A Conceptual Framework for a Navigational Support System for Construction Projects

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Abstract

In a globalized and dynamic world, the construction companies that survive are those able to adapt rapidly and successfully to new conditions. Measuring the performance of construction projects dynamically helps companies survive. Despite more than twenty years of research into project performance measurement, none has explained how important it is to navigate and visualize project performance dynamically in different dimensions. Normally project performance is measured in more than one dimension, such as cost, quality, time, customer satisfaction, safety etc. Unlike in physical spaces, the distance between the target and the current position cannot be measured using tools such as the Euclidian metric. In this research we propose a framework to create a navigational support system to measure project performance in relation to benchmark targets, and consider the correlation between critical success factors in supporting project managers to take appropriate action to reach their goals.

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1. Introduction

Around the world projects fail to meet their objectives. For example, in New Zealand more than 70% of companies have experienced project failure in the past three years. From these results it is apparent that projects undertaken by

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New Zealand companies often cannot deliver on time and within budget, or fail to achieve stated deliverables. In addition, more than 60% of New Zealand companies fail to align their projects with benchmark targets (planned targets) [1, 2]. In the construction industry most projects do not finish on time and within budget. For example, according to property brokers and financial institutions in India, 40% of new homes could not be delivered to the buyers in the first quarter of 2013 because of massive construction delays. According to PropEquity, around 450,000 residential units under construction in India are likely to be delivered 18 months late [3]. Similarly, more than 90% of construction projects by MARA (the biggest company undertaking construction projects in Malaysia) were not delivered on-time [4]. Research in 2012 in Malaysia found that 92% of construction projects did not meet their goals. The delays in delivering construction projects were between 5 and 10% over their duration. Similarly, in Malaysia, in terms of cost, only around 11% of construction projects were completed on budget, with 89% overrunning the agreed price by 5–10% [5]. These statistics show that the construction industry suffers from poor performance [5, 6].

In order to achieve goals under the threat of various uncertainties [7], using effective project monitoring and control systems has become essential in any project-based organization [8, 9]. According to Oncu Hazir (2015) an efficient project monitoring and controlling system should minimize deviation from the project plans and consist of recognising the project status with respect to the plan, analysing the deviations and realising corrective action.

Performance measurement is classified under the following categories: 1- Managerial control tools such as Earned Value Analysis (EVA) [10-12], Balanced scorecards [13], Project Audit, Document checklist, Key Performance Indicators and Benchmarking [14]; 2- Optimization tools to solve operational problems of projects such as various scheduling and resource allocation problems [15]; 3- Decision Support System Applications (DSS) mostly used in planning, organizing and managing manufacturing or service operations [16]. Current performance measurement systems are static. However, the nature of the project is dynamic [17-19]. Therefore a static performance measurement system has a negative effect on the agility and responsiveness of organizations [20]. Effective performance measurement systems for projects will not only identify performance level, but also identify ways in which to improve this in an uncertain environment (strategic level) [21]. According to Oncu Hazir (2015), current performance measurement systems cannot determine the possible need for corrective action. They should be user-friendly and consist of an early warning mechanism. Table 1 shows the current deficiencies in current performance measurement systems [17, 18, 22, 23].

<table>
<thead>
<tr>
<th>Performance Measurement Systems</th>
<th>Flexibility</th>
<th>Dynamism</th>
<th>Visualization</th>
<th>Dynamical Decision-Making</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earned Value Analysis</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Project Auditing</td>
<td>✓</td>
<td>✗</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Project Report Status</td>
<td>✗</td>
<td>✗</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Documentation Check list</td>
<td>✗</td>
<td>✗</td>
<td>✓</td>
<td>✗</td>
</tr>
<tr>
<td>Balanced Scorecard</td>
<td>✗</td>
<td>✗</td>
<td>✓</td>
<td>✗</td>
</tr>
<tr>
<td>Dynamic Balanced Scorecards</td>
<td>✗</td>
<td>✗</td>
<td>✓</td>
<td>✗</td>
</tr>
<tr>
<td>KPI</td>
<td>✗</td>
<td>✗</td>
<td>✓</td>
<td>✗</td>
</tr>
</tbody>
</table>

Another shortcoming of current performance measurement systems is related to data availability. Many previous surveys show that it is extremely difficult to collect raw data on critical factors. Current performance measurement systems mainly focus on cost category, cost efficiency, cost predictability, and cost overrun [24].

The aim of this research is to create a decision support system called Navigational Support System (NSS) to integrate optimization tools, multivariate analysis tools and visualization tools to monitor and control the current performance of a project at a strategic level, and forecast the future position of a project’s performance with respect to the most important KPIs from the best projects (benchmark space). We have applied the proposed system in the construction field to test and validate NSS. This consists of 4 modules. The first handles data management; the second is a filtration module to reduce the dimension of KPIs to make them more understandable for project managers. The third module handles the positioning of current project performance KPIs compared to benchmark KPIs. The fourth
acts as a decision support system (DSS), recommending to decision-makers the corrective action to take to reach the benchmark. In short, NSS predicts the next position of project performance by taking the action recommended by NSS.

2. Research Methodology

We have used design science research methodology [32] as mentioned in the conceptual model of NSS. We have combined the Data-Driven Decision Support System with the Model Driven Decision support system to create the Navigational Support System. We have applied quantitative research methodology to collect from experts (construction project managers) information regarding the most important KPIs. Our target was project managers and the sample size is 34 experts. We have found 43 KPIs in the building sector which are categorized into 9 factors [28, 31]. We have designed a questionnaire in 2 parts. The first relates to the background of experts and demographic information and the second relates to the importance of KPIs. The questionnaires were distributed to construction experts to identify the most important performance factors in the construction filed. We then used secondary data to ascertain the values of selected KPIs. Finally we conducted in-depth interviews with 3 project managers to develop a dynamic model for measuring the performance of construction projects.

3. Conceptual model

The idea of navigation in benchmark space was first introduced by Tiru Arthanari [25], although the idea of physical navigation – on land, sea, or in the air-- is ancient and navigation in space is done successfully these days. In general, the process of monitoring and controlling the movement of a vehicle from one place to another is called navigation [26]. Benchmarking is common in organisational and individual settings. Navigating consists of two steps: finding the position of the system/object with respect to the benchmark and [2] taking action to advance towards the benchmark. Similarly, in the construction industry, project managers are responsible for project success. Therefore project managers should continuously monitor project performance in order to take appropriate action to regulate the project. Continuous monitoring and control procedures in construction can help projects to be accomplished successfully [27]. Due to the dynamic and stochastic nature of construction projects [28], deterministic control methods are not efficient in controlling them [29, 30].

Project managers are keen to know where project performance stands with respect to the performance of best projects (benchmark projects) and where project performance will go by taking action with respect to best practice. In the construction field, project performance is like an object in multidimensional intangible space (cost, time, quality, health and safety, productivity, client satisfaction, and environment) [31] that moves from its current position to another position to reach benchmark targets in the benchmark space. Benchmark space is defined as a space consisting of the factors that affect project performance for best practice. In the first step we use existing knowledge of the area that defines benchmark space. However, to apply this framework in the construction area, we first gathered knowledge of construction project performance from a literature review to identify the benchmark space.

To develop a generic engine to implement the Navigational Support System framework given in fig 1, we should find the true dimension of the subset of important KPIs from the expertly evaluated KPIs to obtain a sparse representation using a multivariate measurement method. This phase is called filtering. The second phase is positioning. After finding the true dimensions of benchmark space or the most important variables from the given benchmark space, we then determine the current position of construction project performance from that space. At this stage we try to find the position of the ongoing performance of the construction project with respect to benchmark space. Furthermore, we consider the correlation among the variables for finding the proper distance between the current state and desired state. In the third phase (or dynamic decision making phase) we use the dynamic behaviour of the performance of construction projects for a dynamic decision-making approach. We will use dynamic models of construction project performance such as system dynamic models or a multistage decision-making approach. Our choice depends on the complexity of the system. For example, in this research we choose very simple construction projects (one-storey residential projects), so that the dynamic of the system is available in the form of a stochastic dynamic decision-making model. The goal of the dynamic decision-making phase is to determine current action in the current state, based on the optimal strategy for the given model.
4. Implementation and Testing of NSS

The Navigational Support System (NSS) is designed with Shiny R, which is a web application framework for R language (version 3.2.4). The construction project performance evaluated by experts is the input of the filtration module to find a subset of a few variables among those defining the benchmarking space. The output of the filtration algorithm is saved as a new file called benchmark space. This file can be updated whenever the best construction project performance file is changed. Then the filtration algorithm runs to define a benchmark target in the filtration module. In order to evaluate KPIs in the construction field, experts with more than 6 years’ experience participated in this study. They were asked to rank different KPIs in construction projects. The evaluated KPIs from the view of 34 experts (41% Project managers, 24% Technicians, 23% owners, 9% site managers and 3% architects) is uploaded to the system as a csv file. The NSS will then automatically find the most important KPIs.

Fig 2 shows that the iron triangle [33] is important in building construction projects in addition to the community satisfaction factor. Project cost turns out to be the most important KPI followed by project time and community satisfaction, while project quality shows the lowest level of importance among 9 factors ranging from (cost, quality,
health and safety, client satisfaction, time, productivity, environment, community satisfaction and employee satisfaction).

As shown in fig 2, cost performance explains around 50% variation. Time, quality and community satisfaction explain -20%, -10% and -20% variation, respectively. The negative sign of time, quality, and community satisfaction illustrates that these factors have a negative correlation with cost. In other words, when the importance of cost increases the importance of time, quality and community satisfaction decreases and vice-versa. Table 2 shows the 4 most important indicators based on the experts’ views, according to the output of the filtration module along with proposed measurement methods collected from literature. The selected KPIs are the most critical among the project level KPIs.

<table>
<thead>
<tr>
<th>Perspective</th>
<th>No.</th>
<th>KPIs</th>
<th>Measurement methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Financial</td>
<td>1</td>
<td>Cost efficiency</td>
<td>(Revenue-Expenses)/Revenue</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Cost Effectiveness</td>
<td>Project cost-Average Cost of similar project/Average cost of similar project</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Design cost predictability</td>
<td>(Performance design cost-planned design cost)/planned design cost</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Construction cost Predictability</td>
<td>(Revenue-planned Revenue)/Revenue</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Financial cost Ratio</td>
<td>((Cost-Revenue) *Interest rate)/Revenue</td>
</tr>
<tr>
<td>Schedule</td>
<td>1</td>
<td>Design schedule predictability</td>
<td>(Performance design Schedule-planned design Schedule) /planned design</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Schedule Effectiveness</td>
<td>(Project Schedule-Average schedule of similar project)/Average schedule of similar project</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Schedule Efficiency</td>
<td>(planned schedule- completed schedule) /Planned schedule</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Project Predictability</td>
<td>(Performed construction schedule-planned construction industry)/Planned construction schedule</td>
</tr>
<tr>
<td>Quality</td>
<td>1</td>
<td>Defect frequency</td>
<td>Number of registered Non-conformance /Number of Tests</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Rework Rate</td>
<td>Number of rework Items/Number o registered non-conformance</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Nonconformance rate</td>
<td>Number of registered Non-Conformance/Gross Area</td>
</tr>
<tr>
<td>External customer satisfaction</td>
<td>1</td>
<td>Percentage of repeat customers</td>
<td>Number of repeat customers/Total number of customers</td>
</tr>
</tbody>
</table>

In the next module the most important KPI values are collected from an ongoing single-storey, one bedroom, 57 m² residential building construction project. The values of selected KPIs of benchmark projects are collected from the Twelfth Annual Construction Industry KPIs [35]. The data is available online at www.kpizone.com. The website gives access to all KPIs for the construction sector. In this research we used activity schedules and monthly cost reviews,
monthly project programs, monthly audits, agreed questionnaires and meetings at regular intervals to establish why the client was dissatisfied with the measurement of performance [36].

The second module of NSS is responsible for finding the distance of ongoing project performance from benchmark project performance with consideration of the relationship of KPIs to each other. Actual and benchmark data will be imported into this second (positioning) module and the current position of construction project performance from benchmark space will be determined. This is so that the project manager can simulate and visualize the differences between actual projects and benchmarked ones. At the data visualization module, by having the two above-mentioned data sets from filtration and update modules, a graph will show the differences between current performance of construction projects and benchmark space in 2- or 3-dimensional format. The current performance of construction project performance will be saved in a file named “current state of construction performance”. Project success depends on several factors and comes from several categories, namely, project related, manager related, contractor related, project management team/team related, external, institutional, and client related. Project success factors are correlated to each other and they are not independent [37]. For example, if a project manager wants a project to be delivered quickly with high quality, then the cost will be increased. If a project is to be fast and cheap, then the quality will be compromised, and if a project is to be delivered with high quality and be cheap then it will take more time to complete [27, 38]. Gudienė, Banaitis [39] suggests that there is a correlation between sub-factors so the underlying relationship among them should be considered to identify the effects on benchmark space (project success). Finding the interrelations among critical success factors helps project managers to control the key factors and allows for rational resource allocation [19]. KPIs of projects are not independent and there is a relationship between different ones [36]. For example, changes to the design of construction projects affects the KPIs of time and cost. If the project is behind schedule, then the cost will be increased to finish the project on time. For instance, an increase in staff, materials and equipment would be made in an effort to decrease the time taken to do additional work and therefore maintain the time KPI to the project goal. An increase in safety means an increase in cost. So we need to consider a metric to find the distance between an ongoing project from best practice by taking into account the relationship between KPIs. In other words, correlation between KPIs should be taken into account to find the proper distance from benchmark space. Therefore the correlation between KPIs needs a metric that takes into account their relationship. Hence, Mahalanobis’ distance metric [40] is used. Fig 3 is the output of distance of ongoing project performance with respect to benchmark projects in terms of different KPIs.

![Fig.3 Distance of an ongoing project from best practice](image-url)
The NSS will calculate the distance of an ongoing project from benchmark projects gathered from UK performance reports [41]. For example, the distance between construction cost and client satisfaction of an ongoing project from best practice is 20.3 and from Fig 3 it shows that there is a negative correlation between construction cost and client satisfaction. The user can use the filtered KPIs to check if it is within benchmark or out of benchmark space. The final Module of NSS is dynamic decision-making to find the best action that the user can take to be closer to benchmark projects, based on the available dynamic model. As mentioned earlier, the dynamic model can be available in terms of stochastic decision making processes or system dynamic models. By executing this module, the data set of the current state of construction projects from the positioning module will be imported into the dynamic decision making module. Also, from the knowledge base system, which is available from literature or previous construction projects, possible actions will be selected. The transition to the next stage based on the current position will be determined by previous projects and the transition probability matrix will be calculated when the dynamic decision making module runs to find the position of construction project performance in the next stage. This process continues until it gets close to benchmark targets. In this module the user selects the status of selected KPIs based on the output of the previous module. Then NSS will recommend to the user the best action to take (fig 4). For example, if the project is within benchmark, the system recommends the project manager to use the nearest supplier, and if the project is out of benchmark to use an experienced supplier to bring project KPIs into the benchmark space.

Fig.4 Recommended actions to project manager

5. Conclusion

This paper provides a computer system for monitoring and controlling KPIs for any projects. By using NSS the project can be monitored in a dynamic environment. The goal of this research is to create an engine for all types of project to be monitored and controlled. Hence, NSS is a generic engine that can monitor and control project KPIs with respect to best practice. Moreover, it recommends driving projects toward benchmark space by taking proper action. The NSS is tested and evaluated in construction project fields to identify the most important KPIs of building construction projects. Thereafter the system automatically finds the position of current project performance from benchmark projects. Finally, the system recommends the best action for project managers to be closer to benchmark target. By applying NSS in the construction project field, cost, time, quality and community satisfaction are selected as the most important KPIs. Thereafter benchmark space is created from the secondary data based on the most important KPIs. Moreover, any ongoing construction project can be evaluated based on the created benchmark space and the dynamic model of the system is developed based on a stochastic decision-making model.

One limitation of this research is that some KPI data related to the people and environment of the benchmark project is not available. Another is related to ongoing project performance that is not available in the organization because not all KPIs are measured regularly by project managers. Also, historical data related to actions that the project managers take to make the project align, is difficult to gather. For future research, developing a decision-making module of NSS using system dynamic models is recommended to overcome the aforementioned limitation.
References


