MASTERFORMAT-BASED SYSTEM FOR EVALUATING THE PERFORMANCE OF CONSTRUCTION PROJECTS USING BACKWARD CHAINING

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ABSTRACT

Evaluating project performance is vital for practicing control over construction projects. Structured analysis of data to detect deviations is very crucial for efficient project evaluation. Limited research efforts were done to develop standard evaluation systems. Among problems that faced researchers is the uniqueness of construction projects. Moreover, work breakdowns of projects, even within the same construction category, are usually structured differently. Recently, standard work breakdown structures were introduced and become well-recognized throughout the industry. These structures offer a big potential to structure the analysis process and produce standard evaluation systems. Masterformat is a work breakdown structure that has been adopted by entities of the industry as the basis of coding product literature, organizing construction bids, and producing commercial cost estimating, cost accounting, and guide specification systems. This paper utilized Masterformat to structure and standerdize the analysis process to evaluate performance of construction projects. Control ratios, which were previously developed in literature, were employed in the analysis to identify work items having potential problems at project micro level. Backward-chaining mechanism was used to automate the implementation of the standard analysis. This study presents a prototype for a potentially user-friendly, generic, and standard system that can be used to monitor construction projects.

Keywords: *Construction project,   Control, Monitoring,   Evaluation,   Backward chaining, Financial ratios.*

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1. INTRODUCTION

This section introduces the performance evaluation approaches that were developed and some of the performance evaluation systems that were previously performed in the literature.

1.1. Performance evaluation approaches

Project performance evaluation approach [LeVitt, 1974; Choromokos and Mckee, 1981] was described utilizing the cost/time envelope diagram to integrate cost and scheduling data. The cost envelope diagram is a graphical presentation of the project's preconstruction cost profile based on early start and late start schedules. As the project progresses, actual project cost are plotted on the same graph. If the actual project cost falls inside the planned envelope the performance of the project is judged to be satisfactory, otherwise the project performance is judged to be unsatisfactory.

Another technique [Stevens, 1986] offered a major modification to the above technique. He recommended plotting only the target project's cost profile and including the project's accomplishments curve on the same graph in order to arrive at a conclusive judgment regarding project performance.

In an attempt to solve problems of reporting integrated cost and scheduling information, ratio-based techniques [Caepari and Varrone, 1985] were developed and adopted by major construction firms and government agencies. These ratios include: cost performance index, scheduling performance index, percent overrun/underrun, planned percent complete, and percent complete.

A technique [Eldin, 1987] was introduced for project management control in the construction industry. This technique evaluates performance at a micro rather than macro level. The technique identified five key control ratios to completely describe project performance at the cost item level. These ratios include; cost per work unit, man-hour per

work unit, cost per man- hour, crew mix ratio, and craft rate ratio. In addition, a problem detection procedure that uses the control ratios was employed to identify project cost items having financial problems and determine the immediate causes of these problems. Moreover, this procedure calculates performance indices and generates cost forecasts. The introduced technique has the potential to resolve management problems concerning the lack of proper integration between cost and time.

1.2. Previous evaluation systems

Four information elements were identified [Baumgeartner, 1986] as the basic requirements of successful construction management and project evaluation systems including: cost summaries; scheduling status reports; overall reported progress; and trend forecasts. Researchers have proposed numerous systems to evaluate the current situation and make future forecasts that will be outlined below.

A very early study [McGartland and Hendrickson, 1985] described potential applications of knowledge based expert systems in the area of construction project monitoring and control.   Sample applications and heuristic rules in scheduling and inventory control are provided. Though, this study did not present a complete example for knowledge based expert systems.

The following paragraphs introduce similar attempts in the literature to produce evaluation systems that have tried to cover the basic requirements of evaluation systems. However, these studies did not exhibit the demanded feature of being generic and comprehensive.

A study [Lemon and Christian, 1991] discussed the development and operation of an application of micro-computers in the prediction, management and monitoring of productivity on job sites using the expert opinions of construction personal. A method of calculating a global productivity index for construction job sites and determining critical areas was discussed.

A computational approach [Teicholz, 1993] was developed to calculate the final cost and budget of a construction project, which is based on the data normally developed by a cost system during the life of the project. The Author argued that the function of generating cost forecasts were lacking in most cost systems. The presented algorithmic approach had been tested using the data from 121 completed construction projects. The proposed method was compared to two other methods and was found to be superior in accuracy, timing, and stability. The forecasting method, sliding moving average, is general in its

approach and may be useful for other situations in which predictions of limited duration time-series data are desired.

Another research [Abudayyeh and Rasdorf, 1993] designed and developed a prototype of an automated cost-and schedule-control system that is based on the work-packaging model and that uses bar coding in its data-acquisition component. This paper discussed the prototype's capabilities and components and illustrated how the system is used in controlling cost and schedule of a study case based on an actual construction project.

A study [Russell and Fayek, 1994] described a schema to perform automated interpretation of daily site records, to identify activities experiencing difficulties, to identify the sources of these difficulties, to identify the types of problems resulting, to find corroborating information from the daily site record, to validate the causes of these problems, and to suggest likely corrective action. A framework is presented wherein each component of the analysis scheme is defined. This framework includes a set of user-assigned activity-interpretation attributes, a set of problem sources, and a set of corrective actions. Expert rules are used to link these components, and fuzzy logic is used to define the imprecise relationships that exist between them. A prototype system has been developed to implement and test the scheme.

A project control system was developed [Ibbs and Abu-Hijleh, 1991]that utilizes the software technology of object-oriented programming to allow for more flexible exception reporting and variance analysis. Specifically, a system user can modify exception thresholds, generate a number of different reports to individually sort production and cost performance, combine reports to study intersection effects and conduct some variance analysis to determine causal relationships. These analyses can be conducted from different time perspectives (this period, cumulative to- date, and forecast remaining), and with integration of cost and time packages.

This paper introduces a management system to evaluate performance of construction projects during the control phase. This system utilizes control ratios at project micro level to achieve proper integration between cost and time, and automates the problem detection procedure using backward chaining mechanism. The system utilizes the work breakdown structure of Masterformat as a basis for a systematic evaluation of construction projects**.** Moreover, Masterformat allows the use of cost estimating manual [Means Building Construction Cost Data, 1991] to collect and organize standard values of the control ratios. Means cost data offers a cost estimate in the same format and at the same level of detail as Masterformat. The system compares the individual line items of the contractor's costs to corresponding budgeted values obtained from Means. This provides a rapid, yet accurate evaluation of the project's cost.

2. CONTROL RATIOS

The mechanism of this analysis [Eldin, 1987] is set to be triggered only when an overrun situation is detected in labor costs. An overrun situation can be identified by the key ratio of labor cost per work unit ($/Q) when comparing its actual value to its budgeted value. If the actual value is greater than its budgeted value, a cost variance is expected and other control ratios need to be examined in order to identify the immediate cause of such a variance.

A cost overrun on any item can be the result of one of two causes or a combination of them. These causes are: low productivity when labor utilization is not attained at the planned efficiency; and higher labor costs than allowed in the budget. Identification of the cause of the overrun can be achieved by examining appropriate control ratios. Productivity problems are tested by the man hour per work unit ratios (Mhr/Q). If the product of dividing the actual value by its budget value is numerically greater than one, a productivity problem is detected and the magnitude of the deviation is a measure of the severity of the problem. Similarly, overruns caused by labor costs can be detected using the cost per man hour ratio ($/Mhr) in the same manner.

If the labor cost is identified as a cause for an overrun, the crew mix ratio and the crafts rate ratio need to be examined to determine the type of corrective action required. The crew mix ratio and the crafts rate ratio are expressed as $[\sum(N_a*R_b)/\sum(N_b*R_b)]$ and $[\sum(N_b*R_a)/\sum(N_b*R_b)]$, where N_a and N_b are the actual and budgeted number of men in a crew, while R_a and R_b are the actual and budgeted craft's rates. Forecast, variance, and performance index of labor costs were described as follows:

$$\text{Forecast} = Q_B \left[(\$/Mhr)_A * (Mhr/Q)_A \right] \tag{1}$$

$$\text{Variance} = Q_B \left[((\$/Mhr)_B * (Mhr/Q)_B) - ((\$/Mhr)_A * (Mhr/Q)_B) \right] \tag{2}$$

$$\text{Performance index} = ((\$/Mhr)_B * (Mhr/Q)_B) / ((\$/Mhr)_A * (Mhr/Q)_A) \tag{3}$$

Where A, and B subscripts denotes the actual and budgeted values respectively; Q is the total quantity in the work item.

3. MASTERFORMAT

Masterformat [Masterformat, 1988] is a system of numbers and titles for organizing construction information into a regular, standard order or sequence. It is produced jointly by the U.S.A Construction Specifications Institute (CSI) and Construction Specifications Canada (CSC). It incorporates a complete organizational format for project manuals by

including bidding requirements, contract forms, and conditions of the contract in addition to a format for specifications.

The specification titles and numbers in Masterformat are organized into sixteen basic groupings of related construction information called "divisions". Each division is identified by a fixed number and title. The divisions are the basic framework of Masterformat and they indicate the location of the subordinate elements of the system. Within each division specifications are written in numbered "sections" each of which covers one portion of the total work or requirements. Masterformat provides a standard system for numbering and titling these sections. The first two digits of the section number are the same as the division number.

Masterformat identifies three levels of detail for a specification section—broadscope, mediumscope, and narrowscope. Broadscope titles are for broad categories of work and provide the widest latitude in describing a unit of work. Mediumscope titles cover units of work of more limited scope. Narrowscope titles are for use in covering extremely limited and very specific elements of work. Maserformat provides five digit numbers only for the broadscope and mediumscope section titles. Unused numbers are available between mediumscope numbers to permit assignment of numbers to selected narrowscope titles needed to accommodate individual project requirements. A general description of the coverage of each broadscope section is provided opposite the listing of titles. The broadscope explanation together with the list of associated mediumscope and narrowscope titles provide an understanding of the scope of the broadscope section.

3. EVALUATION SYSTEM

This paper describes the utilization of backward chaining mechanism to evaluate the performance of construction projects. A prototype was introduced to demonstrate the design and development of the system on concrete division of Masterformat.   The organizational concept of construction project introduced by Masterformat was employed to structure the analysis process. Thus, systematic and generic system is developed to evaluate the performance of projects. Rules were used to represent the project organizational concept of Masterformat as the system knowledge base. The combination of these rules contains knowledge and reasoning required to thoroughly analyze project. Backward chaining control procedure was used to manipulate the knowledge.   A schematic diagram of the system is shown in Fig. 1.

Quantitative comparisons between actual and budgeted data were performed at the lowermost level of the project work breakdown structure. These work items represent the terminals "dead ends" of Masterformat project structure. Terminals could be at broadscope, meduimscope, or narrowscope levels according to the scope of the project. Direct costs of terminal work items including labor, material, and equipment costs can be

directly monitored at this level. This level represents the micro level of construction projects. Project tracking at micro level achieves integration between time and cost. Previously, control ratios were developed [Eldin, 1987] to evaluate labor cost through evaluating constituent elements of Labor Productivity Rate (LPR), and Labor Crew Cost (LCC). If either elements show overrun, labor cost is affected adversely. Man-hour per work unit (Mhr/Q) and cost per man-hour ($/Mhr) are the control ratios to measure LPR and LCC respectively. Similarly, the current study developed ratios to evaluate material and equipment performances. Material cost can be monitored by evaluating Material Consumption Rate (MCR) and Material Purchase Cost (MPC). The quantity of material consumed per work unit (q/Q) and purchase cost of unit of material ($/q) were utilized to evaluate MCR, and MPC respectively. Equipment cost is affected by Equipment Production Rate (EPR) and Equipment Hiring Cost (EHC). Equipment-hour per work unit (Ehr/ Q) and cost per equipment-hour ($/Ehr) are the ratios that evaluate EPR and EHC respectively. Comparing budgeted and actual values of these ratios using rule format evaluates performance at micro level. The determinations output of comparisons enable an overall evaluation of the terminal work item. Control ratios provide data to generate forecasts, determine variances and performance indices, and visualize trends . Forecasts, variances, and performance indices of material, equipment and total terminal work items are calculated as follow:

Equipment cost:

$$\text{Forecast} = Q_B ((\$/Ehr)_A * (Ehr/Q)_A) \tag{4}$$

$$\text{Variance} = Q_B [((\$/Ehr)_B*(Ehr/Q)_B) - ((\$/Ehr)_A*(Ehr/Q)_B)] \tag{5}$$

$$\text{Performance index} = ((\$/Ehr)_B*(Ehr/Q)_B) / ((\$/Ehr)_A*(Ehr/ Q)_A) \tag{6}$$

Material cost:

$$\text{Forecast} = Q_B ((\$/q)_A*(q/Q)_A) \tag{7}$$

$$\text{Variance} = Q_B [((\$/q)_B*(q/Q)_B) - ((\$/q)_A*(q/Q)_B)] \tag{8}$$

$$\text{Performance index} = ((\$/q)_B*(q/Q)_B) / ((\$/q)_A*(q/Q)_A) \tag{9}$$

Work item cost:

$$\text{Forecast} = Q_B [(\$/Mhr)_A*(Mhr/Q)_A + (\$/Ehr)_A*(Ehr/Q)_A + (\$/q)_A*(q/Q)_A] \tag{10}$$

$$\text{Variance} = Q_B [((\$/Mhr)_B*(Mhr/Q)_B + (\$/Ehr)_B*(Ehr/Q)_B + (\$/q)_B*(q/Q)_B) -$$
$$((\$/Mhr)_A*(Mhr/Q)_B + (\$/Ehr)_A*(Ehr/Q)_B + (\$/q)_A*(q/Q)_B)] \tag{11}$$

$$\text{Performance index} = ((\$/Mhr)_B*(Mhr/Q)_B + (\$/Ehr)_B*(Ehr/Q)_B + (\$/q)_B*(q/Q)_B) /$$
$$((\$/Mhr)_A*(Mhr/Q)_A + (\$/Ehr)_A*(Ehr/Q)_A + (\$/q)_A*(q/Q)_A) \tag{12}$$

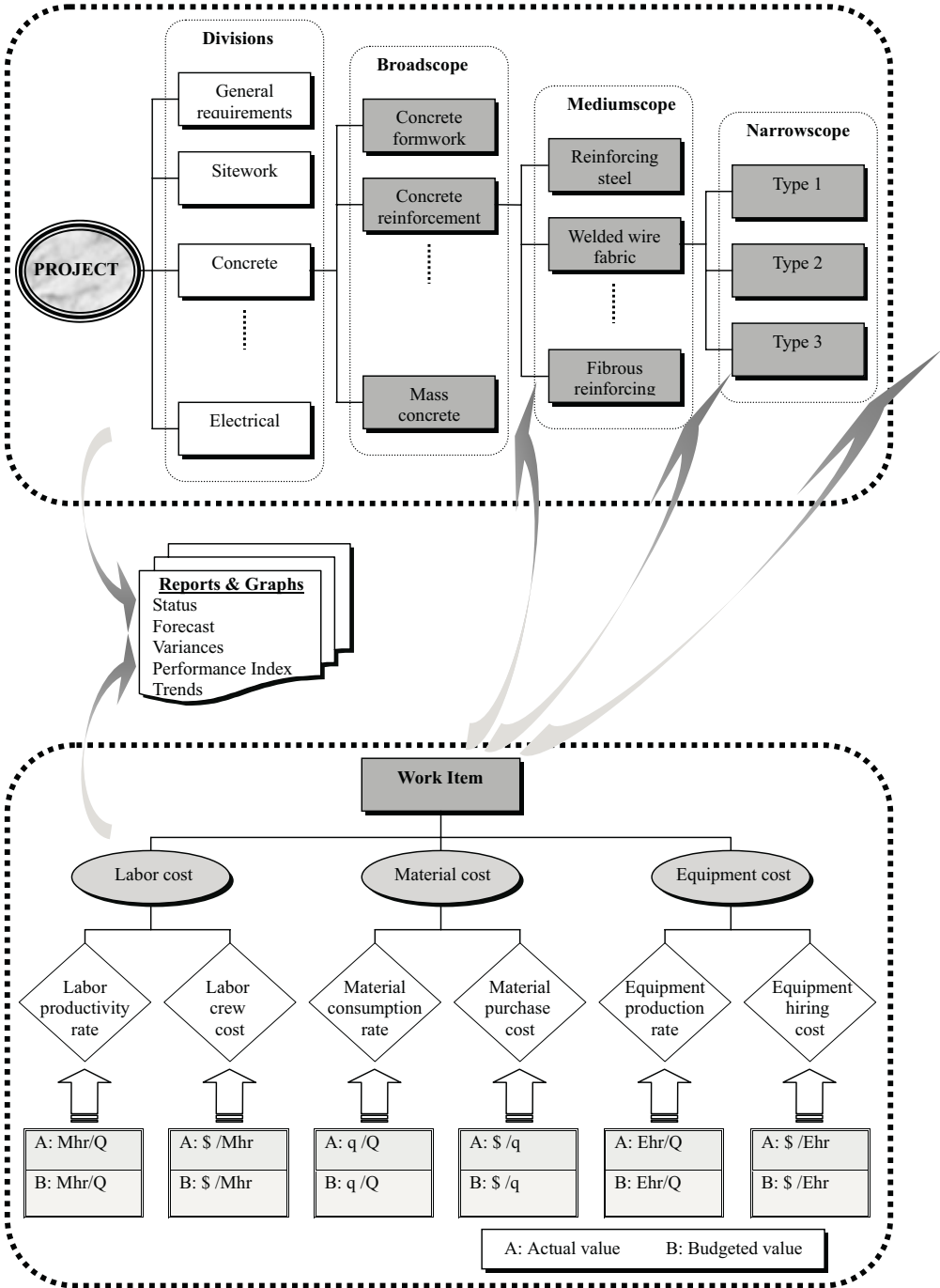the project or any subdivision thereof can be evaluated.

Fig. 1. A Schematic Diagram of the Evaluation System.

Once determinations are performed on terminal work items which have no further subdivisions in Masterformat, Evaluations at upper levels "macro levels" of the project work breakdown structures can be performed. Backward chaining mechanism propagates the effects of evaluations at terminal work items upward through the project breakdown structure to make evaluation at any desired work item. Thus, evaluations can be easily performed for any groupings of work items and ultimately for the whole project. In addition, forecasts can be generated, and variances and performance indices can be determined.

Thus, the system starts with a user's inquiry about the status of a work item or the project as a whole. The system begins with a hypothesis about the request and works backward checking to see if the facts support the hypothesis or not. Once facts are determined at micro level, backward chaining asserts or negates the initial hypothesis to determine the status of the requested work item. This process is adequate to make determinations regarding the status of a work item at any level.

If the status of project is requested, backward chaining can evaluate this request without having to evaluate some rules at micro level since the first evaluated negative-status cost element will suffice to indicate negative status of project. However, micro-level rules should be completely evaluated at any situation to enable computing variances and forecasts at any desired level. Thus, backward chaining was performed using four goals. The first goal is confined to the status of MCR, MPC, LPR, LCC, EPR, and EHC. This insures that all rules are evaluated and consequently all basic calculations necessary for upper levels are done. The second goal is concerning material cost, labor cost, and equipment cost. This insures the availability of a complete report about these three cost elements. The third goal is set at the terminal work item. Finally, the fourth goal is the project as a whole. This procedure insures the availability of a complete performance report at all project levels.

4. SYSTEM PROTOTYPE

The backward chaining mechanism was implemented using an expert system shell of Kappa version 2.1. The domain of this prototype involves the concrete division of Masterformat which is assigned digits 03 in Masterformat and assigned the letter C in this system. Fig.2 shows partially the work break down structure of concrete with three digits to the right of letter C to be assigned to broadscope, and meduimscope levels. Fig.2 shows ten items at broadscope level with three mediumscope items underlying the first item. The unassiged numbers available between the first two meduimscope items are used in this system to designate two narrowscope items underlying the first mediumscope item of C110. These two items, C111 and C112, represent terminal work items since

Masterformat shows no subdivisions thereof.   However, working at micro level of C111which represents Metal pan formwork, needs expansion to subordinate cost elements of material, labor, and equipment denoted as C111M, C111L, and C111E respectively. Further, these three cost elements are divided to cost elements of MCR and MPC for material, LCC and LPR for labor, and EHC and EPR for equipment. The title of C111 and the other titles in Fig. 2 are represented in Kappa by objects with a number of slots defined for each to store object's attributes. For instance, the status of C111 is stored in an object-slot pair of "C111:STATUS" which takes up text values of either "O.K" or "not O.K" to describe whether a potential problem exists or not.

The system starts with an inquiry about the status of an object, C000 for instance. The mechanism proceeds with reasoning that is represented by the rules till the project micro level. The system prompts user to enter ratios' values of this project as shown in Fig.3. These values are stored in slots of the objects at the rightmost level of Fig.2. Consequently, determinations are performed and results are propagated back to make evaluations at higher levels of the project. Outputs of evaluations including status, variance, forecast, and performance index are stored in their respective slots. Then, a user can obtain these values by simply clicking over the required object. A window appears, as shown in Fig. 2 for C111, showing a report including the name of the work item, status, variance, forecast, and performance index. Moreover, the system allows users to store subsequent outputs of performance indices in a multiple-valued slot to enable monitoring the trend of subsequent evaluations of a work item. A plot of the trend can be monitored by pressing OK button of the window shown in Fig. 2. The trend plot of C111 shown in Fig. 4 represents five subsequent evaluation outputs. Data presented in Table 1 include, variances, forecasts and performance indices of material, labor, equipment and the whole work item for these five evaluations. Calculations are based on equations 1 till 12.

A very helpful feature that Kappa offers is the explanation facility. This enables user verify the way the system reached an evaluation. Fig.5 shows the output for a user's inquiry to explain the status of C111. The system replies that the negative status of C111 is due to the negative status of either material, equipment, or labor. The posted window has an explain button to allow user proceeds with more inquiries. Another inquiry was made about the material cost of C111 which resulted in a negative status. This output is attributed to a negative status of either MPC or MCR. A third inquiry was made regarding the status of MPC. A reply was posted to indicate a negative status of MPC since the actual cost of material unit is greater than the budgeted cost. This reply represents one direct cause of the problem which might be due to more than one cause. Likewise, other causes can be detected using the explanation facility.

5. CONCLUSION

This paper introduced a prototype for a management system to evaluate performance of construction projects during the control phase. This system utilized control ratios at project micro level, and automated a problem detection procedure through a backward chaining mechanism. The system utilizes the work breakdown structure of Masterformat which provides titles in a logical sequence for almost all conceivable specification sections that might be required for a construction project. This set a basis for a systematic evaluation of construction projects. In addition, Masterformat titles and numbers can serve as the basis for a system for construction costs estimating and accounting which represents a vital component of evaluation systems. Thus, this study presented a prototype for a potentially user-friendly, generic, and standard system that can be used to monitor construction projects.
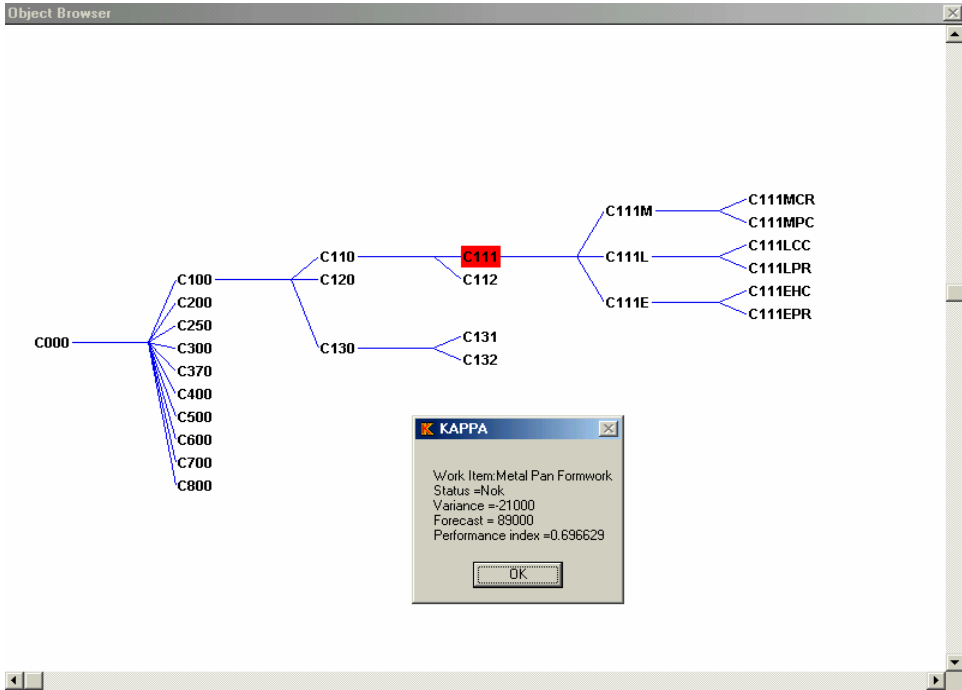
Fig. 2. Partial work breakdown structure of Concrete division in Masterformat.

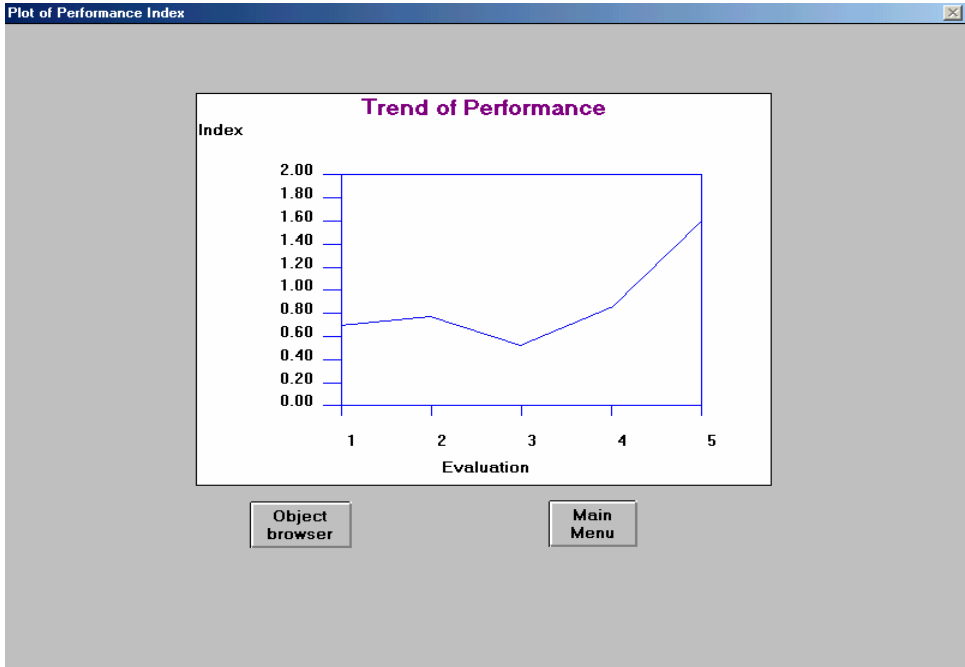Fig. 3. A sample of input data screen.

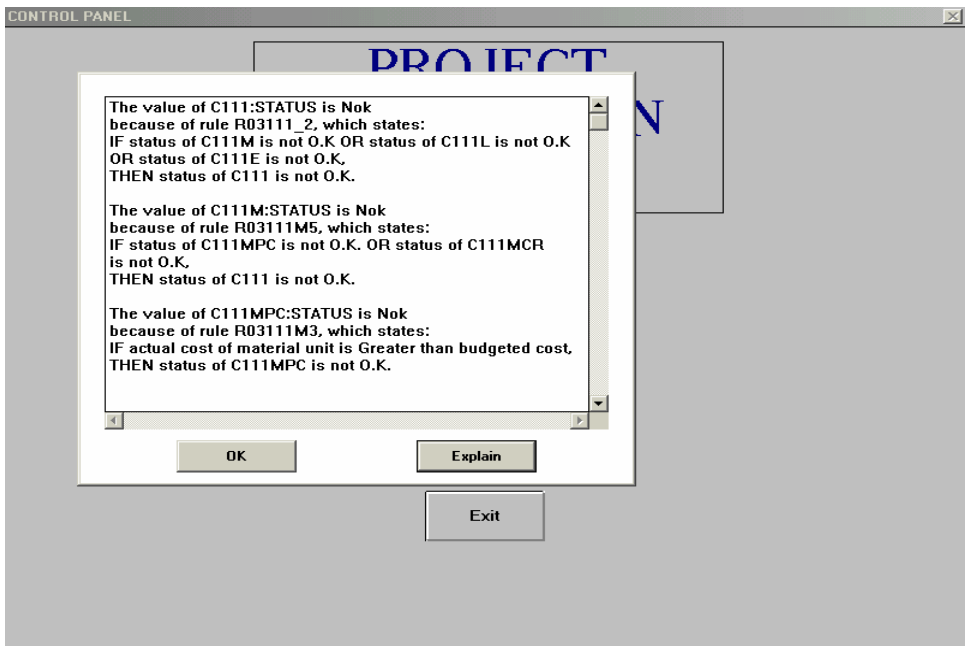Fig. 4. A plot of performance index values of five subsequent evaluations

Fig. 5. The output of a user's explanation inquiry.

Table 1: Forecasts, variances, performance indices for five subsequent evaluations.

Cost element	Evaluations									
	1		2		3		4		5	
	A	B	A	B	A	B	A	B	A	B
Material consumption per unit of work	9	7	3	5	4	6	7	2	3	3
Cost of unit of material	3	2	4	3	6	1	8	3	5	7
Man-hour per unit of work item	4	4	6	2	3	7	4	5	9	2
Cost of man-hour	5	5	8	3	9	2	2	2	1	8
Equipment-hour per unit of work	7	7	5	7	2	4	6	6	7	4
Cost of equipment-hour	6	4	8	8	5	3	3	9	2	6
*Equipment cost forecast	42000		40000		10000		18000		14000	
*Equipment cost variance	-14000		0.0		-8000		36000		16000	
Equipment performance index	0.6667		1.4000		1.2000		3.0000		1.7140	
*Labor cost forecast	20000		48000		27000		8000		9000	
*Labor cost variance	0.0		-10000		-49000		0.0		14000	
Labor performance index	1.000		0.125		0.518		1.250		1.777	
*Material cost forecast	27000		12000		24000		56000		15000	
*Material cost variance	-7000		-5000		-6000		-10000		6000	
Material performance index	0.5185		1.2500		0.2500		0.1071		1.4000	
*Work item cost forecast	89000		100000		61000		82000		38000	
*Work item cost variance	-21000		-15000		-87000		26000		36000	
Work item performance index	0.6966		0.770		0.524		0.853		1.605	

A: Actual cost

B: Budgeted cost

*: Values calculated for a total quantity of 1000 square meters of C111.

6. REFEERNCES

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