Developing a Knowledge Based Information System (KISCCES) for Construction Cost Estimating and Scheduling

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ABSTRACT

The research project is to develop a Knowledge-Based Information System for Construction Cost Estimating and Scheduling (KISCCES). To accomplish the research goal, the researchers develops a prototype project management system that can produce pictorial data to all involved parties, cost and schedule in nearly real-time basis. The scope of the research project includes transferring pictorial data via the wireless network, measuring construction productivity using time-lapse video, and developing a graphical user interface for cost estimating and scheduling. The tasks for this project are outlined as follows: conduct literature review, purchase necessary software and hardware, define measurement data for each activity, conduct field experiments in construction projects to transmit time-lapse video wirelessly and consistently, and develop a prototype graphical user interface to estimate cost and duration on a nearly real-time basis. Upon development of the KISCCES, the researchers evaluate the estimated cost and schedule by statistically comparing it with estimates by construction industry experts.

KEY WORDS
Construction, Real-time, Productivity Measurement, Cost, Schedule, Estimating
INTRODUCTION

Construction project costs and schedules are the most important components in project management due to the importance of meeting estimated budgets and deadlines (Hwang and Liu 2010). Most construction estimates developed by a project manager or estimator are based on historical data (Kim and Reinschmidt 2011). Since accurate estimations must include calculations of productivity, construction companies need to track productivity continuously in order to gauge their performance capacity, maintain profitability, and prepare for future project biddings and schedules (Ghanem and Abdelrazig 2006; Noor 1998; Thomas et al. 2003). Without accurate productivity data, construction companies are unable to produce reliable project management outcomes.

However, productivity data can be inconsistent because various methods of gathering data exist, resulting in difficulties of interpreting and sharing the data. Traditionally, numerous types of productivity measurement techniques were developed, most of which uses the motion and time study theory. Examples of these techniques include stopwatch study, photographic, taping video, time-lapse video, activity sampling (work sampling), craftsman’s questionnaire survey, and a foreman delay survey (Noor 1998; Oglesby et al. 1989).

An ideal method for measuring construction productivity should satisfy the following basic criteria: 1) monitoring multiple trades in one job site; 2) simple; 3) inexpensive; 4) consistent and identical; 5) not very time consuming; 6) reflective of what actually occurs at the site; and 7) timely so that actions are taken on short durations activities (Noor 1998; Thomas and Kramer 1988).

Over the years, several productivity measurement techniques have been developed, including stopwatch study, photographic, time-lapse, GPS, and others (Abudayyeh 1997; Everett and Halkali 1998; Fondahl 1960; Memon et al. 2005; Navon and Shpatnitsky 2005; Oglesby et al. 1989; Peyret and Tasky 2002) existing on-site construction productivity measurement methods have some common limitations such as not providing data necessary for project managers to share detailed information in real-time to determine the project’ performance level. Poor communication and coordination resulted in cost overruns and inaccurate construction schedule forecasts. To improve the quality of construction project management, there is an urgent need to develop an advanced and practical project management system that will overcome mentioned shortfalls.

Previously, Seonghoon Kim and Yong Bai developed a Wireless Real-Time Productivity Measurement (WRPM) System as an on-site construction productivity measurement tool (Bai et al. 2012; Kim 2011). The WRPM System satisfies basic criteria for being an ideal method for measuring construction productivity: It is simple, inexpensive, consistent and replicable, reflective of what actually occurs at the site, and expeditious (Bai et al. 2010; Pan 2005). Once the video camera in the WRPM System takes photos from a construction site, the data processor immediately saves the pictorial data into files. Users can then access the data files to collect productivity data. As a result, collected data is available to users and data analysis can be performed immediately without delay due to necessary transportation of the collected data.
The research project is to develop a Knowledge-Based Information System for Construction Cost Estimating and Scheduling (KISCCES). To accomplish the research goal, the researchers develop a prototype project management system that can produce pictorial data to all involved parties, cost and schedule in nearly real-time basis. The research project will determine whether the developed system can accurately estimate an activity, project level costs, and schedule in real-time. If the research project is successful, construction professionals will be able to control costs of activities in a real-time basis, develop a reliable and functional cost estimation and schedule by reducing the level of uncertainty, and quickly manage construction job sites through better communication and coordination. The system development has to be accomplished in multiple phases:

1. Develop the Wireless Real-Time Productivity Measurement System (WRPM) to collect on-site building construction productivity data.
2. Develop a model and required algorithms for integrating productivity, cost, and schedule data.
3. Conduct experiments at the construction sites to test the developed measurement system for cost estimating and scheduling.
4. Evaluate the knowledge basis by statistically comparing it with cost and schedule estimates by construction industry experts.
5. Identify the current research limitations and needs for future research improvements.

The scope of the research project includes transferring pictorial data via the wireless network, measuring construction productivity using time-lapse video, and developing a graphical user interface for cost estimating and scheduling. The tasks for this project are outlined as follows: conduct literature review, purchase necessary software and hardware, define measurement data for each activity, conduct field experiments in construction projects to transmit time-lapse video wirelessly and consistently, and develop a prototype graphical user interface to estimate cost and duration on a nearly real-time basis. Data collected from the system and industry experts will be used to validate the reliability of the system.

### Wireless Real-Time Productivity Measurement (WRPM)

The WRPM System can provide pictorial data via a wireless network so that anyone in the construction field office or home office can monitor construction activities and analyze productivity in real-time as long as there is an Internet service available at the location. The WRPM system is composed of three major components that are shown below.

1. Pan/Tilt Camera Housing
2. Data Processor
3. Computer

Besides these major components, additional items are also required to operate the system: wireless modems, a solar panel to generate electricity at the job site, AC transformer, a steel pole to mount the camera box, and cables to connect the components.
Figure 1 presents the framework of the WRPM System that was developed during the process of this research project. Once the video camera takes pictures from the construction site, the data processor immediately saves the pictorial data into files. Then, these files are transmitted in real-time via a wireless modem. After finishing the data analysis, productivity data and live pictures are presented in a website so that other users such as the owner, engineers, contractors, and material suppliers can share the information.

Figure 1. Framework of the WRPM System

BREAKDOWN A CONSTRUCTION PROJECT INTO ACTIVITY LEVELS

The researchers will breakdown each category into individual components, for example foundation, column, beam, slab, and wall. To build each component requires resources such as labor, equipment, and material. The process of build each component is defined as a construction activity.

The work breakdown structure (WBS) has been widely used to control the project performance. WBS is defined as “a deliverable-oriented grouping of project elements,” which organizes and defines the hierarchical structure of total projects (Jung and Woo 2004). It is often used in the complex construction projects to identify project information and improve the efficiency of control processes (Chua and Godinot 2006). WBS is often used for integrating the project cost and the project schedule in order to control them (U.S. Department of Energy 1997). As an example of previous research project, the bridge reconstruction project was broken down into four levels for the ease of measurement: level 1 (project), 2 (work zone), 3 (activity), and 4 (operation), as shown in Table 1.

After determining the activities, the next step is to define construction productivity measurement data for each activity. To complete an activity may only need labor and material, equipment and material, or labor, equipment, and material. For this reason, measurements of construction productivity will be different between activities. In addition, quantity survey for each activity will be provided from industry experts.
TABLE 1. Work Breakdown Structure (WBS) for Bridge Reconstruction

<table>
<thead>
<tr>
<th>LEVEL 1 (Project)</th>
<th>LEVEL 2 (Work Zone)</th>
<th>LEVEL 3 (Activity)</th>
<th>LEVEL 4 (Operation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel Girder Bridge</td>
<td>General Mobilization</td>
<td>Set up Crane</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Abutment</td>
<td>Traffic Control</td>
<td>Moving concrete safety barrier</td>
</tr>
<tr>
<td></td>
<td>Pier 1</td>
<td>Demolition</td>
<td>Driving pile</td>
</tr>
<tr>
<td></td>
<td>Pier 2</td>
<td>Excavation</td>
<td>Forming</td>
</tr>
<tr>
<td></td>
<td>Pier 3</td>
<td>Abutment 1</td>
<td>Structural excavation</td>
</tr>
<tr>
<td></td>
<td>Span 1</td>
<td>Abutment 2</td>
<td>Tying rebar</td>
</tr>
<tr>
<td></td>
<td>Span 2</td>
<td>Pier Drill Shafts</td>
<td>Pouring and curing</td>
</tr>
<tr>
<td></td>
<td>Span 3</td>
<td>Pier Columns</td>
<td>Strip and check elevation</td>
</tr>
<tr>
<td></td>
<td>Span 4</td>
<td>Pier Cap</td>
<td>Slope protection, filter fabric and rock</td>
</tr>
<tr>
<td>North side</td>
<td>Slope protection</td>
<td>Set bearing devices</td>
<td></td>
</tr>
<tr>
<td>South side</td>
<td>Beam Setting</td>
<td>Unload beams</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Deck Forming</td>
<td>Set beams</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reinforcing Deck</td>
<td>Install diaphragms, bolting, and tightening</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bridge Barrier Rail</td>
<td>Ground splice</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Concrete Barrier</td>
<td>Prepare deck material</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Backfill Abutments</td>
<td>Prepare deck forming</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Approach road</td>
<td>Overhangs</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Strip</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Place backwall, strip drain, and backfill</td>
<td></td>
</tr>
</tbody>
</table>

DATA COLLECTION PLAN

Once the project management system, including the WRPM System and graphical user interface, is developed, the researchers will conduct field experiments to collect pictorial data wirelessly. The field experiments will address the following questions: Does the WRPM system (for data integration) work as planned? What areas should be improved? The objective of these experiments is to determine whether the integrated system is an accurate tool for measuring productivity and estimating accurate cost and duration. Using the WRPM, all parties in the project can share pictorial data in real-time as shown in Figure 2.

To achieve real-time cost and schedule estimating, a prototype graphical user interface (GUI) using Java programming was created, as shown in Figure 3. The GUI will be used as a user-friendly data input and output estimating tool. When pictorial data is transmitted via the WRPM System, the project manager or estimator identifies the activity (approach road) and inserts data immediately with pictures shown on the right of the window. Project managers can easily identify and input the number of labors, equipment, and materials (Figure 4 and 5). The input data are used for calculating labor costs, material costs, and equipment costs as shown in Figure 3. The sum of those numbers is shown as estimated total cost. Thus, by estimating the cost and production rates, unit prices and durations are also estimated (estimated duration is not shown in Figure 3).
Figure 2. Time study using the WRPM

![Knowledge-Based Information System for Construction Cost Estimating and Scheduling](image)

**Figure 3. Graphical User Interface (GUI)**

![Dialog box when the user inputs Labor](image)

**Figure 4. Dialog box when the user inputs Labor**
PRELIMINARY FIELD DATA COLLECTION
Currently, the researchers are collecting data from a residential construction project in Pooler, GA (Figure 6). The primary objective of this field experiment is to test components of KISCCES, including the WRPM system and GUI.
DATA ANALYSES

Hypothesis

Cost data from the KISCCES will be compared with cost data from the experts group to determine whether the means of these two groups of data are the same. The null hypothesis and alternative hypothesis for these analyses are as follows:

\[ H_0 : \mu_d = 0 \]
\[ H_1 : \mu_d \neq 0 \]

where \( \mu_d \) is the mean difference of cost data estimated from the KISCCES and from the experts group (Figure 7).

To accomplish the objective, estimated costs and durations from the construction companies will be compared using statistical methods to determine if there is a significant difference between them. Researchers will utilize the Statistical Analysis System (SAS\textsuperscript{®}) to analyze the collected data. Three statistical analysis methods will be employed for the data analyses. First, data normality tests will be performed to determine whether data had a normal distribution, since data normality is a required assumption for the hypothesis test. Second, a paired t-test will be conducted as a parametric test to compare two dependent variables (two cost estimates) when data have a normal distribution. Finally, a nonparametric test, the Wilcoxon Signed Rank test, will be carried out for where data did not have a normal distribution.
CONCLUSIONS AND FUTURE RESEARCH DIRECTIONS

Existing cost estimating and scheduling take longer time because historical data are primary sources so it takes to longer to transmit data and pose difficulties for sharing and communicating data among participants involved in construction operations. To address these shortfalls, the WRPM System and the graphical user interface are developed. Field experiments will be conducted on bridge or commercial building construction projects to determine the system’s accuracy as the construction project management system. Statistical analysis results will prove that the developed project management system produces reliable cost and schedule data. Thus, the system can be utilized practically by the construction professionals.

Meeting these objectives will have the following significant project outcomes:

1. Be able to control costs of activities in nearly real-time basis.
2. Be able to develop a reliable and functional cost and schedule by reducing the level of uncertainty.
3. Be able to quickly manage construction job sites through better communication and coordination.

The research project will make several major contributions to the following areas in the construction industry. First, the research project will advance the applications of wireless technologies as well as effective utilization of construction field data management in the construction industry. The developed project management system in the KISCCES is capable of continuously collecting on-site construction productivity data and enhancing owners’ and contractors’ capability to manage construction projects by utilizing the virtually real-time database management system to increase project level cost estimates and project duration estimates. The use of the KISCCES holds promise for improving the level of communication between all parties with reliable project management outputs. Benchmark productivity data of the KISCCES will provide information on lost productivity, workflow management, and alternatives for productivity improvements. In addition, the KISCCES will also provide undergraduate or graduate students with the ability in class to address real world problems, such as inaccurate cost and schedule forecasting.

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