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Dynamic Performance Indicators for Aged-Care Construction Projects

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Abstract**—**Key performance indicators (KPIs) are used for post result evaluation in the construction industry, and they normally do not have provisions for changes. This paper proposes a set of dynamic key performance indicators (d-KPIs) which predicts the future performance of the activity being measured and presents the opportunity to change practice accordingly. Critical to the predictability of a construction project is the ability to achieve automated data collection. This paper proposes an effective way to collect the process and engineering management data from an integrated construction management system. The d-KPI matrix, consisting of various indicators under seven categories, developed from this study can be applied to close monitoring of the development projects of aged-care facilities. The d-KPI matrix also enables performance measurement and comparison at both project and organization levels.

Keywords**—**Aged-care project, construction, dynamic KPI, healthcare system.

I. Introduction

TRADITIONALLY, construction projects have measured their performance by three key performance indicators (KPIs): time, cost and quality, the so-called 'iron triangle' [1]. However, more and more researchers have recently criticized this limited approach for failing to provide comprehensive insight for performance improvement [2] – [5]. Almahmoud *et al*. [6] proposed 67 indicators under two categories of project management core functions: strategic business assessment and project implementation assessment, and recommended these indicators for performance evaluation during the project delivery stage. Toor and Ogunlana [7] surveyed stakeholders' perception of KPIs for large-scale public sector development projects and commented that strategic, sustainability and safety criteria should be included into the KPI matrices. Hwang *et al.* [8] developed 50 performance matrices for pharmaceutical construction projects and concluded that more detailed statistical analysis of the matric is necessary to better serve as performance indicators.

In order to form a construction project KPI matrix, data collection under these three categories are normally essential:

A) Site data of construction activities such as labor input, materials consumed and the duration of an activity,
B) Process data of construction management such as project governance, communication efficiency, and risk management, and
C) Engineering data of the final product such as building capacity, quality workmanship and functional specification.

With increasingly complex KPI matrices, data collection for KPI analysis is becoming more challenging. Beatham *et al.* [9] have pointed out that KPIs should be used either to predict future performance of the activity being measured and present the opportunity to change practice accordingly, or to enable decisions to be made in advance on future associated activities based on the outcome of previous activities. However, most, if not all, of the data is manually collected from various sources, which usually delays a KPI analysis. Because current data collection methods are time- and resource-consuming, many construction organizations do not collect extensive data for a timely KPI analysis, implying that they do not enable corrective measures to be taken shortly after the deviation occurs [10]. In order to have a more effective performance monitoring system, some researchers have proposed automated data collection in construction. Peyret and Tasky [11] applied the radio frequency identification (RFID) technology to monitoring more than 15 construction parameters. They asserted that these data can be used for managerial and supervisory purposes. Naven and Goldschmidt [12] indirectly measured site parameters using various measuring devices such as local sensors and a global positioning system (GPS). They concluded that automated data collection is able to increase the predictability of a construction project. All the work is applicable only to the automatic collection of the site data (category A) of construction activities.

This paper presents an effective way to collect process data and engineering data under categories B and C, respectively, for KPI analyses. A set of dynamic key performance indicators can be effectively generated from the automated workflow in an online construction management system. The rest of this paper is organized as follows. In section II, background and characteristics of aged-care construction projects will be briefly discussed. This is followed by sectin III which describes research methodology and the integrated management system. The detailed results and discussion are then presented in section IV. Concluding remarks and recommendation for future study are provided in section V.

II. Background of Aged-Care Projects

A. Ageing Population

The world is facing a silver tsunami with the rising old-to-young ration and more people at extreme old age than ever before. According to the World Health Organization (WHO) report "Global Health and Ageing 2011", the number of

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people aged 65 or older is projected to grow from an estimated 524 million in 2010 to nearly 1.5 billion in 2050, with most of the increase in developing countries. The remarkable improvements in life expectancy over the past century pose the following challenges now: Do we have sufficient aged-care facilities for the elderly? Do we have a sustained sense of well-being and should we establish a social infrastructure fostering better health in older age?

B. Development of Aged-Care Facilities

The rapidly ageing population places significant demands on aged-care facilities and many countries have announced their plans to expand aged-care capacities. Australia is reforming its aged-care system with a Five-Point Plan. The plan estimates that the total aged care costs including both capitals and expenditures will increase from the current A$7.3 billion to A$12.1 billion by 2020 [13]. The Singapore government has released its plan to develop 56 new senior activity centers, 39 new senior care centers and 10 nursing homes in the next couple of years [14]. All these development plans imply an extremely heavy project load to the project development organization. The organization may need to manage more than 100 projects simultaneously in order to achieve these targets.

C. Characteristics of Aged-Care Projects

The development of aged-care projects falls into the category of small-scale construction projects. There are two types of aged-care projects: new facilities and addition/ alteration work. The cost of building a new nursing home may range from US$ 10 to 20 million whereas the cost of an addition/ alteration of an existing aged-care facility may be as low as US$100k-200k only. The construction cycle of a new nursing home is around 15 to 18 months whereas an addition/ alteration work may last 2 to 3 months only.

III. Research Methodology

A. Case Study

The dynamic key performance indicators (d-KPIs) are developed from a case study. The organization in this case study is in charge of healthcare development projects including general hospitals, community hospitals, polyclinics, aged-care facilities and other healthcare facilities. However, this study focuses on the aged-care projects only.

B. Construction Management Database

The online system for construction project management has been presented in a previous study [15]. Fig. 1 depicts a simplified system structure. The project lifecycle (level I) is grouped under six phases (level II). Within each process group, the individual process is linked by their inputs and outputs. The interactions of process groups also cross phases such that closing one phase provides an input to initiating the next. Under each phase, a work breakdown structure (WBS) is defined at level III, which is not shown in the figure. Through this layered structure, each descending level represents an increasingly detailed description of the project element.

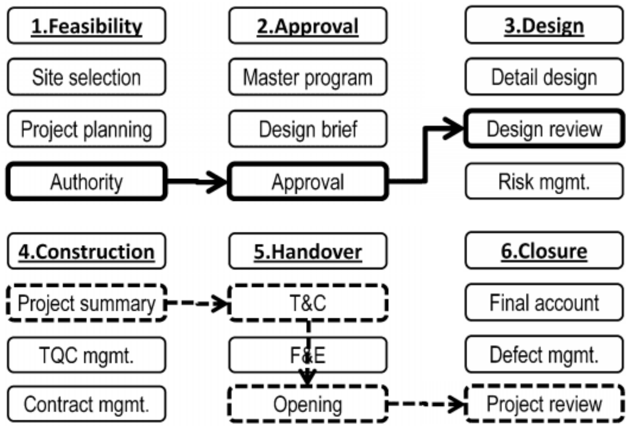

Fig. 1 Construction management database

C. Process Logical Diagram

The process mapping in the database is equipped with two types of logical controls for public aged-care development. The first type of logical control depends on government approval of the investment such as: Clearance from Authority – Preliminary Approval – Final Approval. The second type of logical control depends on proper sequencing of the determined project activities such as: Project Start – Test & Commissioning – Center Opening – Postmortem Review. The integrated process of logical control helps project managers to analyze the constraints of project scheduling, which involves evaluation of the available path and float for each activity. This function is particularly useful for project managers who manage a number of aged-care projects with short construction cycle time.

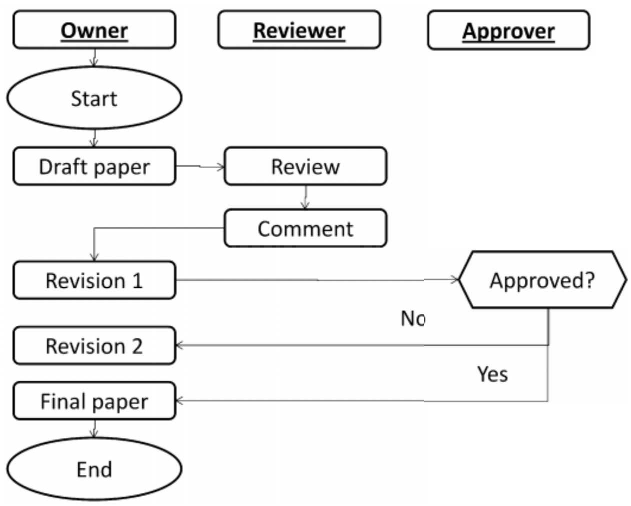

Fig. 2 Online workflow system

D. Automated Workflow

The construction management system is equipped with an automated workflow. Fig. 2 illustrates a typical workflow for online submission and approval. An approval workflow automatically routes the document, assigns review tasks and tracks their progress, and sends notification when needed. The benefits of this simple online workflow are twofold: it saves time and trouble for the users and, at the same tome, collects engineering and process data in the system. In the next section, we will demonstrate how to extract the history data to form a d-KPI matrix.

IV. Results and Discussion

The d-KPIs developed from this case study are summarized in Table I. These KPIs fall into seven categories: project loading, project resource, time, quality, cost, environmental and safety. All these indicators can be directly tracked or extracted from the online construction management system. Due to the length constraints of this paper, we can only provide a few examples to demonstrate how it works. In view of the confidentiality of the cost information, some dummy data are used in the computation. As the purpose of this paper is to construct the d-KPI matrix by using effective data collection from the system, these dummy data will not affect the integrity of the results.

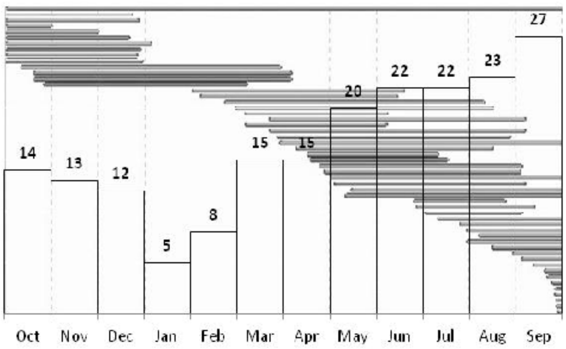

Fig. 3 Annual operating plan (AOP)

A. Project Loading

Every organization has its own annual operating plan (AOP). In a project-based organization, the AOP identifies and monitors progress of all key project priorities for the year that advances the overall strategic plan. Fig. 3 illustrates the financial year 2011/2012 AOP of the organization in this case study. Instead of any regular progress report, this is the master document that can be electronically accessed for real time tracking. While an aged-care project goes through the six phases as shown in Fig. 1, all kinds of review reports and approval paper will be submitted in the online system using the workflow as shown in Fig. 2. These reports and papers contain both engineering information such as gross floor area (GFA) and project information such as the name of the architecture firm. Project administrative information such as date of submission and date of approval of a report or paper can be directly extracted from the system. Moreover, the logical diagram provides the information of status changes of each individual project from planning to construction and then to opening. Combining this information, a dynamic KPI of "AOP progress" can be established without any manual data collection.

TABLE I
Summary of Dynamic Key Performance Indicators

Category	d-KPI
Loading (L)	To measure the project loading
- AOP	- Annual operating plan
- Potential site	- No. of sites under planning
- Approved site	- No. of approved sites
- Under construction	- No. of sites under construction
- Completed site	- No. of sites obtained TOP
- Progress	- Opening/AOP (%)
Resource Plan (R)	To measure the project resources
- Project manager	- No. of project managers needed
- Consultant	- No. of consultants needed
- Contractor	- No. of contractors needed
- MDT	- % of multiple-disciplinary team
- SDT	- % of single-disciplinary team
- D&B	- % of design & built
Time (T)	To measure the scheduling performance
- Contract time	- Contracted construction duration
- Actual time	- Actual construction duration
- EOT	- Variation by extension of time
- Schedule control	- Actual/contracted duration (%)
- SOC	- GFA/construction duration
Cost (C)	To measure the financial performance
- Budget	- Approved project budget
- Progress payment	- Progress payment/budget (%)
- VO	- Variation order
- Final cost	- Total project cost
- Unit cost 1	- Final cost/GFA
- Unit cost 2	- Final cost/bed (nursing home)
Quality (Q)	To measure the quality performance
- QC	- No. of findings per inspection
- QMS	- No. of findings per ISO9001 audit
- Deviation	- No. of deviation from design
- Rework	- No. of rework per inspection
- Final acceptance	- Score of final acceptance
Environment	To measure the environmental performance
- EC	- No. of complaints
- EMS	- No. of findings perISO14001 audit
- Sustainability	- Green mark scores
Safety	To measure the safety performance
- SC	- No. of findings per safety inspection
- Accident	- No. of reportable accidents
- OHSMS	- No. of findings per OHSMS18001 audit

Fig. 3 also shows the monthly project loading over the year, varying from 5 to 27 sites per month. Based on the number of planed sites, approved sites and completed sites, the system automatically computes and forecasts the probability of achieving AOP targets, indicating a reduced or increased uncertainty in the aged-care facilities development program. This indicator can also be used for performance comparison under the sub-categories. For example, each individual project development under the organization can establish its own "AOP progress indicator" for benchmarking with other departments.

B. Speed of Construction (SOC)

According to Chan and Chan [16], construction time refers to the duration of completing a project and the speed of construction (SOC) is defined by GFA divided by the construction time. This indicator measures how well a project is implemented or the degree to which targets of time are met from the start of construction to full opening.

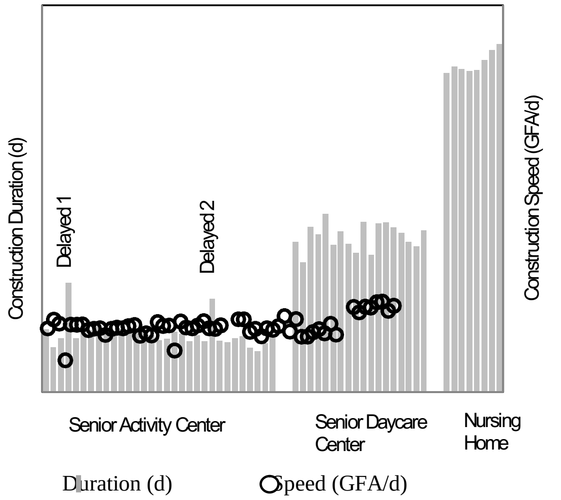

Fig. 4 Construction duration and speed

Two types of data, GFA and construction time, has to be collected to compute the SOC. For a given project, GFA is normally a constant and available from the project database. Construction time is the absolute time that is calculated as the number of days from start on site to practical completion of the project. When the Gantt chart is submitted for approval using the workflow in the online management system, the "planned construction time" is available to compute the SOC. However, the SOC value may be affected by time variation during the construction stage. Whenever there is a request for extension of time (EOT) approved in the system, the SOC will be automatically corrected by including the percentage of increase in construction time.

It can be seen from Fig. 4 that the speed of construction under the categories of senior activity center, senior day-care center and nursing home, respectively, is almost a constant except for the delayed projects. However, the two delayed projects identified in Fig. 4 are far below the average SOC. This indicator is useful for decision making: a) the average SOC under each category can be used as a reliable reference to forecast the construction time of future projects in the same category; b) whenever a project requires an EOT, the system will automatically warn the project manager to take necessary actions accordingly; and c) it also analyzes the impacts of any EOT on the AOP and prompts the organization to fine-tune its project development strategy.

C. Unit Cost

When using public funds to build healthcare facilities, the organization has strong reason to control construction costs. A public healthcare facility has to maximize each dollar spent on its capital project. The integrated project management system enables the organization to achieve effective cost control by imposing a close monitoring throughout the development. The following key steps are built into the online processes to prevent large cost overrun:

- Accurate cost estimation by clearly defining the project scope;
- "Design to budget" by architects and consultants;
- Competitive bidding by pre-qualified contractors, and
- Online submission of any request for variation orders

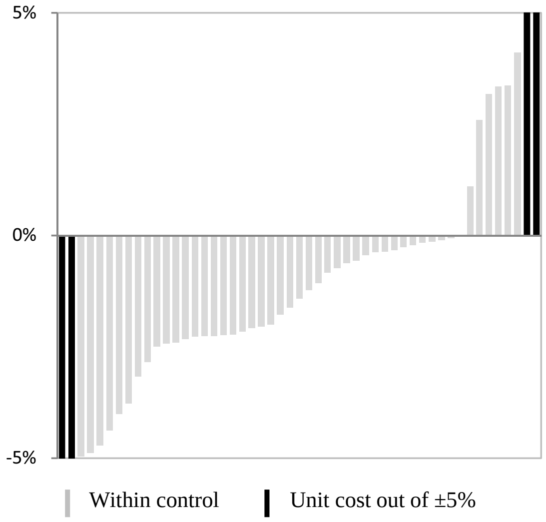

Fig. 5 Project unit cost control (±5% of the norm)

Unit cost (total development cost/GFA) is a common indicator for benchmarking. RSMeans [17] has surveyed 25 major cities in the United States and reported the median cost per square foot for nursing homes falls around US$160 per square foot. In this case study, the online management system tracks every step of cost control and forecast possible cost overrun (> 5%) or under-run (<-5%) accordingly. For example, whenever the cost estimate is available in the system, the unit cost will be automatically computed and compared to the norm. Whenever there is a request for variation order submitted in the system, the unit cost will be re-computed and the project manager will be prompted of its potential impacts on the unit cost prior to decision-making. Fig. 5 illustrates how this warning mechanism works. Those projects with unit cost out of the range are highlighted for further actions. This indicator deploys a powerful tool for the organization to study the unit cost trend under each category so that project managers can leverage historical development cost data against future project budgets.

V. Conclusion

The concept of d-KPIs developed from this study enables the project managers to mitigate project risks by taking corrective actions in time. In comparison with traditional KPIs applied to after-result measurement across the industry, d-KPIs are more suitable for predicting future performance at the project level. The success of effective data collection from an integrated project management database to form d-KPIs depends largely on the proper mapping of construction processes. This finding tends to encourage a project-based organization to adopt a "process-orientated" operating strategy instead of a "result-orientated" one due to the following considerations:

- A good project result is guaranteed if the right development process is in place;
- A good project result obtained from the wrong development process could not be reproduced in other projects;
- A well-established project development process allows real-time project monitoring and, therefore, better project control; and
- Continual improvement of the project performance is possible by regularly calibrating the d-KPI baseline

Although the d-KPIs are developed from the healthcare industry, they can be applied to other industries such as the retail and quick restaurant industries which also manage a large volume of small-scale development projects of their outlets over a large geographical distance.

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