MEASURING CONSTRUCTION PERFORMANCE USING A COMPREHENSIVE APPROACH

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ABSTRACT: This study presents an investigation and development of a construction performance measurement model. A literature review indicated that researchers have offered a variety of models in an attempt to examine construction performance but existing models may not be adequate to embrace a comprehensive measure. Literature reviews were used to develop a working structure for the development of a new conceptual model.

There are generally four areas by which individual performance may best constitute overall construction effectiveness: Time, Cost, Quality and Safety. Various conceptual and application models are reviewed and their limitations are highlighted. A psychology-based measurement mechanism (ProMES) is proposed as the modelling environment. Basic components of the model were determined by questionnaire surveys and a review of literature. It was concluded that project progress variation, time delay, variances of labour and material cost, plant utilisation, quality procedure approval, non-conformance of products, and accident occurrence and investment index will be used in the evaluation model as performance indicators.

To address the issues of reliability, the model was computerised using Visual Basic on objective-hierarchical mechanisms and implemented in five participating construction sites. Results from a comparative study between the model and subjective measurement indicated that an output based on the newly developed model produces significantly better results.

KEYWORDS: Construction Performance, Performance Measurement, Comprehensive Approach, Project Performance

1. INTRODUCTION

Construction sites are temporary production units in construction organisations. Variations and changes in the construction site environment during the production period may impinge upon the performance and productivity of construction projects as a whole and bear obvious and significant effect upon a contractor's profitability. Overall project planning sometimes may not reflect what actually happens during the construction stage, as it is meant to do. Although, during the pre-contract process, the construction industry employ complex planning tools, there is evidence that most on-site production makes use of simple, just-in-time techniques in solving problems associated with day-to-day job-site activities (Cole: 1991 and Cohenca-Sall, Laufer, Shapira, and Howell: 1994). Numerous unknowns which are resolved only as the planned event approaches, such as, availability and supply of resources, make it difficult for detailed construction planning to be completed far in advance of construction activities. In practice they are often only finished prior to the onset of work at the crew level. These dilemmas cause serious concerns for construction planners in exploring and understanding the consequences of unanticipated conditions during an actual operation stage, and often result, to a lesser or greater extent, in delay and reduction in profit and reliability.

In assessing its work performance, the construction industry adopts various key performance indicators. The traditional indicators are completion time, cost, and quality of construction projects. Alfeld (1988), suggested that overall performance on construction sites may simplistically be attributed to three main dimensions; quality, in terms of accuracy of jobs, workmanship, degree of skills; quantity, in terms of productivity, time-constraints, ability to meet planned schedule; and resources, in terms of availability of materials, tools, equipment and manpower. Contractors are believed to perceive performance according to their project goals and organisation's objectives (Cole, 1991). Some may also develop their own measure as far as their particular jobs and resources are concerned. Many have developed performance measures solely based on their construction management experiences.

The objectives of this paper is to describe a methodology used in developing an evaluation model where project managers or construction practitioners can use their own project variables to assess project performance from the start of the construction period through to completion. These variables are established specifically for each project and result from management's own preference based on intensive brainstorming and personal experience. It is believed that the model methodology can provide an enhanced control tool for project managers.

The paper also gives a brief review of the definitions, measurements and evaluations of construction performance through literature. An overview of different perceptions from researchers and practitioners regarding the terminology is provided. Key performance indicators applied by construction practitioners are described.

2. APPROACHES TOWARDS CONSTRUCTION PERFORMANCE

It could be said that researchers tackle performance evaluation problems through various measurement systems. Of these, three main approaches were found to be most in use by construction-related researchers and the industry in practice, namely: single-unit measures, integrated measures and organisational effectiveness. Empirical models were found to have been proposed in an attempt to quantify managerial and technical performance in construction. As well as contractors' attitude towards the term performance, different researchers use different terminology for similar concepts. Accordingly, it is emphasised that the term construction performance in this context should not conflict with efficiency of construction process engineering such as the structural performance of a reinforced concrete beam or a tower crane and the likes of those.

2.1 Single unit measures

During the late 70's until the beginning of the 90's, the majority of construction performance measures involved some measurement of the consequence of work effort put into job-site activities, most of which are concerned with productivity of the workforce. The performance measures in this approach can be obtained through a single unit appraisal in respect of project specific or task-oriented objectives.

There has been evidence of continuous research and development in an attempt to improve single unit performance measurement through a more systematic approach and accurate measures, particularly in the aspect of measuring and applying labour productivity as an indicator of construction performance (Thomas, Sanders and Horner: 1988, Thomas and Kramer: 1988,Talhouni: 1990, Randolph and Napolitan: 1995, Randolph and Raynar: 1997, Portas and AbouRizk: 1997). Apart from that, a considerable number of more improved models have been developed in order to obtain more accurate and convincing dimensions of construction productivity through the use of modern computer-based applications such as regression analysis, neural networks and genetic algorithms (Benjamin, Babcock, Yunus, and Kincaid: 1990, Chao and Skibniewski: 1994, Flood and Nabil: 1994, Thomas and Sakarean: 1994, Kaming Ogunlana, Vidogah and Olomolaiye: 1995, Boussabaine: 1995, Boussabaine and Duff: 1996. Portas and AbouRizk: 1997).

Despite the fact that a single unit measure might prove to be less crucial to construction performance assessment at a higher level as a whole, the implication of such a method remains profitable for use as the key determining performance factors in the industry.

2.2 Integrated measures

Researchers have questioned the adequacy of the single unit method in relation to its performance estimates. Single unit measures might not properly reflect the actual level of how a construction project has performed in a broader sense. An integrated assessment model that enables users to have a broad perception of every aspect of effectiveness is the factual answer to a proper measurement and would be most profitable in terms of appropriate reaction and a probable remedy. Planning, design, procurement, construction, operation and maintenance are processes which practitioners believe should be harmonised and continuous. Nevertheless they are often separated into parts. The industry's discipline makes it difficult to identify critical factors towards success since each party responsible for a particular process has their own objectives and often seeks to achieve their own success. A significant amount of effort is needed to gather information concerning as many extensive aspects as possible and present the industry with a comprehensive picture of overall performance. It was believed that this more elaborate approach could provide the industry with a more reliable solution of better performance evaluation. Recently, researchers and practising engineers have paid considerable attention to alternative approaches to project performance integration. It is also generally accepted that project performance may be enchanced when the interaction between each influential indicator occurs positively on a regular basis.

Integrated units can sometimes be seen as a more apparent means of performance evaluation resulting from a combination a number of unit performances assessed individually. In other words, integrated unit performance may well be another reflection of single unit measure. For instance, performance of concrete plant in one project is measured by weighting productivity of labourers involved and efficiency of the concrete mixer together with concrete-mix type, any of which may also be measured separately.

2.3 Organisational effectiveness

It is a common belief that targeted performance is dependent upon how and in what direction a construction organisation as a whole wants to perform. In other words, correct measurement of performance may rely heavily on what people responsible for overall success of an organisation want to measure. These measures are concerned mainly with achieving the ultimate goals related to objectives established prior to commencing the project. Thus, obtaining the correct measures throughout a project life cycle becomes an important step in the performance improvement and assessment process of organisations. Researchers have offered a variety of models for examining construction organisational effectiveness (Dias and Ioannou: 1996, Handa and Adas: 1996)

It has been shown that much of work has been done by researchers in the field of construction performance measurement and evaluation. As a result a number of different techniques and various evaluation models have been developed for the purpose of the performance measurements. Construction sites endure dynamic situations in which people and resources are involved in constant changes in their working movement. Good team performance has been claimed to be a crucial component for the success of operation-based organisations working in today's technologically developing environment. In common with other manufacturing industries construction exercises in a specific domain. Along with other operational-based organisations, construction also shares an equivalent attribute as an industry operating in a unique, ever-changing environment.

The performance definition in this current research is the achievement of both efficiency and effectiveness with regard to project goals. It was observed that the methods of integrated units and aspects of organisational effectiveness indicated advantages over detailed models and therefore their concepts can be used as the basic structure for the development of performance modelling. To be precise, the development of a performance assessment model should focus on integrated control of human factors and machinery, both of which bear significant influences on overall output of their production.

3. METHODOLOGY

The model uses the mechanism of ProMES (Productivity Management and Enhancement System) as a performance evaluation vehicle. Developed by an American psychology researcher, the ProMES approach provides management with a unique view of organisational productivity (Pritchard, 1995). This approach to measuring construction effectiveness has several unique features. It combines all the functions of a unit into a single index of productivity that reflects differential importance, allows for direct comparison of different units, identifies priorities for increasing productivity, and provides for aggregating measures to higher levels of the organisation.

ProMES model basically works on different indicators identified as having impact on construction projects as a whole. By combining levels of outputs of these indicators, based on individual relationship towards project performance uniquely specified by project managers at the outset of evaluation, ProMES approach would provide performance answers. It would also allow cross-units examination since individual outputs are standardised into a similar basic scale (-100 to +100).

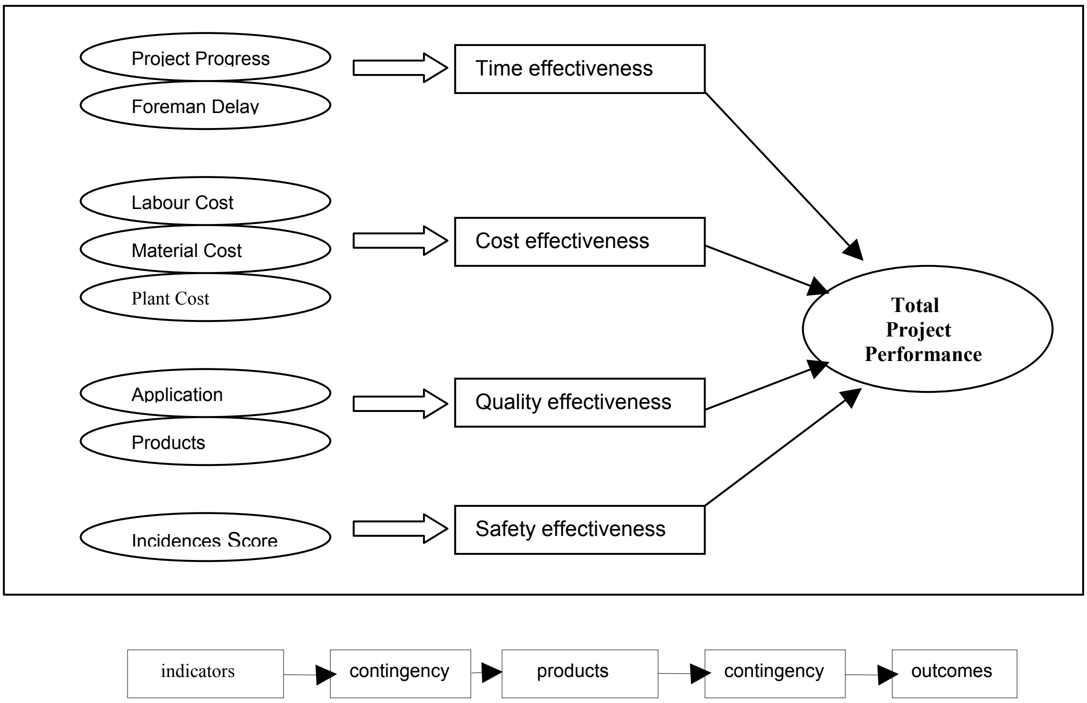
The methodology for this research includes four basic steps: (1) Identification of key project variables or product areas; (2) Identification of performance indicators for product areas; (3) Establishing relationship between product areas and performance indicators; (4) Performance Modelling. Figure 1 illustrates a structure for the development of the methodology in respect of contractors' on-site performance evaluation.

3.1 Identification of Key Product Areas

Measuring all parts of performance is vital to the success of the methodology. Understanding the indicators and measuring every important part of performance should be accurately and completely accomplished. Complicated measures might be appropriate as long as personnel understand them well enough to know what behaviour positively and negatively affects each indicator. Only directly measurable parameters, which might provide an insight into how construction performance has been affected, are considered. A few measures for some indicators might not be readily available and thus can be newly developed. Any identified parameters may not be comprehensive measures of complete construction performance, but they should reflect concerns arising from the main construction objectives involved.

Before stepping forward to an examination of a performance analysis framework, it is therefore necessary to develop an understanding of the multidimensional nature of performance. Clear objectives of performance and future application have to be addressed and common understanding has to be shared. Indicators of construction success must be identified and agreed among project participants. Historically, Cost, Time, Quality and Safety are the factors considered as being the most crucial to the success of construction projects. Most literature in recent construction management research also works under the same domain of these terminologies. They are therefore assigned as the main product areas.

Figure 1 General performance measurement model



A pilot study by Sinthawanarong (1997) suggested that both contractors and designers have a similar perception of the existence of the potential benefit in measuring construction performance. The same study, conducted by interviews, gave an insight into the availability of data and how pre-identified performance indicators would fit as components into the proposed model. It was found that most on-site construction data, such as safety records and project completion time, were applicable for use in the model. Where some product areas were newly developed for use in this prototype model, efforts were made to modify such data to an appropriate format.

3.2 Identification of Performance Indicators

A few measures for some indicators were not readily available and thus are newly developed. These are; Percentage of passed quality applications, Percentage of non-conformance of the product, Safety cost and accident scores, and Foreman Delay Survey scores. Although these parameters are merely comprehensive measures of construction performance, they are useful images, reflecting insights into the main purpose of construction.

The next task centred on ascertaining the product areas of construction projects and indicators that influence performance, based on the premise that individual projects differ according to the degree of these product areas measured in terms of the indicators.

The most difficult part in this research was to sort out precisely the factors, which can delineate the differences in contractors' performance. In determining the indicators, previous studies served as guidance in selection. At an early stage of the research it was decided to include as many factors as possible, as long as they were considered as indicators to the performance behaviour. However it was found that a number of them were not obtainable or impractical for use in construction projects. As a result the model removes factors that were considered to be insignificant. Development of the eight indicators with regard to project monitoring and success evolved through a literature survey and the previous survey. The performance indicators representing outputs in respect of Time, Cost, Quality, and Safety performance are presented as follows:

- *Time performance: Project Progress*

The indicator is defined as the completed gross floor area in square metres (m^2) divided by the total construction floor area specified on the outset of the model input. (%)

- *Time performance: Foreman Delay Survey*

The indicator is defined as the total number of operative delay hours as a result of identified causes, divided by the total number of operative working hours according to the master plan. (%)

- *Cost performance: Variance of Labour*

The indicator is defined as the increase or decrease in the budget in respect of labour cost in an evaluation cycle in British pounds (% +- Cost)

- *Cost performance: Variance of Material*

The indicator is defined as the increase or decrease in the budget in respect of material cost in an evaluation cycle in British pounds (% +- Cost)

- *Cost performance: Variance of Plant*

The indicator is defined as the increase or decrease in the budget in respect of plant usage expenditures in an evaluation cycle in British pounds (% +- Cost)

- *Quality performance: Application for Quality Application*

The indicator is defined as the implication of the extent to which the quality control inspection meets specified criteria. It is presented in the form of percentage of quality control inspections passed at the first time of the approval. (%)

- *Quality performance: Non-conformance of the Product Score*

The indicator is defined as the implication of the extent to which the constructed products are completed without a need for correction. It is presented in the form of a Cause-Effect score calculated from the frequency of non-conformance cases modified by possible causes. (%)

- *Safety performance: Safety Cost and Incidence Score*

The indicator is defined as the implication of the extent to which investments cost in safety and direct accident costs are incurred. It is presented in the form of a combination of accident occurrence index and total cost of safety.

3.3 Establishing Relationship between Indicators and Product Areas.

There are two contingencies in the integrated model; the relationship between product areas and the overall construction performance, and the relationship between indicators and the individual area performance. The former may be established by using a set of questions with regard to the degree of current significance of the product areas to the construction project during each evaluation cycle. The latter relationship is initially drafted in graphical format by management. Both contingencies share the same modification attributes, which imply the relationship between performance indicators and product areas.

The contingencies uniquely developed were based on literature in the product areas' domain: Time, Cost, Quality and Safety. A number of assumptions were made about the degree to which construction project or specific tasks were considered as successful and the actual magnitude of performance associated with them. It should be noted indicators such as Safety Investment and Incidence Score were newly developed and might be misleading if implied in other uses. The developments of the contingencies however have no negative effect on the methodology, bearing in mind that all components are flexible and may be rebuilt according to any project variations.

The purposes of establishing as an empirical set of contingencies were to: (1) validate the applicability of the model to construction projects; (2) integrate them into the model as active components for reference; (3) investigate the relationships between products areas and their associated performance indicators; and (4) to check understanding of potential users towards practical applications.

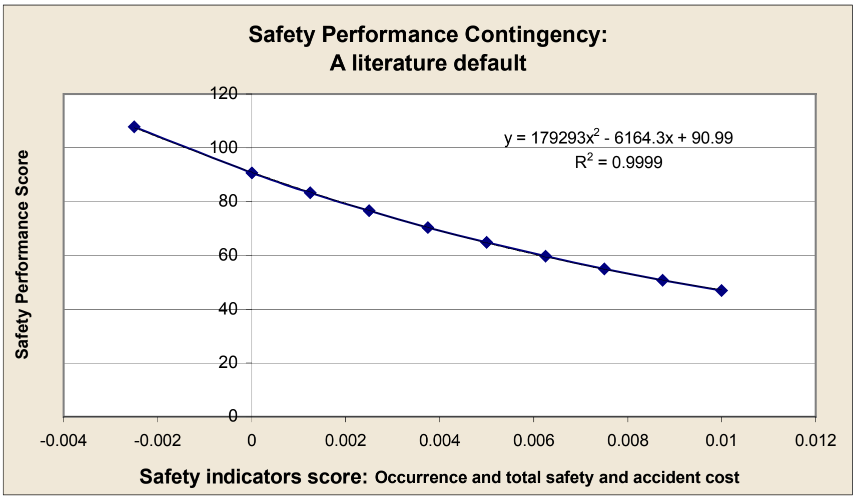


Figure 2 Safety Performance Contingency

The performance effectiveness score ranges from –100 to 100. When assigning an indicator value on y-axis at Nil, the corresponding performance would imply "neither good nor bad" Performance at 100 and at –100 would imply "Excellent" and "Very poor" performance, respectively. Accordingly, the range of Maximums and Minimums of the associated performance values will be indicated on the x-axis. An example of performance contingency in relation to Safety is given in Figure 2.

3.4 Performance Modelling

The methodology of the development of the package involved guiding the user to design, measure and modify objectives of a project, and link them to effectiveness scales. The developed package was separated into modules, as shown in *Figure 3 Structure of the performance model*. The calculation module is only completed in the Microsoft Excel worksheet and is implemented in a separate function. Within this platform the main function for all calculations in the model has been included, along with default literature values of the performance contingencies. The method of developing the package was by the use of prototypes. One advantage of Microsoft Visual Basic is that it is an effective tool for use with a prototyping development strategy because applications may be built relatively fast.

3.4.1 Structure of the Package

The main structure of the model was composed using an Excel worksheet, which is a user-defined input cell that normally defines most calculations and captures most components of the input data. The defined worksheets generate a general form of the model with various numbers of input format, as well as graphical presentations based on designated worksheets. The user interface from the Visual Basic Editor then calls the worksheets to function as specified by the *User Code,* then sends the corresponding output back to the user interface accordingly. If requested, feedback presentation may also be presented within the active worksheet.

The performance measurement model allows a reasonable amount of flexibility to users. The idea is to give construction project personnel more control and freedom according to their project objectives. This is to say, instead of forcing users to rely on the literature values of contingencies, the package also offers them the opportunity to set up their own project criteria in the form of percentage contribution towards project success. Functioned as Microsoft Excel objects, contingency relationships set up earlier by users were allowed to be altered by only moving the pointers in their corresponding graphs upwards or downwards, thus enabling the results to be predicted from the corresponding calculated data. This function clearly provides the user with more control over the contingencies.

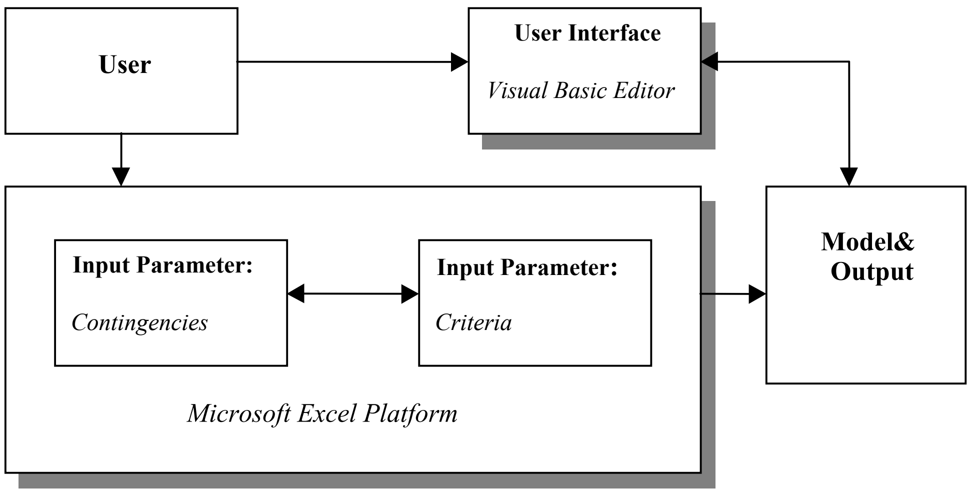


Figure 3 Structure of the Performance Model

The design of the user interface made use of interactive dialogue design provided on the Visual Basic editor, which shows how the menus and user interface operate. It should be noted that the interactive dialogue diagrams are only a partial description of the programme because the actual programme was Event-Driven. Short cut and speed keys were included, and a number of help menus have been integrated.

3.4.2 Implementation of the package

The actual coding of the package for the algorithm and data structures has been completed using a combination of Excel worksheet and Object code in the Visual Basic Editor. The consequence of such development has made it possible to successfully create a performance measurement package, which is convenient and flexible. The execution procedure of the package involves the following steps:

1. Defining importance of the product areas
2. Defining importance of the performance indicators
3. Defining contingencies for the performance indicators
4. Choosing and implementing calculation procedures
5. Presentation of output and feedback

3.4.3 Implementation of the User Interface

The package programme requirements and basic design criteria were discussed in the section 3.4.2. The implementation of the User Interface was subsequently described. The user interface developed should be familiar to anyone who has previously used a Microsoft Windows 95 programme environment. Basically both platforms are in a Mouse-Driven environment and most functions on the platforms are executed by clicks of the mouse, which is called an Event-Driven Environment.

3.4.4 Integration of Interface and Algorithms

Once the procedures of coding the algorithms, data structure and presentation in the Excel worksheet and the user interface had been designed, the next process was to integrate all components together to form a coherent package. The coding of procedures could be completed in two ways; by writing in the Visual Basic compiler or recording macros on the Excel platform. For reasons of simplicity and time constraints, the latter approach was chosen. The main advantage of using macros on the Excel platform, apart from rapid development, is that the main procedures can be accessed from main programme and alterations to data may be easily done via the user interface or Excel worksheet.

4. TESTING THE MODEL

To determine whether the new method of assessing or measuring construction performance produce significantly different outcomes from the subjective assessment on average, during the weekly evaluation cycle, all participating project managers in 5 randomly selected construction sites (A-C) were asked to rank the extent to which they believed each product area of Time, Cost, Quality and Safety, were performing by checking a box in a self-described nine-point scale. To achieve the comparison, the values taken from the project manager should correlate with the values taken from the model. The participating contractors were also asked to provide a percentage in respect of their project performance in the corresponding week.

The data was recorded and correlated with the rank that the developed model indicated they should have. These were determined by calculating the construction performance that an individual site normally produced in each product area. At 10% confidence level with 14 degrees of freedom, for a two-tailed test, the null hypothesis would not be rejected if the absolute value of t_o is below 1.76 ($t_{0\ 0.05=1.76}$). Testing at 5% confidence level ($t_{o\ 0.025=2.16}$), the null hypothesis can not be rejected when the absolute value of t_o are below 2.16.

The results over 15-week implementation period concluded that for the categories in which $t_0 > 2.16$, the two approaches yield different results. Most areas from most samples are significant with the exception of those from Time category for Site A and C. The statistical tests indicated that performance results measured by the developed performance measurement model are significant suggesting that the measure based on the approach produces statistically different results from subjective judgement. Since the new model provide more systematic performance measurement tools and a well-defined measure, compared to pure subjective assessment, using the approach to measure performance would be more beneficial.

5. CONCLUSIONS

The research established four key performance indicators for which conclusive integration would best reflect how well construction performs in terms of both project management and operational output itself. Eight performance indicators associated with the four key indicators have been established through literature surveys. By taking account of previous studies and practical applications in this area, the research has developed the likely relationships or so-called contingencies of certain levels of their outputs with probable performance levels. The contingencies shown in this research would be presented to the users as the default values so that some comparisons between the literature and the users' perception may be made. It should be noted that the model users would be able to alter such default values as appropriate to their work, when the model becomes fully functional. Along with the validation of the indicator-contingency, sample sets of some relationships between product areas and overall performance were explored through an opinion survey for the purpose of initial model development. Statistical results also indicated that performance as calculated from the model was more reliable that those measured from a subjective approach.

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