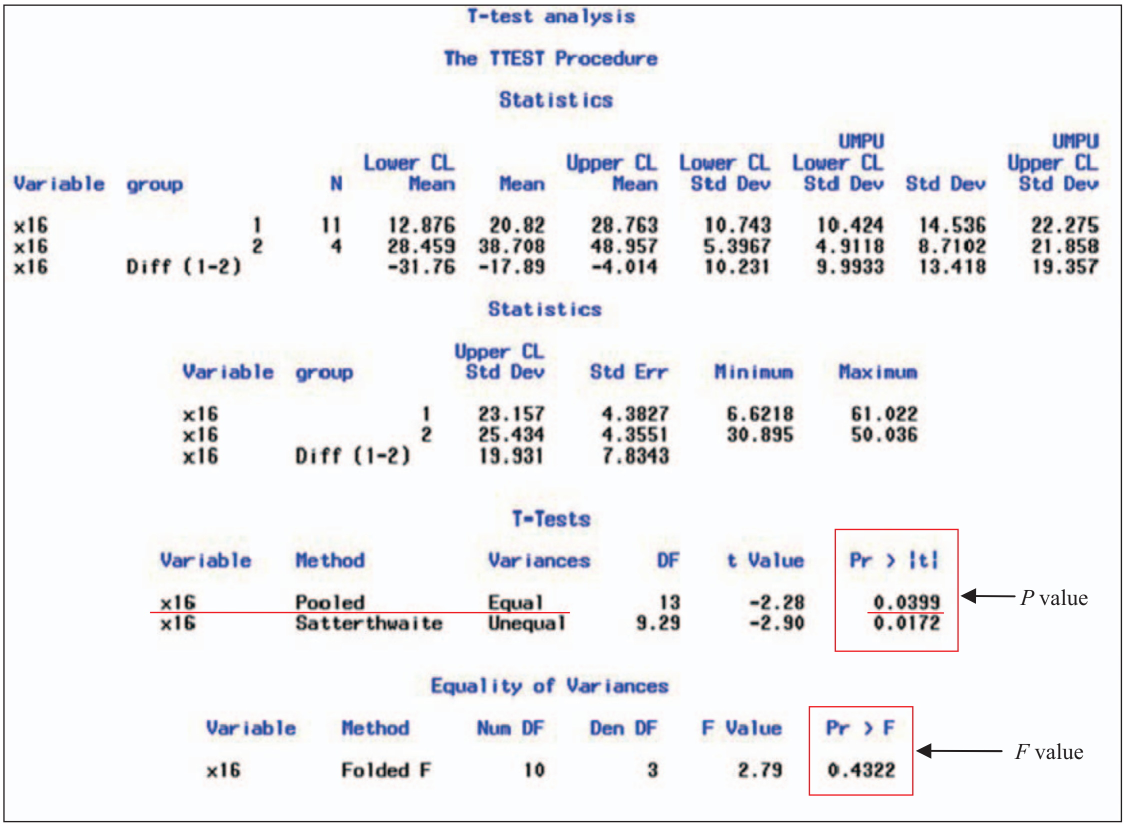
3. Significance Analysis

The advanced analysis was divided into two stages: the first stage was the basic data processing of the normalization of case data and the second was carrying out advanced analysis on the standard case database, namely the indicator significance analysis and the indicator identification analysis, to obtain the classification equation. This research adopted a T-test and equality of variances for significance analysis. This study used 31 indicators as shown in Table 8. The equation can be applied to determine a future project's tendency to be a warning or a benchmark case.

(1) The establishment and import of case data, and the calculation of indicator values. The first step was to import data and information from the company database including the basic information of the case and the data of indicators 1-16 into the case data value table, and the second step was to

Table 8. Advanced analysis indicators.

No.	Indicator descriptions	No.	Indicator descriptions
0	Planned schedule %	16	Σ actual man-hours %
1	Planned main work %	17	Actual schedule % this month
2	Actual main work %	18	Actual work % this month
3	Planned coordination work %	19	Actual cost % this month
4	Actual coordination work %	20	Actual man-hours % this month
5	Planned project %	21	Project SPI
6	Actual project %	22	Project CPI
7	Planned work %	23	Project work SPI
8	Actual work %	24	Project work CPI
9	Recognition %	25	Recognition CPI
10	Planned payout request %	26	Project payout request SPI
11	Actual payout request %	27	Project payout request CPI
12	Receipt %	28	Project CR
13	Planned value %	29	Project work CR
14	Actual cost %	30	Project payout request CR
15	Planned man-hours %		



```
                              T-test analysis

                           The TTEST Procedure

                               Statistics

                                                                         UMPU                 UMPU
                           Lower CL          Upper CL  Lower CL  Lower CL            Upper CL
Variable  group       N      Mean     Mean     Mean    Std Dev   Std Dev   Std Dev   Std Dev

x16              1   11    12.876    20.82   28.763    10.743    10.424    14.536    22.275
x16              2    4    28.459   38.708   48.957    5.3967    4.9118    8.7102    21.858
x16       Diff (1-2)       -31.76   -17.89   -4.014    10.231    9.9933    13.418    19.357

                              Statistics

                                  Upper CL
           Variable  group         Std Dev    Std Err    Minimum    Maximum

           x16                 1    23.157     4.3827     6.6218     61.022
           x16                 2    25.434     4.3551     30.895     50.036
           x16       Diff (1-2)     19.931     7.8343

                                T-Tests

         Variable    Method          Variances      DF    t Value    Pr > |t|

         x16         Pooled          Equal          13      -2.28      0.0399
         x16         Satterthwaite   Unequal      9.29      -2.90      0.0172

                         Equality of Variances

           Variable    Method     Num DF    Den DF    F Value    Pr > F

           x16         Folded F       10         3       2.79    0.4322
```

Fig. 7. Significance test result of indicator (x16).

calculate the data and information imported at the first step to calculate indicator no. 0 and indicator nos. 17-30.

(2) Data normalization, integration of all the data in the standard case database for advanced analysis. Due to the different schedules of various cases, the numbers of data points were different, and all the indicator values were standardized to formalize the expected schedule ranges to ensure all weights of cases were consistent and to prevent the domination of

Table 9. *P* value of significance variance analysis of various indicators.

	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%
x1	0.55	0.32	0.29	0.32	0.35	0.37	0.39	0.36	0.36	0.35	0.37	0.40	0.45	0.47	0.49	0.52	0.53	0.51	0.44	0.34
x2	0.32	0.37	0.66	0.90	0.55	1.00	0.58	0.17	0.10	0.09	0.09	0.07	0.13	0.17	0.12	0.22	0.38	0.63	0.99	0.34
x3	0.79	0.86	0.99	0.86	0.70	0.60	0.53	0.48	0.44	0.43	0.43	0.43	0.44	0.49	0.58	0.58	0.59	0.66	0.92	0.34
x4	0.27	0.65	0.83	0.87	0.62	0.85	0.74	0.21	0.12	0.13	0.16	0.11	0.21	0.20	0.18	0.41	0.78	0.42	0.37	0.34
x5	0.80	0.67	0.60	0.47	0.45	0.34	0.23	0.17	0.11	0.10	0.06	0.03	0.02	0.02	0.03	0.05	0.14	0.40	0.71	0.11
x6	0.71	0.41	0.63	0.88	0.83	0.74	0.83	0.24	0.07	0.05	0.05	0.02	0.05	0.07	0.06	0.14	0.29	0.66	0.48	0.07
x7	0.63	0.41	0.36	0.40	0.44	0.46	0.49	0.46	0.47	0.46	0.47	0.50	0.55	0.56	0.57	0.60	0.62	0.59	0.50	0.34
x8	0.30	0.40	0.67	0.92	0.58	0.95	0.64	0.19	0.11	0.11	0.11	0.08	0.15	0.20	0.16	0.31	0.57	0.90	0.51	0.34
x9	0.71	0.41	0.43	0.34	0.32	0.08	0.06	0.00	0.00	0.02	0.05	0.04	0.05	0.04	0.05	0.04	0.04	0.06	0.08	0.15
x10	0.93	0.98	0.85	0.37	0.52	0.46	0.52	0.21	0.27	0.29	0.29	0.17	0.24	0.19	0.20	0.16	0.07	0.04	0.15	0.45
x11	.	0.45	0.55	0.54	0.86	1.00	0.62	0.82	0.88	0.99	0.76	0.71	0.85	0.86	0.79	0.97	0.90	0.67	0.48	0.29
x12	.	0.45	0.43	0.82	0.84	0.92	0.62	0.83	0.59	0.63	0.56	0.34	0.39	0.52	0.34	0.96	0.92	0.74	0.53	0.26
x13	0.79	0.66	0.60	0.48	0.46	0.35	0.24	0.18	0.13	0.11	0.07	0.04	0.03	0.03	0.06	0.11	0.25	0.57	0.72	0.09
x14	0.90	0.94	0.91	0.51	0.23	0.21	0.12	0.08	0.04	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
x15	0.40	0.56	0.85	0.87	0.67	0.55	0.48	0.39	0.35	0.31	0.32	0.35	0.41	0.46	0.52	0.55	0.57	0.55	0.49	0.34
x16	0.75	0.55	0.42	0.24	0.03	0.02	0.03	0.06	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
x21	0.85	0.28	0.44	0.69	0.82	0.27	0.36	0.70	0.92	0.88	0.99	0.71	0.36	0.30	0.48	0.53	0.68	0.64	0.61	0.34
x22	0.61	0.41	0.33	0.31	0.34	0.06	0.00	0.08	0.32	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
x23	0.27	0.34	0.61	0.97	0.73	0.65	0.89	0.11	0.11	0.15	0.18	0.11	0.20	0.22	0.24	0.48	0.89	0.54	0.31	0.34
x24	0.18	0.32	0.24	0.29	0.48	0.11	0.01	0.24	0.37	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
x25	0.61	0.41	0.28	0.28	0.38	0.07	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
x26	.	0.50	0.53	0.85	0.48	0.84	0.59	0.43	0.80	0.64	0.47	0.65	0.40	0.26	0.30	0.15	0.08	0.05	0.11	0.14
x27	.	0.55	0.56	0.79	0.37	0.38	0.14	0.34	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
x28	0.94	0.37	0.79	0.79	0.83	0.06	0.12	0.29	0.67	0.38	0.08	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
x29	0.27	0.53	0.77	0.83	0.81	0.21	0.27	0.92	0.63	0.98	0.28	0.04	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
x30	.	.	0.53	0.77	0.31	0.59	0.21	0.29	0.13	0.05	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

cases of long duration and with more data points. The corresponding values of various indicators were obtained according to the expected schedules.

(3) Significance variance analysis as the basis for classification judgment. Indicators failing the significance variance verification represented low reference values for distinguishing warning and benchmark cases; indicators passing the significance variance analysis represented relatively high reference values. According to the given classifications, this study used the assumption verification to analyze whether there was a significant variance between groups at a significance level of 10%. Taking the cumulative actual project progress (x16) as an example, if the schedule progress was at 30%, warning and benchmark cases had no difference in value; thus the null hypothesis was $\mu_1 = \mu_2$, and the alternative hypothesis was $\mu_1 \neq \mu_2$ as follows:

$$\begin{cases} H_0 : \mu_1 = \mu_2 \\ H' : \mu_1 \neq \mu_2 \end{cases} \tag{4}$$

This study expected to negate H_0 to indirectly prove the significance, and thus the warning and benchmark cases were significantly different. When the P value was greater than α, the error probability of rejecting H_0 was beyond the standard (significance level α), and therefore H_0 was not rejected; in other words, H' was negated. Consequently, when the indicator (x16) was at the 30% schedule, there was no significant difference between the statistics of the warning and benchmark cases. When the P value was smaller than α, the error probability of rejecting H_0 was acceptable, and hence H_0 was rejected and H' was accepted. For example, the P value of the indicator (x16) is 0.03999, which is less than 10% (Fig. 7). The indicator (x16) at 30% of the schedule showed that there was no significant difference between the statistics of the warning and benchmark cases, which was valuable for judgment. As a result, the indicator can be integrated at 30% of the schedule for judgment of the project in terms of developing the direction.

This study conducted significance variance analysis of the 31 indicators, with P values being recorded as shown in Table 9.

A Gantt map of various indicators according to significance level was developed as shown in Fig. 8. The darker color

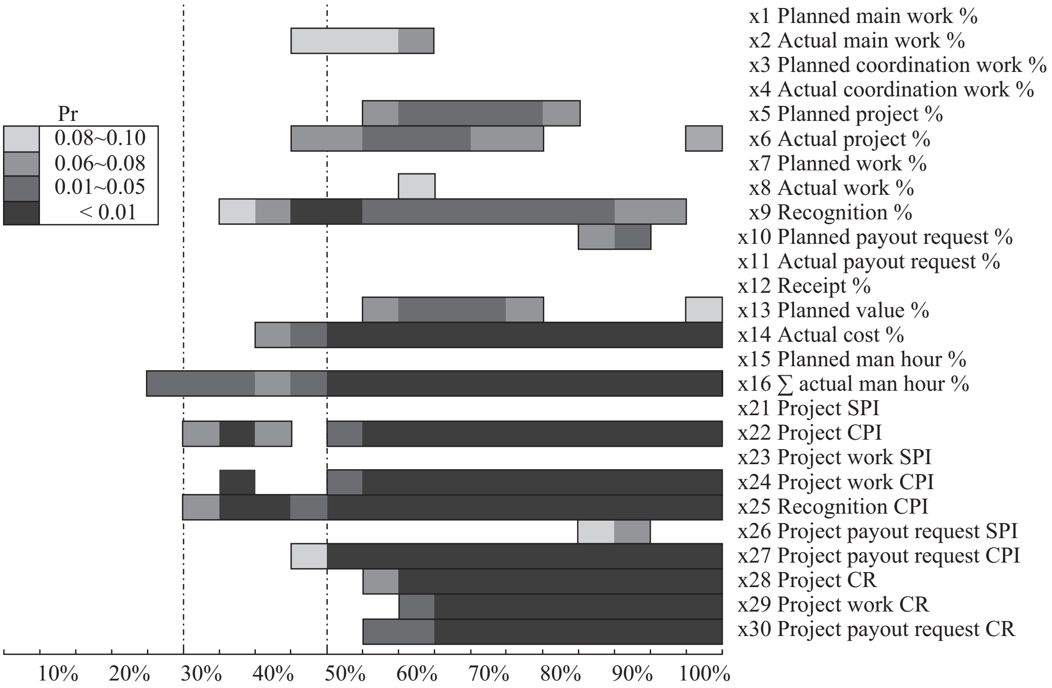


Fig. 8. Gantt chart of indicators' significance.

Table 10. Top 8 indicators.

% complete level	Integrated level
Actual project % (x6)	Project CPI (x22)
Recognition % (x9)	Project work CPI (x24)
Actual cost % (x14)	Recognition CPI (x25)
Σ actual man-hours % (x16)	Project payout request CPI (x27)

represents a larger *P* value and a more significant indicator. As shown in Fig. 8, Actual cost percentage (x14), Σ actual man-hours percentage (x16), Project CPI (x22), Project work CPI (x24), Recognition CPI (x25), Project payout request CPI (x27), Project CR (x28), Project work CR (x29), and Project payout request CR (x30) were the most significant. The significance of Project CR (x28), Project work CR (x29), and Project payout request CR (x30) can be interpreted by the relevant CPI and SPI indicators. Financial indicators and reporting tools are the core instruments used for enterprise survival (Jussupova-Mariethoz and Probst, 2007); it was decided to integrate Actual project percentage (x6), which was relatively more related to project implementation, and Recognition percentage (x9), which was relatively more related to the accounting recognition process, as they had a high overall significance as the key indicators. Thus this study defined eight major indicators of project implementation performance evaluation (Table 10).

4. Discriminant Analysis

This study used two variables according to various indicators, the expected schedule and indicator value, to distinguish groups: the benchmark group (group 1) and the warning group (group 2). The classification equation is the linear classification equation of two unknown variables, which are "a" and "b" in the equation in Fig. 2. Time in the equation is the expected schedule, Var. is the indicator, "a" is the trans-axial coefficient of Time, "b" is the trans-axial coefficient of Var., and with a constant item. The purpose of the constant item is to ensure that the verification fraction (F (Time, Var.)) uses zero as the basis for classification determination (Fig. 9).

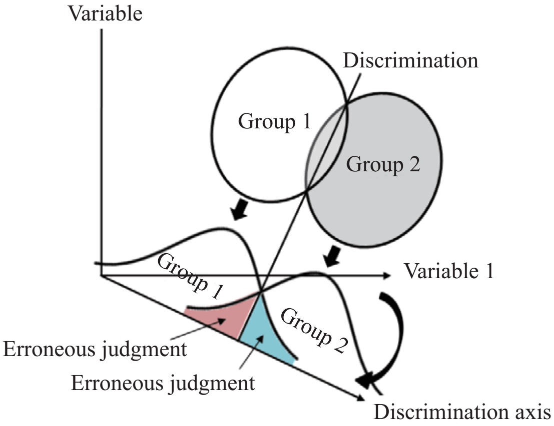


Fig. 9. Diagram of Fisher linear discrimination.

Finally, this study used the classification equation to judge the input analysis data (240 batches). The judgment results are shown in Table 11. The probability of misclassification of the benchmark cases as warning cases was 11.9% and the probability of misclassifying warning cases as benchmark cases

Table 11. Statistics of erroneous judgment.

From group	1	2	Total
1	155	21 *1	176
	88.1%	11.9%	100.0%
2	8 *1	56	64
	12.5%	87.5%	100.0%
Total	163	77	240
	67.9%	32.1%	100.0%

*1: misclassified

Table 12. Classification functions of top 8 indicators.

Indicators	Classification function F (Time, Var.)	Upper bound	Lower bound
Project CPI (x22)	= 0.0217 Time + 10.5350 Var. + -14.9820	0.38	-1.59
Project work CPI (x24)	= 0.0439 Time + 13.4826 Var. + -20.9589	2.85	-1.54
Recognition CPI (x25)	= -0.0481 Time + 11.1180 Var. + -6.8211	1.61	-0.50
Project payout request CPI (x27)	= 0.0006 Time + 11.4392 Var. + -14.0473	0.68	-1.64
Actual man-hours % (x16)	= 0.1116 Time + -0.1296 Var. + 1.3979	2.63	-0.22
Actual cost % (x14)	= 0.3447 Time + -0.4659 Va. + 5.9306	3.98	-2.71
Actual project % (x6)	= 0.0817 Time + -0.0819 Var. + 1.0857	2.28	-0.56
Recognition % (x9)	= 0.0545 Time + -0.0617 Var. + 1.0922	1.51	-0.53

* F(Time, Var.) ≥ upper bound → benchmarking case

* F(Time, Var.) ≤ lower bound → risky case

* others → general case

was 12.5%. After the verification analysis of the eight indicators, this study obtained the following classification equations as shown in Table 12.

VI. SYSTEM DEVELOPMENT

Based on the selected indicators as described previously, after carrying out system planning and establishing the system model, this study developed a project performance measurement system that can be integrated with the existing project management system. The system has an indicator analysis function and control diagram drawing functions, and mainly consists of the project's basic information, data processing, and graphical drawing modules (Fig. 10).

1. Data processing module. When the user enters the main screen of the system, eight major indicators will be listed on the project warning screen. The results of the classification of the eight major indicators are labeled in red, yellow, and green colors. Red indicates that the indicator values of the case are close to the warning cases in the standard case database; yellow indicates that the indicator values of the case are close to the general cases in the standard case database; green indicates that the indicator values of the case are close to the benchmark cases in the standard case database. Hence, the user can directly determine the project's performance by visual observation (Fig. 11).

If the user selects "Project No.," the screen will immediately change to the indicator's historical judgment information. The user can then find out major issues from the historical judgment information of the indicator as suggestions for improvement. If the user selects the project's name, the screen will immediately change to the page showing the project's detailed information to allow the user to obtain detailed information on the project or browse the indicators of the project.

2. Graphical drawing module. This includes the project success rate and project control diagram pages. The user can select a project for drawing from a drop-down menu, and can select the project control diagram from the main menu on the left to enter the project control page (Figs. 12 and 13). Its function is similar to the project control diagram drawing function of the project-warning page. The system default graphical drawings are the project curves of the benchmark cases and warning cases. The user may select diagrams of different standard deviations to generate different graphics by pressing the drawing button (Fig. 14).

VII. CONCLUSITONS

The two major contributions made by this study were the establishment of the project classification factor assessment indicators and the Web-based information system. This study

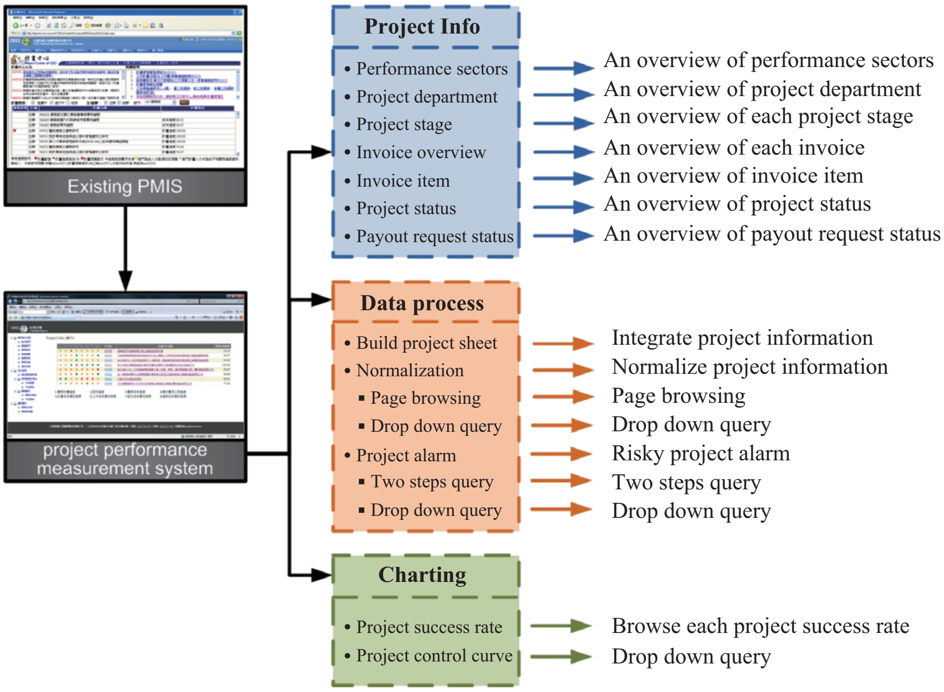
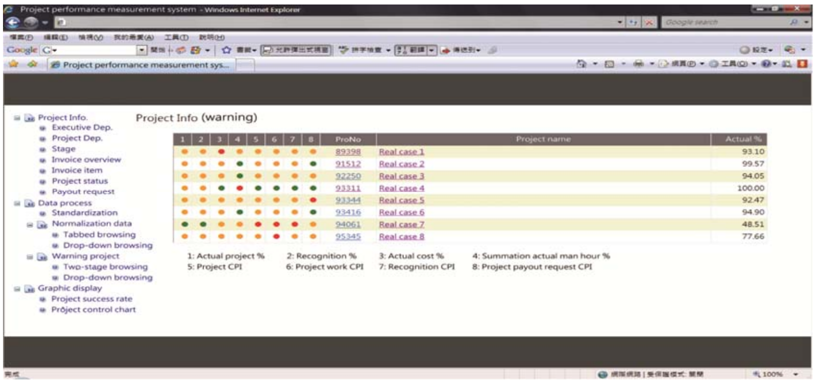


Fig. 10. System framework.

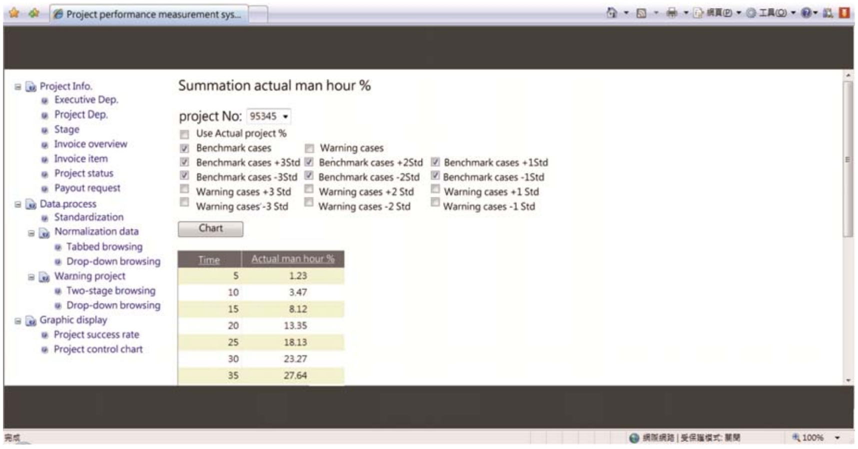


Project Info (warning)

1	2	3	4	5	6	7	8	ProNo	Project name	Actual %
🟠	🟠	🔴	🟠	🟠	🟠	🟠	🟠	89398	Real case 1	93.10
🟠	🟠	🟠	🟢	🟠	🟠	🟠	🟢	91512	Real case 2	99.57
🟠	🟠	🟠	🟢	🟠	🟠	🟠	🟠	92250	Real case 3	94.05
🟠	🟠	🟢	🔴	🟢	🟢	🟢	🟢	93311	Real case 4	100.00
🟠	🟠	🟠	🟠	🟠	🟠	🟠	🔴	93344	Real case 5	92.47
🟠	🟠	🟠	🟢	🟠	🟠	🟠	🟢	93416	Real case 6	94.90
🟢	🟢	🟠	🟠	🔴	🔴	🔴	🟠	94061	Real case 7	48.51
🟠	🟠	🟠	🟠	🟠	🔴	🟠	🟠	95345	Real case 8	77.66

1: Actual project % 2: Recognition % 3: Actual cost % 4: Summation actual man hour %
5: Project CPI 6: Project work CPI 7: Recognition CPI 8: Project payout request CPI

Fig. 11. Screen for project alarm.



Summation actual man hour %

project No: 95345

☐ Use Actual project %
☑ Benchmark cases ☐ Warning cases
☑ Benchmark cases +3Std ☑ Benchmark cases +2Std ☑ Benchmark cases +1Std
☑ Benchmark cases -3Std ☑ Benchmark cases -2Std ☑ Benchmark cases -1Std
☐ Warning cases +3 Std ☐ Warning cases +2 Std ☐ Warning cases +1 Std
☐ Warning cases -3 Std ☐ Warning cases -2 Std ☐ Warning cases -1 Std

Time	Actual man hour %
5	1.23
10	3.47
15	8.12
20	13.35
25	18.13
30	23.27
35	27.64

Fig. 12. Screen for indicator selection.

Fig. 13. Project control curve.

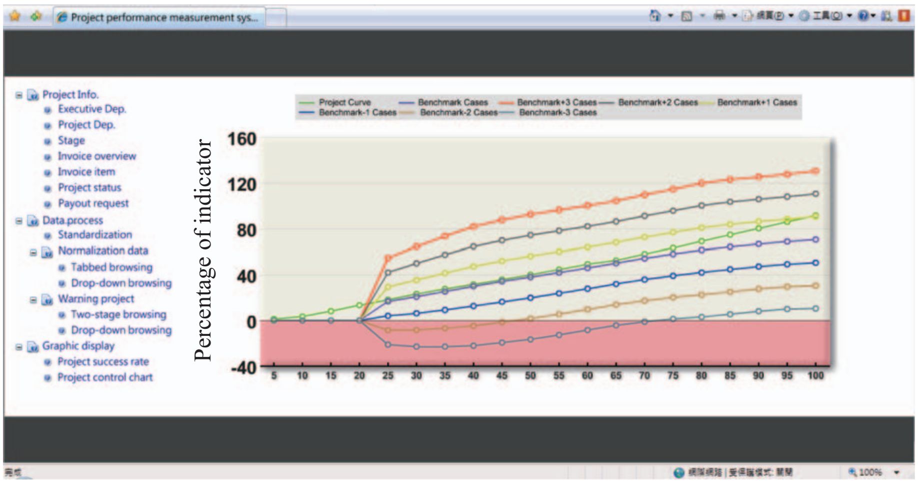


Fig. 14. Custom project control curve.

selected classification factors and performance evaluation indicators applicable to consultancy firms, using the selected approach on a number of completed cases, and summarized eight performance control indicator values and a judgment measures model to determine a future project's tendency to be a warning or a benchmark case. The proposed indicator values and discriminant measures were proven to be capable of representing the project performance of actual projects. This study was suitable for supervision and project management in the engineering consultancy industry.

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