AUTOMATED PROGRESS MEASUREHEMT FOR CONTRUCTION PROJECT

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ABSTRACT: The progress is widely used as a critical index for successful construction project management. In spite of the importance of progress measurement, the excessive management effort to collect and maintain detailed data has been highlighted as a major barrier to measurement of highly accurate progress. In order to reduce the required workload and to enhance accuracy, several researches have been conducted. These researches can be categorized into two groups. First group focuses on automated data collection utilizing advanced technologies only for limited construction tasks. The second group is a research area where the standard progress measurement methodologies encompassing entire construction tasks are investigated. Topics include the adjusting the level of details, standardizing work processes, and applying flexible WBS. However, the techniques for automated data collection are not fully investigated yet in the second group. Combining these two research areas can provide a solution for more effective progress management in terms of enhancing accuracy and optimizing workload. However, there has been no comprehensive research addressing these two research groups in an integrated manner. In this context, the purpose of this paper is to propose a methodology that identifies the most suitable measurement method and data acquisition technology (e.g., GPS, RFID, etc.) for entire construction tasks of a project. The proposed methodology in this paper will be able to facilitate the selection process of data acquisition technologies for entire construction tasks of a project and to support the overall enhancement of automated progress management.

Keywords: Progress Management, Progress Measurement, Automated Data Collection, Data Acquisition Technologies

1. INTRODUCTION

The construction progress is valuable information for monitoring current status and forecasting future risks. Thus, the progress is widely used as a critical index for successful construction project management.

In order to ensure effective progress management, timely gathering of highly accurate progress data on construction sites is required.

These accumulated data on progress measurement are considered important not only for the related project, but also for use in future projects.

In spite of the importance of progress measurement, the excessive management efforts (or workload) to collect and maintain detailed data has been highlighted as a major barrier to measurement of highly accurate progress.

For instance, McCullouch (1997) indicates that 30~50% of the site manager's duty hours is spent on collecting and analyzing site data, making it difficult to effectively gather site progress data.

Various researches are being conducted to address a key obstacle to progress management: workload optimization. These researches can be categorized into two groups.

The first research group, which focuses on the automation of construction data gathering, uses advanced data acquisition technology (DAT) such as barcode, radio frequency identification (RFID), global positioning system (GPS), 3D laser scanner, PDA, etc.

However, the application of automated data collection is limited to specific construction tasks (for example, formwork, structural steel, and other task types). The research group related automated data collection also focuses only on core technologies (for example, RFID and GPS), thus having limitations.

The second group is a research area where the standard progress measurement methodologies encompassing entire construction tasks are investigated. Topics include a flexible WBS that can determine of the levels of details based on the importance of the work package, quantifying the workload, standardizing work processes, and the automatic creation of results-based standard work packages.

However, the techniques for automated data collection are not fully investigated yet in the second group.

Combining these two research areas can provide a solution for more effective progress management in terms of enhancing accuracy and optimizing workload.

However, there has been no comprehensive research addressing these two research groups in an integrated method.

Based on the characteristics of various construction task types, appropriate automated progress measurement patterns (for instance, tracing labors to measure the progress, etc.) and kinds of DAT for progress measurement differ, but there has been no study yet in this regard.

Against such a backdrop, this research aims to propose a methodology for selecting Automated Progress Measurement Pattern (APMP) and DAT according to the characteristics of construction task type for automated progress measurement, from the perspective of construction projects.

2. RESEARCH ON AUTOMATED PROGRESS MANAGEMENT

Various researches are being conducted to reduce the workload of progress management in construction projects, as mentioned. The research areas are divided into automation of construction data gathering and automation of WBS creation.

2.1 Research on Automated Construction Progress Data Collection

Navon and Goldschmidt (2002 and 2003) monitored labor injection location in real time and examined whether the related work would be completed. Sacks et al. (2003) monitored labor location information by attaching GPS receivers to labors' helmets, and developed a model for converting such monitored information into labor injection location and time information.

Navon (2005 and 2007) also proposed a model for the use of DAT, the tracing of the labor injection location, the tracing of labors, and the model of civil engineering equipment and tower cranes.

There are other DAT-based researches such as a research on using RFID technology to manage concrete purchasing and tracing (Jaselskis et al., 1995), a research on using 3D laser scanning technology to measure soil volume (Jaselskis et al., 2005), and a research on monitoring road surface subsidence (Chang et al., 2005).

2.2 Research on the Automation of Standardized WBS Creation

Jung and Woo (2004) proposed a measure for minimizing administrative workload using a flexible WBS, and a methodology for quantifying workload. Jung (2005) conducted follow-on researches on these subjects, and defined five project variables that influence workload.

Jung and Kang (2007) defined company-wide common criteria for measuring performance results and developed standard progress measurement packages aimed at objectively measuring results.

The structure of these criteria properly reflects the characteristics of each project. To select work packages that are suitable for specific work sites and to boost the reliability of the results data accumulation, evaluation factors and adequacy evaluation measures were defined.

Based on numerous projects' results data accumulation and database development, Jung and Kang (2007) also developed a methodology to automatically generate the WBS of projects. Zhang et al. (2009) and Ibrahim et al. (2009) also proposed a semi-automated progress measurement system using computer vision.

3. AUTOMATED PROGRESS MEASUREMENT PATTERN

This research examined construction data gathering automation, and thus defined the factors of the selection of APMPs and determined APMP and DAT alternatives via APMPs.

Search years: 1995 - 2008	
ASCE Journal	17
Automation in Constr.	8
Korea Institute of Constr. Engineering and Management	8
Architectural Institute of Korea	5

Factors of selection	**Detailed items**	**Description**
Target of progress measurement	Labor	Laborers by work type
	Material	Materials and materials packaging boxes
	Equipment	Transportation equipment, earth work equipment, and lifting equipment
	Document	Work diaries and invoices
Scope of progress measurement	Site gate	Measurement of site carry-in and carry-out progress details
	Physical Breakdown (Locator)	Project, Section of Works, One Building, An assemble, Floors, zone, etc.
	Scope of measurement not specified	In case progress measurement is possible, regardless of the measurement place
Levels of automation of progress measurement	Automated	Progress measurement that depends on DAT 100% (GPS, RFID, etc.)
	Semi-automated	DAT + human measurement (RFID, Barcode, PDA, etc.)
Type of progress information measured	Location information	Tracing movement paths of targets of progress measurement
	Carry-in and carry-out information	Whether to inject targets of progress measurement into work places
	Image	Image of work situations
	Work volume	Work volume as specified in documents

Figure 1. Factors for Developing Automated Progress Measurement Pattern

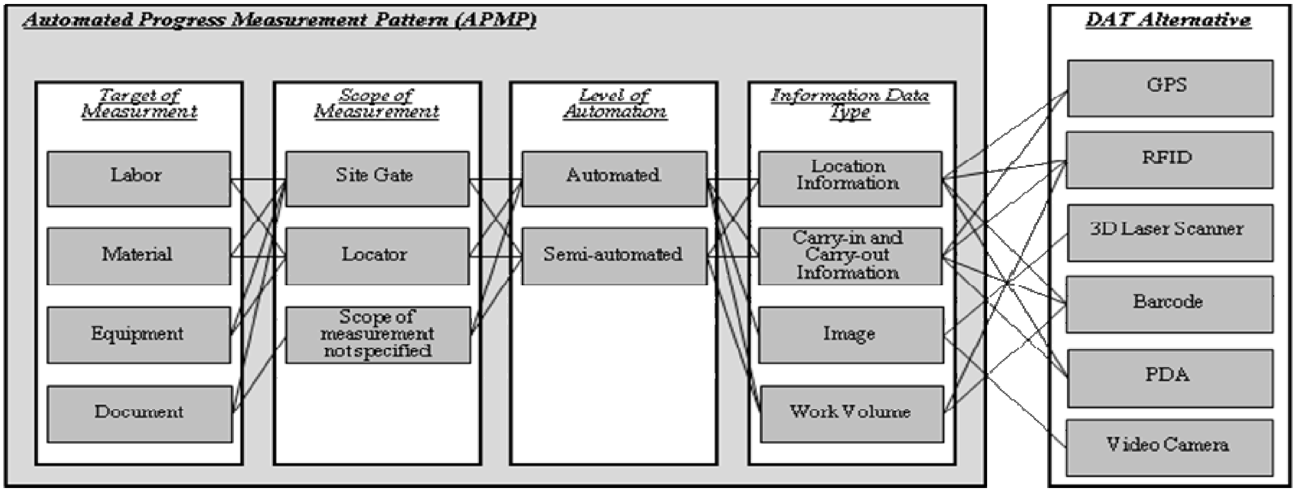


Figure 2. Automated Progress Measurement Pattern Determination Diagram

3.1 Factors of APMP Development

This study defined four APMP selection factors and details, namely, the target of the progress measurement, the scope of the progress measurement, the levels of automation of the progress measurement, and the type of progress information to be measured. These were examined based on a study on construction progress automation (Figure 1).

The target of the progress measurement includes the labors, materials, equipment, etc. that constitute the criteria for measuring the progress. The scope of the progress measurement includes the location of the labors and the borderline areas or points from which carry-in or carry-out details are measured. he levels of automation of the progress measurement are the factors that satisfy the comprehensibility of the progress measurement (automation and semi-automation measurement). The type of progress information measured refers to the type of progress data gathered by the progress measurement DAT, and constitutes the basic data for the calculation of the progress of work packages.

3.2 Developing APMPs

This study created 96 APMPs by combining detailed items of four APMP selection factors (Figure 2).

Not all the 96 APMPs were applicable, though. For instance, equipment (the target of the progress measurement), the site gate (the scope of the progress measurement), automation (the level of automation of the progress measurement), and the Image (the type of progress information measured) are impossible to measure or else their measurement would be ineffective. Such impossible or ineffective APMPs can occur.

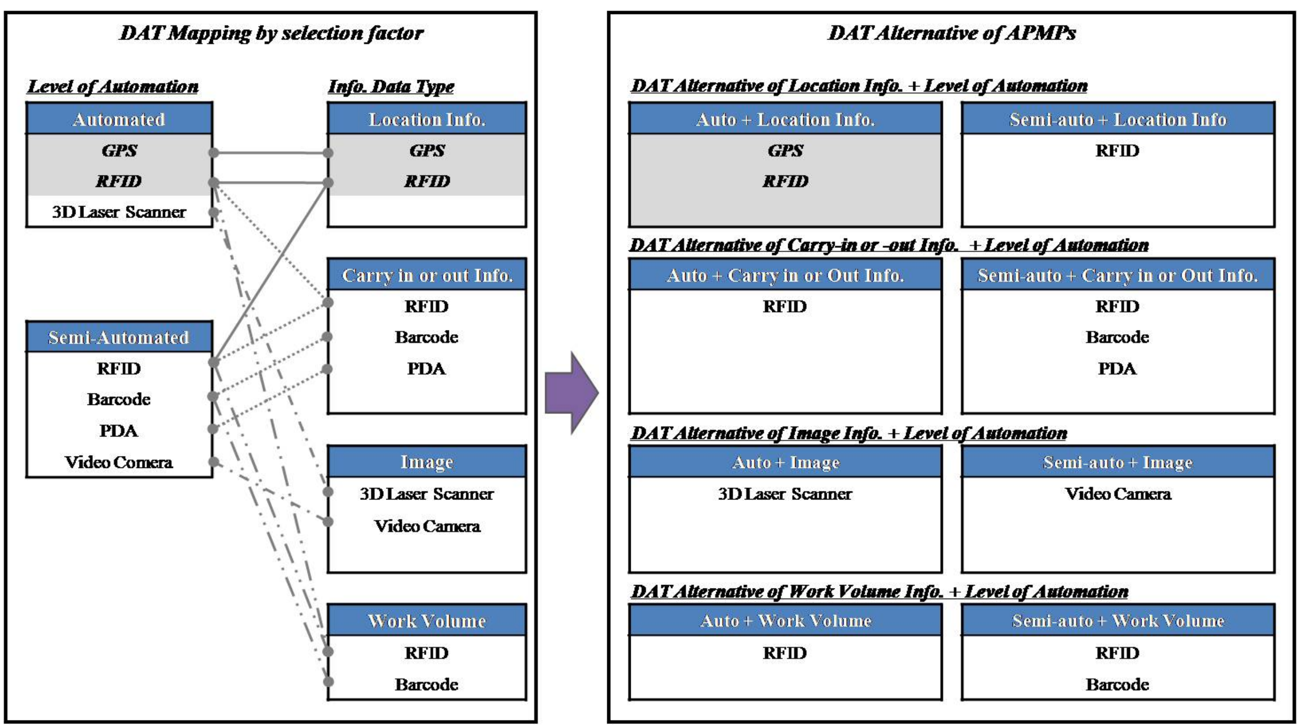
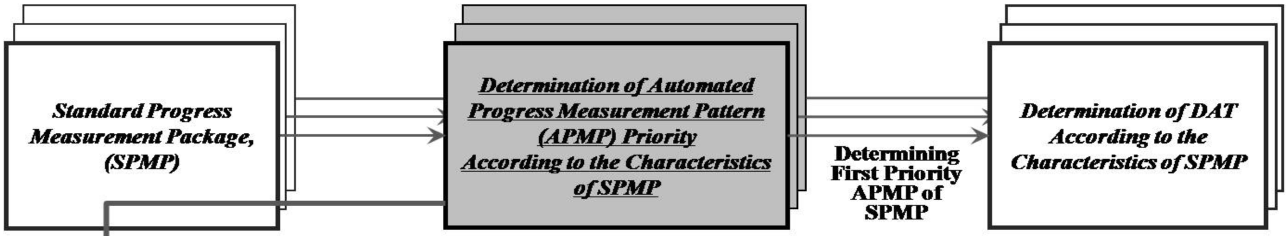


Figure 3. Method of Selection of the Progress Measurement DAT Alternatives for Each APMP



APMP Selection Factor	Evaluation Basis	Point
①Target of progress measurement	Possibility of progress measurement by each target	1point or 0point
②Scope of progress measurement	Similarity to locator of SPMP at database	1point~5point
③Level of automation of progress measurement	Feasibility of information type gathering	0.6point~1point
④Type of progress information measured	Adequacy of information type	1point~5point
⑤Possibility of progress measurement	Possibility of progress measuremnt	1.2point, 0.8point, 0point
APMP Priority Score = (② + ④) * ③ * (① * ⑤)		

Figure 4. Determination Method of APMP Priority According to the Characteristics of SPMP

Thus, to pinpoint the types of progress that are impossible to measure or the measurement of which would be ineffective, the mutually influential relationship between APMP selection factors was examined, from which 17 applicable APMPs were determined.

3.3 DAT Alternatives for Each APMP

The kinds of progress measurement DAT that are directly influenced by APMPs (Figure 3), and that are thus applicable DAT alternatives for all APMPs, were determined.

The DAT alternatives for each APMP were automatically selected by mapping out the DAT for each detailed item on the information type, and the DAT for each detailed item on the levels of automation (Figure 3).

For instance, when the DAT (GPS and RFID) that is applicable to the detailed item on the information type, i.e., the location information, is mapped out with the DAT (GPS, RFID, 3D Laser Scanner) that is applicable to the detailed item on the levels of automation, the DAT alternatives for the APMPs with automated automation levels and the information type of which is the location are GPS and RFID, as selected (the bold and italic figures in Figure 3).

4. APMP PRIORITY DETERMINATION

To determine the APMPs in line with work packages, this study proposed a priority score calculation method, and determined the APMP priority scores for concrete work.

4.1 APMP Priority Score Calculation Method

Each work package for progress measurement has 17 applicable APMPs, the most suitable of which should be selected in line with the related work package.

Thus, this study proposed a method of assessing the APMP priority. The priority score was calculated according to the score of the four selection factors and the score of the progress measurement possibility levels (Figure 4). The calculation equation used is as follows.

APMP priority score = {(progress measurement scope score + progress measurement information type score) × progress measurement target score × progress measurement scope score × progress measurement possibility level score}

First, in line with the characteristics of work packages for progress measurement, determine the possibility of measuring the progress of the achievement of the targets.

Second, the score for the detailed items on the progress measurement scope is automatically calculated according to the similarity with the size of the locator size, which is predetermined in the progress measurement work package.

Third, the score for the detailed items on the measured progress information types is automatically calculated according to the adequacy of the progress data on the related measured progress information types, in association with the progress measurement scope.

Fourth, the score for the detailed items on the progress measurement automation levels is automatically calculated according to the ease of gathering, in association with the automation levels of the detailed items on the progress measurement.

Fifth, in line with the characteristics of work packages for progress measurement, the levels of progress measurement possibility for related progress measurement types are examined based on nine considerations.

4.2 Calculation of the APMP Priority Score for Concrete Work

This study applied the APMP priority score calculation method for the target of concrete work.

Table 1. The Calculated APMP Priority Score in Concrete Work (An Example)

Target of progress measurement		Scope of progress measurement		Level of automation of progress measurement		Type of progress information measured		Level of possibility	Priority score
Detailed items	Score	Detailed items	Score	Detailed items	Score	Detailed items	Score		
Equipment	1	Site Gate	5	Automated	1	Carry-in/out	5	1.2	12
Equipment	1	Locator	5	Automated	1	Carry-in/out	5	1	10
Labor	1	Locator	5	Automated	1	Location	5	1	10
Equipment	1	Locator	5	Automated	1	Location	5	0.6	6
Labor	1	Locator	5	Automated	0.9	Carry-in/out	5	0.6	6
Labor	1	Locator	5	Semi-Automated	1	Carry-in/out	5	0.6	5.4

As mentioned, the score for the progress measurement scope, the measured progress information types, and the levels of progress measurement automation was automatically calculated from the established information on the work packages for the concrete work, and the score for the progress measurement targets and the progress measurement possibility was determined according to the judgment of the manager.

The calculated APMP priority score for concrete work is shown in Table 1. The progress measurement types such as the “equipment - site gate – automation - carry-in and carry-out information” had the highest priority.

Specifically, in the case of concrete work, it was concluded that the most appropriate APMP is that by which the carry-in and carry-out information (the information type) on ready-mix-concrete trucks (the target of measurement) is automatically (the level of automation) calculated on the site gate (the scope of the measurement). By comparing the measured work volume and the planned work volume, the progress of the concrete placement onto the related floor can be calculated.

5. DAT SELECTION METHOD

APMPs with two or more DAT alternatives call for the selection of the DAT that is suitable to the related progress measurement package work. The APMP with RFID as a DAT alternative also calls for the selection of an appropriate RFID for diverse RFID types.

5.1 Considerations for Selecting the APMP DAT

This study determined the following five considerations for selecting the DAT that is suitable to the related work package.

The first consideration is the type of storage for the progress data, which is classified into the type in which only the unique ID of the progress measurement target is recorded, which thus synchronizes with the databases, and the type that includes diverse information in addition to the information on the ID of the progress measurement target. For the unique ID type, GPS and FID-Active are applicable; and for the type that involves other information, RFID-passive and barcode are applicable.

Table 2. Method of DAT Selection According to the Characteristics of SPMP

Combination of Selection Factors	DAT Alternative	Selection Method
Automation - Location Info.	GPS RFID-Passive RFID-Active	1)Data storage type (GPS/RFID-Active vs. RFID-Passive) 2)Work environment (GPS vs. RFID-Active) 3)Whether or not to revise the data (RFID-Read/Write vs. RFID-Read Only)
Semi-automation - Carry-in/out Info.	RFID-Passive Barcode PDA	1)Data gathering method (RFID/Barcode vs. PDA) 2)Whether or not to revise the data (RFID-Read/Write vs. RFID-Read Only) 3)Ability of the DAT (RFID-Read Only vs. Barcode)
Semi-automation – Work Volume	RFID-Passive Barcode	1)Whether or not to revise the data (RFID-Read/Write vs. RFID-Read Only /Barcode) 2) Ability of the DAT (RFID-Read Only vs. Barcode)
Automation - Carry-in/out Info Automation – Work Volume	RFID-Passive RFID-Active	1)Data storage type (RFID-Active vs. RFID-Passive) 2)Whether or not to revise the data (RFID-Read/Write vs. RFID-Read Only)
Semi-automation - Location Info	RFID-Passive	1)Whether or not to revise the data (RFID-Read/Write vs. RFID-Read Only)

The second consideration is the working environment, which is classified into the external and internal working environment. This is considered in determining the DAT of the APMPs the progress of which is measured via position tracking. In external working spaces, GPS is applicable; and in internal working spaces, RFID-active is applicable.

The third consideration is whether or not to revise the progress data. When the progress data that are recorded in tags need to be revised, the RFID-Read/Write type should be applied; and when the progress data do not need to be revised, the RFID - read-only type should be applied.

The fourth consideration is the progress data gathering method, which is classified into the semi-automatic gathering method, by which the information on the tags affixed to the targets of the progress measurement through the reader is recognized, and the manual gathering method, in which the information is directly recorded. For the semi-automatic gathering method, RFID and barcode are applicable; and for the manual gathering method, PDAs are applicable.

The last consideration is the ability of the DAT. The recognition distance, the possibility of multiple reading, the information quantity of the data, and the durability should be examined for the selection of an appropriate DAT.

For the selection of the APMP DAT, these five considerations should be taken into account according to the combination characteristics of the selection factors (Table 2).

5.2 Selection of the APMP DAT for Concrete Work

In the case of concrete work, the equipment, the site gate, automation, and the carry-in and carry-out information were the priority APMPs (Table 1). These APMPs' DAT alternative is RFID, and an appropriate type of RFID needs to be determined of diverse types.

Thus, as shown in Table 2, the progress measurement DAT method was applied to the automation and the carry-in and carry-out information. In association with (1) the type of storage of the progress data and (2) whether or not to revise the progress data, the DAT was selected to measure the progress of concrete work.

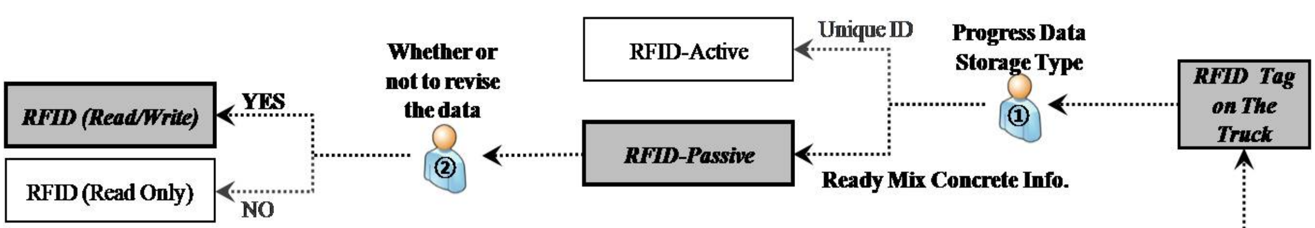
In the case of the type of storage of the progress data, the tags need to contain an ID, the ready-mix-concrete volume, and other information. Thus, the RFID-passive type should be applied. In the case of whether or not to revise the progress data, since the tags affixed to the trucks are reutilized and their information is changed, the RFID-read/write type was selected (Figure 5).

6. CONCLUSION

From the overall perspective of a construction project, with a view to reducing the comprehensive progress management workload, this study proposed automation methods for progress measurement in association with the characteristics of each work package for progress measurement, such as the APMP selection methodology, the APMP priority score selection methodology, and the DAT selection methodology. These methodologies were applied to a particular work package (concrete work) in this paper in order to illustrate the methodology in detail.

This study most significantly suggests that, from the viewpoint of the entire project, it is possible to offer individual progress measurement automation methods that are most suitable to all work packages for progress measurement.

It is also possible to offer results-based standard automation methods for progress measurement by work package. Specifically, based on the accumulation and analysis of results data, priority APMPs by work packages for progress measurement and the accompanying progress measurement DAT can be continually reinforced as a company-wide standard.



Automated Progress Measurement Patterns (APMP) of Concrete Work

Target of Progress Measurement	Scope of Progress Measurement	Level of Automation	Type of Progress information	Possibility of Progress Measurement	APMP Priority Score	DAT Alternatives		
						GPS	RFID	Barcode
Equipment (1)	Site Gate (5)	Automation (1)	Carry-in/out (5)	(1.2)	12		V	
:	:	:	:		:	:	:	
Equipment (1)	Locator (5)	Automation (1)	Location (5)	(0.6)	6	V	V	
:	:	:	:		:	:	:	

Figure 5. DAT Selection Procedure Targeting Concrete Work

It is deemed that the proposed methodologies will optimize the progress management workload, enhance progress measurement accuracy and timeliness, standardize and objectify progress measurement methods and indices, and improve the efficiency of the accumulation and reutilization of results data, so as to contribute to the development of overall progress management automation infrastructure for construction projects.

Based on these proposed methodologies, a follow-on study will be conducted on the most suitable progress measurement automation methods for all work packages in sample projects (progress measurement types and DAT for progress measurement).

REFERENCES

[1] Jaselskis, E. J., Gao, Z., and Walters, R. C., “Improving Transportation Projects Using Laser Scanning”, *Journal of Construction Engineering and Management*, ASCE, 131(3), 377-384, 2005.

[2] Jaselskis, E. J., Anderson, M., Jahren, C. T., Rodriguez, Y., and Njos, S., “Radio-Frequency Identification Applications in Construction Industry”, *Journal of Construction Engineering and Management*, ASCE, 121(2), 189-196, 1995.

[3] Jung, Y., “Integrated Cost and Schedule Control: Variables for Theory and Implementation”, *Proceedings of the Construction Research Congress 2005*, ASCE, San Diego, USA, 2005.

[4] Jung, Y. and Woo, S., “Flexible Work Breakdown Structure for Integrated Cost and Schedule Control”, *Journal of Construction Engineering and Management*, ASCE, 130(5), pp. 616-625, 2004.

[5] Jung, Y., and Kang, S., “Knowledge-Based Standard Progress Measurement for Integrated Cost and Schedule Performance Control”, *Journal of Construction Engineering and Management*, ASCE, 133(1), pp. 10-21, 2007.

[6] McCullouch, B., “Automating Field Data Collection in Construction Organizations.”, *Proceedings of 4th Construction Congress*, ASCE, Minneapolis, Minnesota, USA, 1997.

[7] Navon, R., “Automated Project Performance Control of Construction Projects”, *Automation in Construction*, 14(4), 467-476, 2005.

[8] Navon, R., “Research in Automated Measurement of Project Performance Indicators”, *Automation in Construction*, 16(2), 176-188, 2007.

[9] Navon, R. and Goldschmidt, E., “Monitoring Labor Inputs: Automated-Data-Collection Model and Enabling Technologies”, *Automation in Construction*, 12(2), 185-199, 2002.

[10] Navon, R. and Goldschmidt, E., “Can Labor Inputs be Measured and Controlled Automatically?”, *Journal of Contruction Engineering and Management*, ASCE, 129(4), 437-445, 2003.

[11] Sacks, R., Navon, R., and Goldschmidt, E., “Building Project Model Support for Automated Labor Monitoring”, *Journal of Computing in Civil Engineering*, ASCE, 17(1), 19-27, 2003.

[12] Zhang, X., Bakis, N., Lukins, T.C., Ibrahim, Y.N., Wu, S., Kagioglou,M., Aouada, G, Kaka, A.P., and Trucco, E., “Automating progress measurement of construction projects”, *Automation in Construction*, 18(3), 294-301, 2009.

[13] Ibrahim, Y.N., Lukins, T.C., Zhang, X., Trucco, E., and Kaka, A.P., “Towards automated progress assessment of workpackage components in construction projects using computer vision”, *Advanced Engineering Informatics*, 23(1), 93-103, 2009.