

Development of a Real-Time Productivity Measurement System for Bridge Replacement

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ABSTRACT

Increased attention has been paid to the highway bridges, one of the critical components of the nation's transportation network, since the terrorist attacks of September 11, 2001, Hurricane Katrina, and the tsunami in South Asia. To enhance the capability of rapid bridge replacement after extreme events, a real-time productivity measurement system has been developed. The developed system has the potential to enhance the capability of rapid bridge replacement by providing more accurate onsite productivity information. Using the information, a more reliable construction schedule could be developed to support the rapid bridge replacement operations. To validate the system, field experiments were conducted at U.S. Highway 36 near Washington, Kansas. This paper presents the major components of the developed system, the framework of the system, and the preliminary field experiment results.

Key words: bridge—construction—productivity—replacement

INTRODUCTION

The terrorist attacks on September 11, 2001, and subsequent potential threats to U.S. transportation systems, have presented an urgent need to develop emergency management plans to quickly react to the possible consequences of an extreme event. These events include terrorist attacks as well as man-made and natural disasters, such as explosions, fires, floods, and earthquakes. Highway bridges, as a critical component of the nation's transportation network, have received closer attention from government agencies. The reasons that bridges are the key element of the nation's transportation system are as follows (Barker and Puckett 1997):

1. A bridge controls the capacity of the system.
2. A bridge is the highest cost per mile of the system.
3. If a bridge fails, the system fails.

To respond to an extreme event, a developed emergency management plan must include four related components (Parsons Brinckerhoff 2002):

1. Mitigation: Steps taken in advance to reduce the potential loss from an extreme event.
2. Preparedness: Steps taken in advance to facilitate response and recovery after an extreme event.
3. Response: Steps taken during or immediately after an extreme event to save lives and property.
4. Recovery: Steps taken to restore the affected areas to their normal status.

Since September 11, 2001, several research projects have been conducted to identify the infrastructure's vulnerabilities and to help government agencies develop or update the emergency management plans with a focus on mitigation, preparedness, response, and recovery. The American Association of State Highway and Transportation Officials (AASHTO) recognized the need to address the nation's vulnerability assessment requirements for highway transportation and sponsored the development of a guide for critical asset identification and protection (SAIC 2002). The guideline's authors divided vulnerabilities in highway transportation into the following three general categories:

1. The physical facilities themselves (e.g., bridges, tunnels, roadways, and interchanges).
2. The vehicles operating on the system.
3. The information infrastructure that monitors and manages the flow of goods, vehicles, and people on the highway system.

This guide provides a starting point to identify and mitigate the vulnerability of and consequences to highway transportation assets from terrorist threats or attacks. A companion document, *A Guide to Updating Highway Emergency Response Plans for Terrorist Incidents*, also funded by AASHTO and developed in parallel with the previous guide, assists government agencies in preparing and executing a coordinated emergency response to terrorist threats or attacks to the highway transportation system (Parsons Brinckerhoff 2002). Besides these two guides, AASHTO and the Federal Highway Administration sponsored other research projects on bridge and transportation security. One project was titled *Design of Highway Bridges for Extreme Events*, which was supervised by the National Cooperative Highway Research Program (NCHRP). The objective of this research was to develop a design procedure for application of extreme event loads and combination loading to highway bridges (Ghosn et al. 2003). Another project was titled *Surface Transportation Security*, which was also supervised by the NCHRP. Results of this project were released in NCHRP Report 525 (2004).

State departments of transportation (DOTs) also initiated efforts to investigate and develop methods to lessen the impact of terrorist attacks and other extreme events on their transportation infrastructure. Two

recent research projects concentrated on bridges. One project was entitled *Design of Bridges for Security* and was intended to determine how bridges may be economically designed for security (Burkett et al. 2004). The other project was entitled *Rapid Bridge Replacement Techniques* and was intended to identify optimal bridge replacement and repair techniques (Bai and Burkett 2006). Bridge replacement techniques were to include both temporary and permanent replacement.

Results of previous research indicate that there is an urgent need to address the recovery component in the bridge emergency management plans. Specifically, one of the areas that must be improved in the recovery is to develop innovative technologies that could be used to produce an accurate and reliable construction schedule to support rapid replacement operations. For example, the estimated time for the replacement of the I-40 Webbers Falls Bridge started at 12 months, then went down to 6 months, and finished in a little over 2 months. Although the replacement was finished ahead of the original schedule, the process clearly indicated that an accurate and reliable schedule was unable to be produced and provided to the general public based on the existing construction technologies.

PROBLEM STATEMENT

Currently, most of the construction schedules are developed using the critical path method (CPM). A scheduler builds a CPM network based on durations of construction activities and relationships between activities with the consideration of resource constraints. Durations of activities are determined based on historical data (similar work done in the past) or estimation done by someone in the company (e.g., project manager, project engineer, or superintendent). Construction duration can be estimated using the following formula:

$$\text{Duration} = (\text{Quantity of Work}) / (\text{Construction Productivity}) \quad (1)$$

Because the quantity of work is relatively easy to determine accurately using printed drawings or a CAD system and specifications, the accuracy of the duration largely depends on the accuracy of construction productivity. There are many factors that will impact the construction productivity, such as weather, site condition, quality of supervision, complexity of each task, and labor skill level and age. To quantify these factors and to determine exactly how these factors impact the construction productivity are beyond the capability of current technology. Without accurate productivity data, it is not difficult to understand why a scheduler is unable to produce a reliable CPM schedule. In summary, poor productivity data impacts the accuracy of activity durations, and inaccurate activity durations make it impossible to produce a reliable construction schedule.

Productivity has been widely used as a performance indicator to evaluate construction operations through the entire construction phase. There are many methods that can be used to determine onsite construction productivity, such as questionnaires, activity sampling, still photography, time study, time-lapse filming, and full-time videotape recording (Adrian 2004; Oglesby et al. 1989). Among these methods, time study, also called stopwatch study, is the classic productivity measurement method developed by Frederick W. Taylor in 1880 (Meyers 1992). Since 1980, more and more construction companies have utilized time-lapse filming and full-time videotape recording methods due to the advancement of technologies and cost reductions for required equipment. However, these methods are conducted by employing additional people to manually collect data on the construction sites. As a result, using these methods increase costs, delay the analyses, and interfere with crew activities that may produce inaccurate data.

OBJECTIVE

The objective of this research project is to develop a prototype wireless real-time productivity measurement (WRITE) system that could be used to measure the onsite construction productivity for rapid bridge replacement. Using the real-time productivity data, engineers and project managers may be able to accurately determine bridge replacement progress and easily share the information with all parties involved in the bridge replacement project. Thus, the wireless real-time productivity measurement technology has great promise for improving construction schedule forecasts and increasing emergency response capability after extreme events.

DEVELOPMENT OF WRITE SYSTEM

The developed WRITE system includes a video camera, a digital camera, a data processor, an AC transformer, two antennas, and a laptop computer, as shown in Figure 1.



Figure 1. Major components of the WRITE system

The video camera and digital camera are housed in a steel box that can be mounted on a pole or wall. An operator can rotate the steel box horizontally (360 degrees) and vertically. The data processor, also called minicomputer, contains a software program called VM95 that can control the camera movement, the number of shots, the duration of a shot, and the zooming. A monitor, a keyboard, and a mouse are necessary items for the data processor to display real-time pictures and live video. The AC transformer transfers electric energy to other components. It can be mounted indoors or outdoors. Two antennas are used to transfer data wirelessly within a 12-mile range. Figure 2 shows the framework of the WRITE system.

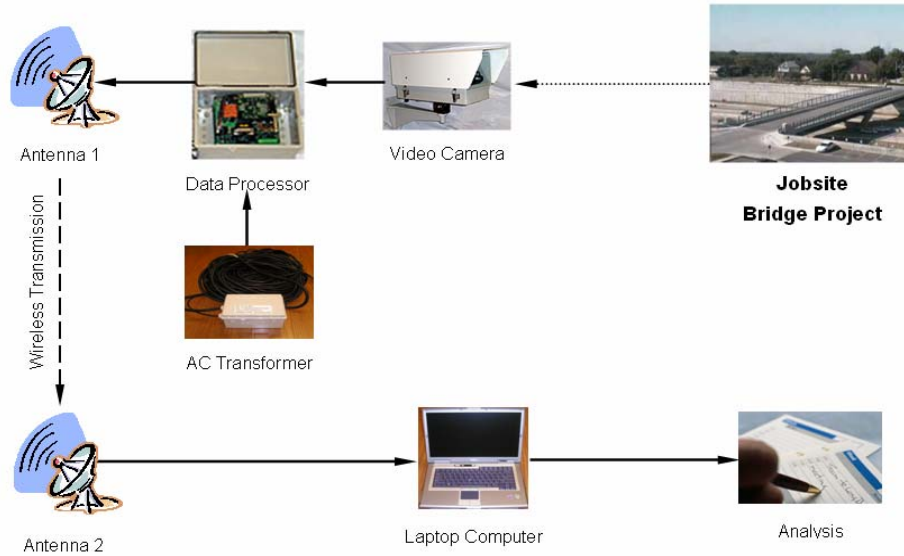


Figure 2. Framework of the WRITE system

In June 2007, researchers conducted field experiments on US-36 near Washington, Kansas. The main purpose of the field experiments was to determine if the developed WRITE system can be used to measure onsite productivity accurately. To accomplish this task, a comparison test was made between the productivity data collected by the WRITE system and the productivity data gathered using the stopwatch study, the classic productivity measurement method developed by Frederick W. Taylor. Figures 3 and 4 show the field experiment setup using the WRITE system and stopwatch, respectively.



Figure 3. Field experiment setup using the WRITE system on US-36



Figure 4. Data collection using stopwatch

These two time study methods were utilized to measure the onsite productivity for an asphalt paving construction project. The hypothesis for the analysis is as follows:

$$H_0: \mu_1 = \mu_2 \quad (2)$$

$$H_1: \mu_1 \neq \mu_2 \quad (3)$$

In the hypothesis test, μ_1 and μ_2 are means of cycle time for the asphalt paving construction measured by the WRITE system and stopwatch, respectively. The cycle time is the sum of working time (applying hot-mix asphalt to the desired width and thickness) and nonworking time (idle or waiting) of asphalt paving. For the preliminary experiments, a total of nine cycles were observed, and each cycles lasted for five minutes. Using the two-tail t test, the null hypothesis cannot be rejected at the significant level of 5% (t statistic = 0.022 < $t_{(0.025, 8)} = 2.306$). This result indicates that statistically there is no difference between the productivity measurements taken by the WRITE system and the stopwatch study.

CONCLUSION

After the September 11, 2001, terrorist attacks, Hurricane Katrina, and the tsunami in South Asia, rapid replacement of damaged infrastructure such as bridges after extreme events has received close attention from government agencies, engineering and construction communities, and the general public. To enhance the capability of rapid replacement of damaged infrastructure after extreme events, there is an urgent need to develop innovative technologies that could be used to produce an accurate and reliable construction schedule to support rapid bridge replacement operations. To respond to this emergency need, a wireless real-time productivity measurement system was developed and tested in a construction project site. The preliminary test results indicated that the developed system can measure the onsite construction productivity accurately. Additional field experiments are scheduled in the near future to fully test the system. Results will be reported at a later time. If successful, the capability of rapid bridge replacement will be improved significantly.

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