DEVELOPMENT OF KEY PERFORMANCE INDICATORS TO ESTABLISH THE BENEFITS OF 4D PLANNING

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Performance measurement has received considerable attention by both academic researchers and industry over a past number of years. Researchers have considered time, cost and quality as the predominant criteria for measuring project performance. In response to the Latham and Egan reports to improve the performance of construction processes, the UK construction industry has identified a set of non-financial Key Performance Indicators (KPIs). Following an increased utilisation of IT based technology in the construction industry and in particular 4D (3D+time) planning. A literature review reveals that a systematic measurement framework to evaluate the value of such systems at both quantitative and qualitative levels does not exist. The aim of this ongoing research is to develop a suitable measurement framework to identify and analyse key performance indicators for 4D applications. Two major issues have been addressed in this research: an absence of a standardised set of 4D based KPIs and lack of existing data for performance evaluation. This paper reports on the first stage of the research study for the identification of 4D performance measures. The ultimate objective of this research is to deliver project based 4D performance measures and to identify how project performance can be improved by the utilisation of 4D planning.

Keywords: 4D planning, information technology, performance measurement, value, visualisation

INTRODUCTION

Applications of Information Technologies (IT) are progressing at a pace and their influence on working practice can be noticed in almost every aspect of the industry. The potential of IT applications is significant in terms of improving organisation performance, management practices, communication and overall productivity. The thrust for improved planning efficiency and visualisation methodology has resulted into the development of 4D planning.

Visual 4D planning is a technique that combines 3D CAD models with construction activities (time) has demonstrated advantages when compared with traditional tools. In current practice, planners develop a sequential relationship between various construction activities on the basis of available 2D drawings and information. The traditional planning approach does not assist planners to consider the constructability issues during the advanced development of schedules. As a result such issues are left for later decisions on the site. In 4D planning project participants can effectively visualise, analyse, and communicate problems regarding sequential, spatial and

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temporal aspects of construction schedules and thereby rehearse construction progress in 3D at any time during the construction process. As a consequence, much more robust schedules can be generated to reduce rework and improve productivity. According to *Dawood et al. (2002)* 4D planning allows participants in the project to effectively visualise and analyse the problems since the sequencing of space and temporal aspects of the project are considered by visualising and communicating the project schedule. The industry based Key Performance Indicators (KPIs) that have been developed by the Department of Trade and Industry (DTI) sponsored construction best practice program (CBPP) are too generic and do not reflect the value of deploying IT system for construction planning and in particularly 4D planning. The key objective of this research study is to overcome the presence of a generalised set of KPIs by developing a set of 4D based KPIs at project level.

The Construction Industry Institute (CII) conducted research into the use of three-dimensional computer models in the industrial process and commercial power sector of AEC (architectural, engineering and construction) from 1993 to 1995 (*Griffis et al., 1995*). The major conclusions of the CII research include a reduction in interference problems; improved visualisation; reduction in rework; enhancement in engineering accuracy and improved jobsite communications. *Songer (1998)* carried out a study to demonstrate the use of 3D CAD technology during the project planning phase. The study focuses on the impact of using 2D and 3D technologies in the project schedule review. Songer's experimental results demonstrated that the use of 3D-CAD technologies during planning stage on a construction project can assist in enhancing the scheduling process by reducing the number of missing activities and relationships between various activities as well as invalid relationships in the schedule and resource fluctuations for complex construction processes.

The Centre for Integrated Facility Engineering (CIFE) research group at Stanford University documented the applications and benefits of 3D and 4D modelling in their technical reports (*Koo & Fischer-1998, Haymaker & Fischer-2001 and Staub-French & Fischer-2001)*. The application of the Product Model and Fourth Dimension (PM4D) approach at Helsinki University of Technology Auditorium Hall 600 (HUT-600) project in Finland also demonstrated the benefits of 4D modelling approach in achieving higher efficiency; better design quality and the early generation of a reliable budget on the project *(Kam et al. 2003)*.

Various research efforts have been undertaken in an attempt to capture current construction planning techniques. Researcher *(Songer et al. 2001; Messner & Horman 2003; and Haymaker & Fischer 2001)* evaluated the effectiveness of computer visualisation (4D CAD) to demonstrate the potential of 4D CAD visualisation techniques compared to traditional planning approaches during the planning review process.

The whole basis of using 4D planning is to identify logical sequencing of the construction activities in construction projects prior to its execution. A rehearsal of the construction processes over time will identify and assist in overcoming spatial and resource conflicts for example, workspace conflicts, constructability, workflow etc which cannot be represented by using conventional planning techniques

The above studies lack well-established metrics that would allow the quantification of 4D planning at project level. In the absence of well-defined measures at project level, the priority of this research project is to establish a set of key performance indicators that will reflect the influence of 4D applications in construction projects. This will assist in justification of investment in advanced technologies in the industry. The remainder of the paper discusses the research methodology adopted, ranking of 4D KPIs and research findings.

RESEARCH METHODOLOGY

The methodology has three interrelated phases:

i. Identification of performance measures through literature review.
ii. Conducting semi-structured interviews with project and planning managers to establish and priorities the performance measures.
iii. Data collection to quantify the identified performance measures.

To achieve the objectives of the study two principal methodologies have been considered:

1. An extensive literature review on the performance measurement to identify the initial set of KPIs.
2. Exploration of the industrial view to formulate the key performance measures from a 4D planning view point.

Initially, thirty industry decision-makers with experience in using 4D planning on construction projects were contacted and invited to take part in the research. A total of 20 interviews were conducted, resulting in a 67% response rate. In a sample size of twenty interviews used in this study, 12 (60%) were planning managers and 8 (40%) were project managers on commercial projects in and around London. They assisted in sharing information on how to collect the required data and in identifying the methods to measure construction processes in detail. The questionnaire was designed to collect the information regarding the current “state of understanding” within the industry regarding 4D performance measures.

Three major construction projects in London (currently under construction with a combined value of £230 million) were selected for the research study and data collection. To minimise the risk of collecting irrelevant data, a snowball sampling method was devised. A semi-structured interviewing technique was used to elicit information from them to obtain their views about the key performance indicators at project level. The data and information obtained from semi-structured interviews was analysed using the Delphi technique. This technique was chosen since it is ideal for modelling real world phenomena that involve a range of viewpoints and for which there is little established quantitative evidence *(Hanks & McNay 1999).*

IDENTIFICATION AND SELECTION OF KPIS

The development of the performance measure list included due consideration of the performance measurement characterised by Rethinking Construction, the construction best practice program which launched industry wide KPIs for measuring the performance of construction companies *(CBPP-KPI-2004).* The Construction Best Practice Program identified a framework for establishing a comprehensive measurement system within both the organisation and project level. Other literature includes *Kaplan & Norton (1992); Li. et.al (2000); Chan et.al (2002); Cox et.al (2003); Albert & Ada (2004); Bassioni et.al (2004)* were used for the identification of performance measures. Project and planning managers working for major construction companies on the above mentioned three construction projects were invited for interviews.

First task for the interviewee was to identify and rank the performance measures using a four (4) point Likert Scale. The second task was to identify the information required to quantify each measure. Their input was considered to be critical in the success of this research. The concept behind conducting semi-structured interviews was to evaluate how project and planning managers perceive the importance of performance measures, which will assist in the identification of project based performance measures that can be used to quantify the value of 4D planning. The interview included both open and closed questions to gain a broad perspective on actual and perceived benefits of 4D planning. Due consideration has been given to the sources from where data has to be collected in a quantitative or qualitative way. The research team intends to continue the interviewing process with senior planning managers. This will assist in gathering more substantial evidence about KPIs. The analysis of semi-structured interviews resulted in the development of following 4D-based KPIs as represented in table 1.

FINDINGS AND RANKING OF KPIS

Interviewees were asked to rank the identified KPIs. The ranking of the KPIs was done by using a four (4) point Likert Scale. For the prioritisation process, each KPI was graded on a Likert scale of 1 to 4 (where 1= Not important, 2 = fairly important, 3 = Important and 4 = Very important) to measure the importance of each performance measure. The benefits of 4D planning will be quantified on the basis of prioritised KPIs. The performance measures will be further classified in qualitative terms (rating on a scale) and quantitative terms (measurement units).Using responses from a four (4) point Likert Scale, the average weighted percentage value for each performance measure was calculated. Figure 1 represents the weighted (%) ranking of the performance measures on the basis of the views of the respondents. The performance measures perceived as being highly important by the respondents are: *time, safety, client satisfaction, planning efficiency and communication.* As shown in figure 1, time and safety has scored the top ranking as compared to other performance measures.

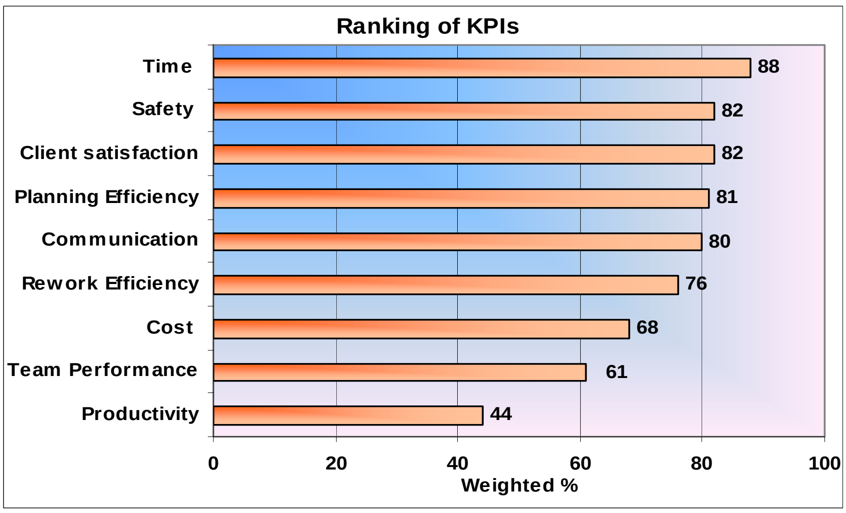

Figure: 1: Ranking of Performance Measures

Table 1: Definition of the Identified Performance Measures

Measure	Definition
Time	It can be defined as percentage number of times projects is delivered on / ahead of schedule. The timely completion of a project measures performance according to schedule duration and is often incorporated to better understand the current construction performance. Schedule performance index (Earned value Approach) was identified to monitor the performance of schedule variance.
Safety	It can be defined as a measure of the effectiveness of safety policy and training of the personnel engaged in activities carried out on site. Safety is a major concern for every construction company, regardless of the type of work performed. Safety is normally measured quantitatively by Time lost as a result of accidents per 1000 man hrs worked and number of accidents per 1000 man hrs worked.
Client satisfaction	Client satisfaction can be defined as how satisfied the client was with the product/facility. Usually measured weekly/monthly or shortly after completion and handover.
Planning Efficiency	Planning efficiency has been represented in terms of Hit Rate percentage (%). Hit rate percent indicates the percentage (%) reliability of the commencement date for each activity or package(s) by comparing the planned programme against the actual programme.
Communication	Information exchange between members using the prescribed manner and terminology. The use of a 4D interface allows the project team to explore the schedule alternatives easily and assist in deploying 4D approach. Communication can be quantified in terms of number of meetings per week and time spent on meetings (Hrs) per week.
Rework Efficiency	Rework efficiency can be defined as the activities that have to be done more than once in the project or activities which remove work previously done as a part of the project. By reducing the amount of rework in the pre-construction and construction stages, the profits associated with the specific task can be increased. Rework can be represented in terms of number of client changes, number of errors (drawing/design), number of corrections (drawing/design), number of requests for information to be generated, number of claims and number of process clashes spotted due to sequencing of activities.
Cost	Percentage number of times projects is delivered on/under budget. Cost performance index (Earned value Approach) has been identified to monitor the performance of cost variance.
Team Performance	Ability to direct and co-ordinate the activities of other team members in terms of their performance, tasks, motivation and the creation of a positive environment.
Productivity Performance	This method measures the number of completed units put in place per individual man-hour of work. Some of the identified productivity performance measures are; number of piles driven/day, number of piles caps fixed / day, tonnes of concrete used / day/m^3 and pieces of steel used per day or week.

Table 2 represent the ways to quantify the prioritise 4D KPIs at the different stages of a construction project. For example, ‘Time’ has been ranked (88%) as top KPI by the respondents and we propose to use ‘Schedule Performance Index’ to measure it. Schedule performance index (Schedule efficiency) can be defined as the ratio of the earned value created to the amount of value planned to be created at a point in time on the project. Similarly, we propose to measure ‘Safety’ in terms of ‘Safety Index’ i.e. Number of accidents per 1000 man hrs worked and time lost in accidents per 1000 man hrs worked. Further, identified KPIs have been represented in their respective indices form to indicate the effect of any given change in the construction process.

HIT RATE ANALYSIS

The construction industry is using different planning and control techniques to complete a project as per planned schedule programme. The critical success factor on

Table 2: 4D-based KPIs in order of priority

Ranking	KPIS	Indices	Performance measures	Stages of Construction
1	Time	Schedule Performance Index	(i) Schedule Performance	Pre-construction & Construction
2	Safety	Safety Index	(i) Number of accidents per 1000 man hrs worked (ii) Time lost in accidents per 1000 man hrs worked	Construction
3	Client Satisfaction	Satisfaction Index	(i) Number of client change order (ii) Number of client queries (iii) Satisfaction questionnaire (iv) Number of claims (time/cost)	Construction & Post-Construction
4	Planning Efficiency	Hit Rate Index	(i) Percentage of activities started & completed on time (Hit Rate %)	Construction
5	Communication	Communication Index	(i) Number of meetings per week (ii) Time spent on meetings per week (iii) Number of request for information responded	Pre-construction & Construction
6	Rework Efficiency	Rework Index	(i) Number of errors (Drawing) (ii) Number of corrections (Drawing/Design) (iii) Number of claims (Quality) (iv) Number of planning clashes.	Pre-construction & Construction
7	Cost	Cost Performance Index	(i) Cost Performance	Pre-construction & Construction
8	Team Performance	Team Performance Index	(i) Personnel turnover & productivity (ii) Timeliness of information from team	Pre-construction & Construction
9	Productivity	Productivity Index	(i) Tonnes of concrete used per day / m^3 (ii) Pieces of steel used /day or week (iii) Number of piles driven / day (iv) Number of pile caps fixed / day	Construction

a construction project is the reliability of the commencement date for each activity as per planning schedule. A late finish of an activity can inhibit the starting of another successive activity. This will ultimately results in an increase in the project duration time. Hit rate indicates the percentage (%) reliability of the commencement date for each activity in a package(s) by comparing planned against actual programme i.e. percentage of activities started and completed on time. Hit rate percentage is a crucial indicator to represent the efficiency of planning on a construction project. Consideration has also given to those activities which were not started and completed on time to give a better understanding of hit rate analysis. The activities which are not started and completed on time can be classified in the following categories:

i. Percentage of activities started late & finished late

ii. Percentage of activities started early & finished early

iii. Percentage of activities started late & finished early

iv. Percentage of activities started early & finished late

Hit rate (%) for two (Project A & project B) out of three identified projects were used to evaluate the preliminary analysis of planning efficiency. Those activities which are starting late and finishing late in each of the two identified projects (Project A & B) have been considered. The evaluation of percentage of activities which are started and finished late is of prime importance because it may ultimately delay the succeeding trade activities. Those activities which are started and finished late are further classified as percentage of activities completing before planned duration (< planned duration); on-time and after planned duration (> planned duration) in each of the two projects. Work packages for the calculation of hit rate percentages (%) for two past projects have been collected from the documentation done by the companies interviewed. Baseline and actual durations in terms of start and finish dates for each activity in a package(s) is required to calculate the hit rate percentages (%).

Hit rate percentage has been calculated on a package by package basis to analyse the interference of one package over the other. Firstly, start and finish variance value was extracted for each activity in a package(s). Start Variance was defined as the difference between a baseline start date of a task or assignment and its currently scheduled start date. Start Variance can be calculated by using following formula:

Start Variance = Actual Start - Baseline Start

Where as, Finish Variance was defined as the difference between the finish date of a task or assignment and its current finish date. Finish Variance can be calculated by using following formula:

Finish Variance = Actual Finish - Baseline Finish

Then the activities having zero start and finish variance have been segregated from rest of the activities. The activities with zero start and finish variance are the activities which are started and finished on time. Hit rate percentages can be calculated by using following formula:

Hit Rate Percentage (%) = (Total Number of activities having zero start and finish variances / total number of activities in a package) x 100.

Project A is a 700,000 sq ft office and retail development in London. Hit rate percentage for the project A has been calculated on the basis of 7 work packages. The hit rate percentage for project A was 48 % and 26% of activities out of 30% of the activities which are started and finished late have been completed within the planned duration implying that the duration estimates were correct though they were started late and finished late. Figure 2 shows an analysis of hit rates percentages (%) for project A.

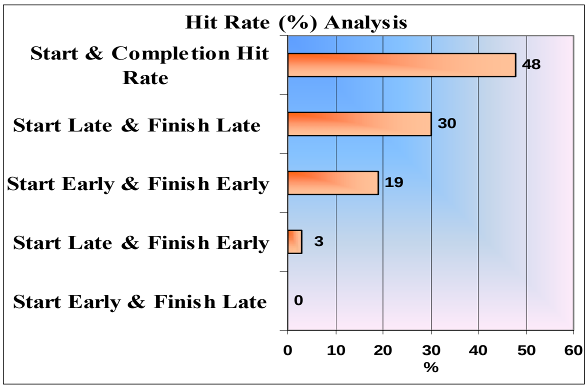

Figure: 2: Hit Rates (%) Analysis for Project A

Project B was developed to cater the requirements of residential, office and retail spaces in London city. Hit rate percentage for project B was calculated on the basis of four work packages. The hit rate percentage for project B was 65 % and 24% of activities out of 30% of the activities which are started and finished late have been completed within the planned duration implying that the duration estimates were correct though they were started late and finished late. Figure 3 shows an analysis of hit rates percentages (%) for project B.

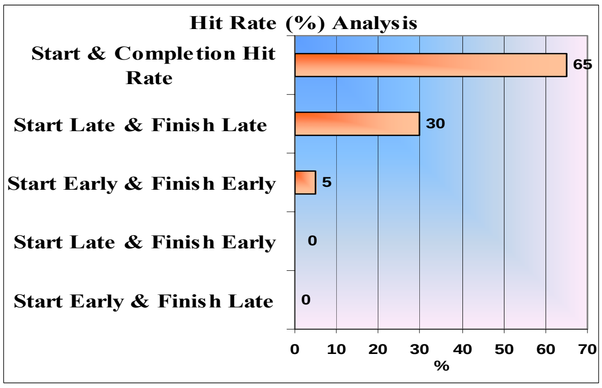

Figure: 3: Hit Rates (%) Analysis for Project B

Initial outcomes of the hit rate (%) percentages has demonstrated that the use of 4D planning technologies during pre-construction stage on a construction project can assist in enhancing the efficiency of planning on a construction project.

FINDINGS OF INTERVIEWS

Evaluation of the information gathered through interviews has assisted in understanding how project and planning managers perceived the benefits of 4D planning, how it could be improved, how performance is measured and what are the barriers in the successful implementation of 4D planning within the industry. A majority of the project managers felt that the use of 4D planning has assisted them in risk reduction in schedule programme, decreasing the amount of rework and reduction in overall project duration. Evaluation of the information collected from the semi-structured interviews has revealed following benefits of using 4D planning:

- Risk reduction in a programme.
- Detecting planning clashes

- Improves visualisation.
- Assist in reducing overall project duration
- Enhanced client satisfaction
- Assists in reducing the amount of rework required to be done.

Project managers felt that work force attitude (lack of awareness), lack of sufficient IT skilled people, resistance to change by General Contractors were cited as the major barriers for successful implementation of 4D planning. The major impediments in the implementation of 4D planning in construction are:

- Lack of sufficient IT skilled people with the required knowledge of 4D planning.
- Software incapability to represent the 4D model at detailed level.
- Time and money involved in training to upgrade the skills of work force.
- Resistance to change within the industry.
- Construction companies are not eager to invest in Research &Development.
- Industry is slow to adopt the potential benefits of 4D planning as compared to the manufacturing industry. This is due to a combination of attitudinal resistance for change and technical difficulties in developing the 4D models at a detailed construction process level.

FUTURE RESEARCH ACTIVITIES

The current and future research activities will include:

- Continuing the interview process to further confirm the 4D based KPIs.
- Establish a methodology for data collection and to quantify the identified KPI indices for the three construction projects.
- Benchmarking the KPIs indices with industry norms and identifying the improvements in construction processes resulted due to the application of 4D planning.
- Identifying the role of supply chain management in the development and updating of construction schedule for the 4D planning. The main contractor's viewpoint is that 4D is unable to bring any confirmed value as compared to their own planning system. Interviews with project managers have revealed that there are varying views between the main contractors and trade contractors on the usage of 4D planning on a construction project. The concern at the moment is the availability of the information, time used in the collection of information and cost factor attached in the implementation of the 4D technology. All the stakeholders were agreed that an early deployment of 4D brings about lot of transparency to resolve the conflicts among the various trades during the preconstruction phase.

CONCLUSIONS

Research studies and industrial applications has highlighted the benefits of 4D in a subjective manner and it has been stipulated that 4D can improve the overall project performance by identifying clashes, improving communication and improved co-ordination. The evaluation of 4D planning in the construction management literature has not been addressed seriously from performance measurement viewpoint. This study has developed five key performance indicators consistently perceived as being highly significant at project level are: time, safety, client satisfaction, planning efficiency, and communication. A lack of system compatibility, standardisation and willingness of the user to adopt this technology were cited as main barriers for the implementation of 4D planning. The evaluation and justification of 4D planning is crucial to promote the value embedded in it.

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