

Developing a Real-Time Basis Construction Cost Estimating and Scheduling (RBCCES) System

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The research project is to develop a Real-Time Basis Cost Estimating and Scheduling (RBCCES) System. The RBCCES System is 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 were performed as follows: conduct literature review, purchase necessary software and hardware, define measurement data for each activity, conduct field experiments in a residential construction project 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 RBCCES, the researchers conducted field experiments in a residential construction project and determined reliability of the estimated cost and schedule by statistically comparing it with estimates based on the most commercially available cost index. The developed project management system produces reliable cost and schedule data, which can be utilized practically by the construction professionals.

Key Words: Real-time, Productivity, 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 such as cost estimates and schedules.

Over the years, several productivity measurement techniques have been developed, including stopwatch study, photographic, time-lapse, GPS, and others (Fondahl, 1960, Oglesby et al., 1989, Abudayyeh, 1997, Everett and Halkali, 1998, Peyret and Tasky, 2002, Memon et al., 2005, Navon and Shpatnitsky, 2005) 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's 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. 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).

The objective of this research project is to develop a prototype of the Real-Time Basis Construction Cost Estimating and Scheduling (RBCCES) system. To accomplish the research goal, the researchers developed 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 determined whether the developed system could accurately estimate an activity, project level costs, and schedule in real-time. The system development has to be accomplished in multiple phases:

1. Develop the Wireless Real-Time Productivity Measurement (WRPM) system to collect on-site construction productivity data.
2. Develop a prototype Graphical User Interface (GUI) to estimate nearly real-time construction costs and schedules.
3. Conduct experiments at construction sites to test the RBCCES system.
4. Identify the current research's limitations and needs for future research improvements.

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 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. Previously, Seonghoon Kim and Yong Bai developed a Wireless Real-Time Productivity Measurement (WRPM) System as an on-site construction productivity measurement tool (Kim, 2011, Bai et al., 2012). 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.

Method

An urban earthmoving operation is defined as construction in an area where there is an increased density of man-made structures in comparison to the surrounding areas. In this research, two projects were selected from I-235 urban interchange reconstruction projects, both of which began and ended in 2004. Four different types of earthmoving operations were randomly selected from these interchange reconstruction projects. Equipment fleet for those operations included trucks and an excavator.

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 framework of the WRPM System was developed during the process of this research project as shown in Figure 2. 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. Using the WRPM, all parties in the project can share pictorial data in real-time.

Breakdown a Construction Project into Activity Levels

The work breakdown structure (WBS) is often used in the complex construction projects to identify project information, improve the efficiency of processes, and integrate the project cost and schedule in project management (Chua and Godinot, 2006, U.S. Department of Energy, 1997). In this research project, the residential construction project was broken down into three levels for the ease of measurement: level 1 (project type), 2 (activity), and 3 (operation), as shown in Figure 2. Each category was broken down into individual components, for example slab on grade, decking, wall, and roofing. To build each component requires resources such as labor, equipment, and material. After determining the activities, the next step is to define cost and schedule measurement data for each activity. In addition, quantity survey for each activity was conducted using commercially available software called "OST (OnScreen Takeoff)" as shown in Figure 3.

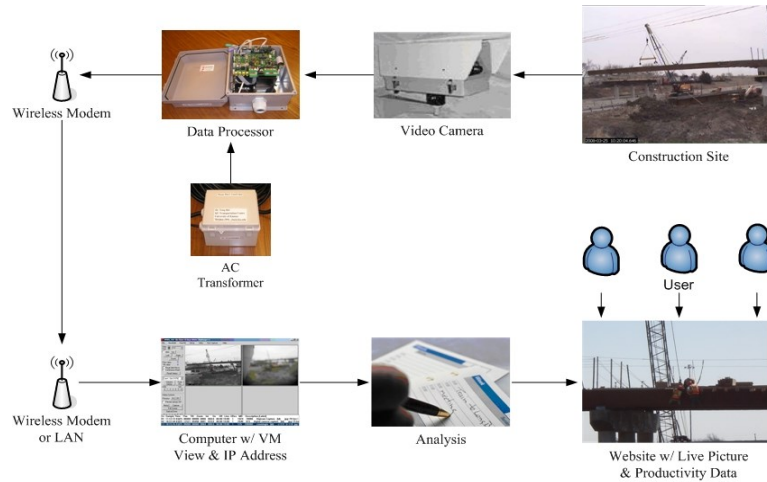


Figure 1: Framework of the WRPM System

Level 1 (Project)	Level 2 (Activity)	Level 3 (Operation)	Unit	Quantity	Duration (days)	Crew No.	Unit Price	
							RBCCES	RS Means
Residential Construction (Apartment in Pooler)	Slab on Grade	Footing	cy	194	5.00	12		
		Vapor Barrier for slab	sf	12096	0.25	5		
		Rebar for slab	ton	na	2.00	5		
		Forming for slab	sfca	na	1.00	6		
		Posttensioning	lf	3250	0.50	5		
		Placing Concrete	cy	149	1.00	13		
		Stripping form	sfca	na	0.25	4		
	Decking	1st Floor	sf	12096	2.00	4		
		2nd Floor	sf	12096	3.00	7		
		3rd Floor	sf	12096	4.00	6		
	Wall	1st Floor	MBF	11	3.00	6		
		2nd Floor	MBF	10	5.00	5		
		3rd Floor	MBF	11	3.00	8		
	Roofing	Truss	sf. Floor	12096	2.00	6		
		Decking	sf	13396	2.00	3		

Figure 2: Work Breakdown Structure (WBS) for Residential Building

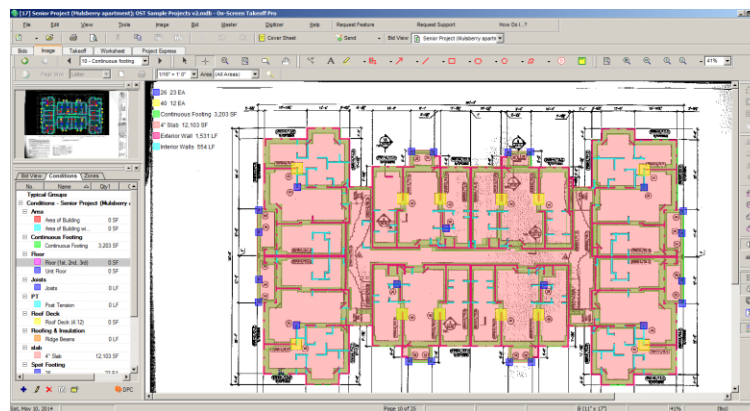


Figure 3: Quantity Survey of each operation Using OST (OnScreen Take-off)

Data Collection

Upon completion of development of RBCCES System, the researchers conducted field experiments to collect pictorial data wirelessly. The field experiments addressed the following questions: Does the WRPM system (for data integration) work as planned? What areas should be improved? The objective of these experiments was to determine whether the integrated system is an accurate tool for measuring productivity and estimating accurate cost and duration.

Category	Cost
Labor	\$ 546.51
Materials	\$ 843.25
Equipment	\$ 253.58
Estimated Total Cost	\$ 15490.16

Figure 4: Graphical User Interface (GUI)

To achieve real-time cost and schedule estimating, a prototype graphical user interface (GUI) using Java programming was created, as shown in Figure 4. The GUI was 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 (e.g. 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 5). The input data are used for calculating labor costs, material costs, and equipment costs. 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.

	# of People	# of Hours	Hourly Rate	Total		# of People	# of Hours	Hourly Rate	Total
<input checked="" type="checkbox"/> Operator Foreman	1	3	\$ 34.25	\$ 102.75	<input type="checkbox"/> Operator			\$ 32.25	\$ 0
<input type="checkbox"/> Gradechecker			\$ 32.25	\$ 0	<input type="checkbox"/> Carpenter Foreman			\$ 29.75	\$ 0
<input type="checkbox"/> Carpenter			\$ 28.5	\$ 0	<input type="checkbox"/> Labor Foreman			\$ 24.0	\$ 0
<input checked="" type="checkbox"/> Laborer	3	3	\$ 19.75	\$ 177.75	<input type="checkbox"/> Flagger			\$ 19.75	\$ 0
<input type="checkbox"/> Concr/Pipe/GC Lab			\$ 21.5	\$ 0	<input checked="" type="checkbox"/> AC/Driller	1	3	\$ 22.67	\$ 68.01
<input type="checkbox"/> Powderman			\$ 22.67	\$ 0	<input type="checkbox"/> Mason Foreman			\$ 34.25	\$ 0
<input checked="" type="checkbox"/> Mason	2	3	\$ 33.0	\$ 198.0	<input type="checkbox"/> Teamster-4mg			\$ 24.75	\$ 0
<input type="checkbox"/> Teamster-Foreman			\$ 28.5	\$ 0	<input type="checkbox"/> Transp/Rock/Pull			\$ 27.75	\$ 0

Figure 5: Dialog box when the user inputs Labor

The researchers collected data from a residential construction project (Figure 6). Recently, the residential building construction has been continuous gain in revenue and experience in lack of skilled labor as the baby boomer ages (Lasalle, 2013). The primary objective of this field experiment is to test components of RBCCES, including the WRPM system and GUI in order to determine that the real time system can be used as reliable as RS Means, which is used as the most widely used cost index in U.S (Figure 7).

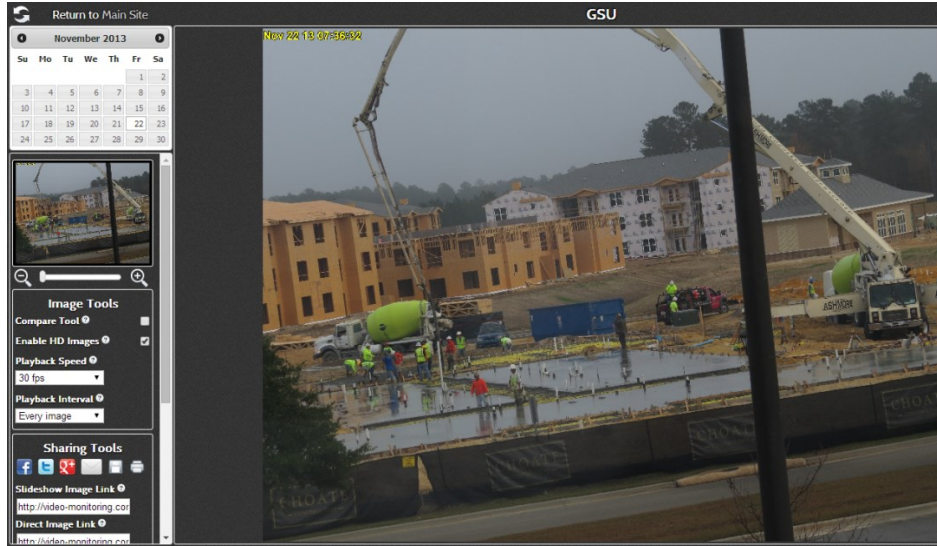


Figure 6: Data Collection from a Residential Construction Project (Slab on Grade Concrete Placement)

Level 1 (Type)	Level 2 (Activity)	Level 3 (Operation)	Unit	Quantity	Duration (days)	Crew No.	RBCCES				RS means			
							Unit Price	Material	Labor	Equipment	Unit Price	Material	Labor	Equipment
Residential Consturction (Apartment in Pooler)	Slab on Grade	Footing	cy	194	5.00	12	205.39	122.00	82.89	0.50	197.00	122.00	74.50	0.50
		Vapor Barrier for slab	sf	12096	0.25	5	5.28	5.20	0.08		14.20	5.20	9.00	
		Rebar for slab	ton	na	2.00	5								
		Forming for slab	sfcu	na	1.00	6								
		Posttensioning	lf	3250	0.50	5	0.33	0.13	0.21		0.17	0.13	0.05	
		Placing Concrete	cy	149	1.00	13	132.53	103.00	23.38	6.15	126.60	103.00	17.45	6.15
		Stripping form	sfcu	na	0.25	4								
	Decking	1st Floor	sf	12096	2.00	4	0.76	0.58	0.18		1.11	0.58	0.53	
		2nd Floor	sf	12096	3.00	7	1.05	0.58	0.47		1.11	0.58	0.53	
		3rd Floor	sf	12096	4.00	6	1.11	0.58	0.53		1.11	0.58	0.53	
	Wall	1st Floor	MBF	11	3.00	6	805.20	375.00	430.20		975.00	375.00	600.00	
		2nd Floor	MBF	10	5.00	5	1014.20	375.00	639.20		975.00	375.00	600.00	
		3rd Floor	MBF	11	3.00	8	982.54	375.00	607.54		975.00	375.00	600.00	
	Roofing	Truss	sf. Floor	12096	2.00	6	3.01	2.52	0.27	0.22	3.24	2.52	0.50	0.22
Decking		sf	13396	2.00	3	0.54	0.42	0.12		0.89	0.42	0.47		

Figure 7: Operation level Unit Prices for RBCCES and RS means

Results

The two-step approach was employed for the data analyses using the Minitab®. First, a data normality test, the Mann-Whitney test were performed to determine whether data had a normal distribution, since data normality was a required assumption for the hypothesis test using the paired t-test. Second, if data had a normal distribution after normality tests, a paired t-test would be conducted as a parametric test to compare two cost estimates. If data did not have a normal distribution, the Mann-Whitney test would be carried out. The first four columns, (1) to (2) of Table

I show the description of measurement data and the rest of Table 1 shows p values of normality tests and comparison tests.

Hypothesis

Cost data from the RBCCES were compared with cost data from the RS Means Building Construction Cost Data (Spencer, 2010) to determine whether the means of these two groups of data are statistically the same. The construction cost data is the most commonly used construction cost index in the U.S. The null hypothesis and alternative hypothesis for these analyses are as follows:

$$\begin{aligned} H_0 : \mu_d &= 0 \\ H_1 : \mu_d &\neq 0 \end{aligned} \quad (1)$$

where is μ_d the mean difference of cost data estimated from the RBCCES.

Normality Tests

Two normality tests, the Ryan-Joiner test and the Anderson-Darling test, were conducted to determine if the experimental data followed normal distribution, as shown in Table 1. As shown in columns 3 and 4 of Table 1, for computed p values of <0.01 and <0.005, lower than the significance level of 5%, the null hypothesis that measurements follow normal distribution was rejected at the significance level of 5%. This means that at this significance level, unit cost prices of operations estimated using RBCCES and RS Means were not normally distributed. Therefore, it was concluded that a nonparametric test, the Mann-Whitney Test, was employed to analyze the data. The most powerful nonparametric test is used for comparing two populations (Easton and McColl, 2006). In addition, data with non-normality were transformed to normally distributed data to conduct a hypothesis test, paired t-test.

Comparison Tests

A nonparametric test, the Mann-Whitney test, was utilized to determine whether two populations have the same population median (η). As shown in columns 5 of Table 1, test results indicated that the null hypothesis was accepted at the 5% significance level because a computed p-value, 0.9081, was greater than the value of 0.05. Thus, statistically, there were no differences in the median values of the two cost estimating methods between RBCCES and RS Means. Analysis results indicated that, statistically, two compared cost estimates were the same.

After transforming non-normality data to normally distributed data, the paired t test was conducted to determine if there were significant differences between cost estimates using RBCCES and RS Means. Using the two-tail t test, the null hypotheses cannot be rejected at the 5% significant level because a computed p-value, 1.00, was greater than the value of 0.05, as shown in columns 6 of Table 1. These results indicated that statistically there were no differences between these two cost estimates methods.

Table 1 Description of Data and Results of Data Analysis

Variable	Number of Data	Normality Test (P value)		Comparison Test (P value)	
		Ryan-Joiner	Anderson-Darling	Mann-Whitney	Paired t-test (After Data transformation)
(1)	(2)	(3)	(4)	(5)	(6)
Unit Prices of Operations	12	<0.01	<0.005	0.9081	1.00

Conclusions and Future Research Directions

Existing cost estimating and scheduling have limitations to be accurate and response fast because historical data are primary sources so it takes 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 were developed. Field experiments were conducted on a residential building construction project to determine the system's accuracy as the construction project management system. The statistical analysis results proved that the developed project management system produces reliable cost and schedule data compared to the most leading cost index in the U.S. Therefore, the system can be utilized practically by the construction professionals.

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 RBCCES is capable of continuously collecting on-site construction productivity data and enhancing owners' and contractors' capability to manage construction projects by utilizing real-time database management system to increase project level cost estimates and project duration estimates. The use of the RBCCES holds promise for improving the level of communication between all parties with reliable project management outputs such as cost estimates and schedules. In addition, the RBCCES will also provide undergraduate or graduate students with the ability in class to address real world problems, such as inaccurate cost and schedule forecasting. Moreover, the system can be utilized to resolve buildability and constructability issues with more detailed construction practice analyses (Jarkas and Bitar, 2012).

Previously, a computer vision-based video interpretation model was developed to automatically extract productivity information from videos of construction operations in real-time (Gong and Caldas, 2010, Bai) If the RBCCES System can use these image process technologies, cost estimating and scheduling processes would be performed with greatly reduced effort and cost. Although current technology has improved productivity measurement speed, data collection effort, and data cost, developed models may not be as practical and fast as required by the construction industry. Currently, the research team aims to develop the RBCCES System with the image process technology (Figure 8). If the research project is successful, construction professionals will be able to control costs of activities in a real-time, 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.



Figure 8: Image Processing for Detection Equipment (Kim et al.)

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