4th Construction Specialty Conference

4e Conférence spécialisée sur la construction

Montréal, Québec
May 29 to June 1, 2013 / *29 mai au 1 juin 2013*

Tracking Scraper-Pusher Fleet Operations Using Wireless Technologies

Ali Montaser and Osama Moselhi
Department of Building, Civil & Environmental Engineering, Concordia University, Montreal, Canada

Abstract: Scrapers and pushers are important part of equipment fleets in large earthmoving operations such as dams and highway construction projects, which demand moving large amounts of soil within relatively short time. This paper presents an automated methodology for tracking and estimating productivity of Scraper-Pusher fleet operations in near-real-time utilizing wireless technologies. The technologies deployed in the developed method are Radio Frequency Identification (RFID) and equipment switch limit. Low cost passive RFID tags are attached to scrapers and fixed RFID readers are attached to pushers. The read range of used RFID tag is centimeters, to be activated only when the pusher with the attached RFID reader is pushing the scraper for loading operations. On the other hand, switch limit is a switch operated by motion detection of a machine part. In the case of scraper, the movement of scraper bowl will activate the switch limit. The function of switch limit is to record the signal time when the scraper bowl opens or closes. Fusing the data captured from RFID reader and switch limit is used to identify loading, travel, dumping and return time that constitute the scraper cycle time. The collected data is analyzed and processed automatically, without human intervention, to calculate the productivity of the scraper-pusher fleet and to report it directly to onsite personnel. Relational database is developed to implement and automate the proposed method. The developed database is used to process the data captured by the RFID and the switch limit to calculate earthmoving productivity in near-real-time.

1. Introduction

Estimating actual productivity is essential element in estimating the time and cost required to complete construction operations (Oglesby et al 1989). Manual methods for data collection, storage, retrieval and analysis are time consuming and prone to human error and may result in delayed corrective actions with undesirable cost consequences (Sacks et al, 2002). Data collected manually usually stored on paper; rendering it difficult to access and examine. Therefore, some information items end up being not readily available to project teams to make timely decisions. Failure in effectively tracking construction progress and in retrieving related information on demand may result in schedule delays and cost overruns (De la Garza and Howitt, 1998). Earthmoving operations have received considerable attention from researchers and industry professional. Wide ranges of methods were used in planning of these operations in search for optimum fleet configurations (Alkass and Harris, 1988, Hajjar and AbouRizk 1999, Marzouk and Moselhi, 2004, and Moselhi and Alshibani 2009). Scrapers and pushers are an important part of equipment fleets in large earthmoving operations such as dams and highway construction projects, which demand moving large amounts of soil within relatively short time. Scrapers alone are capable of loading, hauling, and dumping excavated soil efficiently but for short hauling distances (Eldin and Mayfield 2005). Generally, scrapers need the support of pushing tractors during loading operations to reduce scraper tires tearing and wearing and also to reduce the loading time and, therefore, maximize productivity. Determining the optimum selection of the size, model, and number of pushers and scrapers is a complex process that relies on many factors such as equipment availability, conditions of haul-roads, equipment performance and travel time (Farid and Husaini1990 and Alshibani and Moselhi 2012).

Recent advancement in automated site data acquisition technologies made tracking and monitoring of earthmoving operations feasible. Spatial information using Global Positioning System (GPS) supported by Geographical Information System (GIS) is an effective method to track earthmoving operations. Montaser et al (2011, 2012) developed a method utilizing GPS and Google Earth to extract the data needed to calculate hauling trucks actual productivity in near-real-time. However, this method is not suitable for tracking Scraper-Pusher fleet due to the change in the cut and fill locations from one cycle to another making tracking the operation very difficult and inaccurate. Computer vision-based systems could be used to track earthmoving operations but focusing mainly on loading process (Rezazadeh Azar and McCabe 2011). As well such technology has many limitations specially in differentiating between hauling units if they have the same colour, dust obstruction to camera line of the sight and inability of calculating travel, dumping and return durations which constitute complete hauling cycle.

Auto-ID and data capturing technologies allow identification, data collection, and information storage for equipment without human intervention (Rasdorf and Herbert, 1990, McCullouch and Lueprasert, 1994, and Marsh and Finch, 1998). With its lower cost and increased capabilities, radio frequency identification (RFID) gained acceptance in different applications such as resource tracking, progress reporting, maintenance and tracking and locating material on construction sites (Goodrum et al, 2006, Ergen et al, 2007, Grau and Caldas, 2009 and Razavi, and Haas, 2010 and). RFID technology overcomes most limitations of other tracking technologies such as bar code and magnetic strips. It does not require direct line-of-sight, not sensitive to direct sunlight, tags could not be damaged easily and can be encapsulated, if needed. It could collect data in dirty, harsh, hazardous conditions. RFID has proved to be reliable in terms of long-term data storage in harsh environments (Lu et al, 2011).

RFID is a wireless communication of data through radio waves. RFID system has two main components; reader and tags. These tags contain transponders that release messages readable by RFID readers. The reader receives signals emitted from tags attached to objects. RFID tags fall into two broad categories, active and passive, depending on their source of electrical power supply. Active RFID tags have their own power source; usually an attached battery. The power to passive tags is provided through the reader from the tag antenna when the tag is in the read range zone of the reader. Passive tags are low-cost; they can cost as little as five cents each, and new technologies are constantly making them less costly to integrate into different materials and products (Jaselskis et al, 1995, Weinstein, 2005 and Finkenzeller, 2010). RFID was also used to calculate actual productivity of the hauling trucks. It is based on attaching low cost passive RFID tags to hauling units (trucks) and attaching fixed RFID readers to designated gates of projects' dump areas. The RFID readers will identify and record the time each truck enters or exits one of these gates. The time differences are considered as loading, traveling, dumping and returning cycle times (Montaser and Moselhi 2012). However, this system is developed mainly for earthmoving operations of building projects and will not work accurately in highway construction.

Switch limit is a type of sensor that detects occurrence and absence of events. Specifically, mechanical switch limit are switches that are mechanically activated. So, they have some sort of arm, lever, knob, plunger, which is automatically activated by making contact with another object. As the object makes contact with the actuator of the switch, it eventually moves the actuator to its "limit" where the contacts change state. Example of switch limit is the one connected to the fridge door, when the fridge door is opened, it activates and opens the light and close the light when the door is closed (ABB, 2013). The proposed models lack the capability of fusion of data collected from more than one sensor, which is crucial to the proposed method, as described in the following section. In addition, very little work have been done utilizing data sensed from equipment itself. It should be noted that the current applications of RFID technology in construction is focusing on identification generally. The developments made in this paper makes full utilization of the collected RFID and switch limit captured data to perform near-real-time estimates of earthmoving operations.

2. Proposed Methodology

Figure 1 depicts a schematic diagram for the proposed methodology and its components. Low cost Ultra High Frequency (UHF) rugged encapsulated passive RFID tags are attached to scrapers and fixed RFID readers are attached to pushers. The read range of used RFID tag is centimeters, to be activated only when the pusher with the attached RFID reader is pushing the scraper for loading operations. Then, the RFID reader starts capturing the RF signals from the scraper tag. On the other hand, switch limit will be connected the scraper bowl to monitor its motion. The movement of scraper bowl will activate the switch limit. The function of switch limit is to record the time when the scraper bowl opens or closes. The switch limit will be sending its data via cable to micro controller that is attached also to the scraper. Scraper micro controller has a wireless communication module that could send and receive data to/from RFID readers. The data captured by RFID from scrapers passive tag and switch limit will be transferred wirelessly to a web server housed in one of the contractor temporary offices onsite. The collected data will be analyzed and processed automatically, without human intervention. Fusing the data captured from RFID reader and switch limit is used to identify loading, travel, dumping and return time that constitute the scraper cycle time and consequently the productivity of scraper-pusher fleet earthmoving operations. The results will be reported to project stockholders via web-based reporting system.

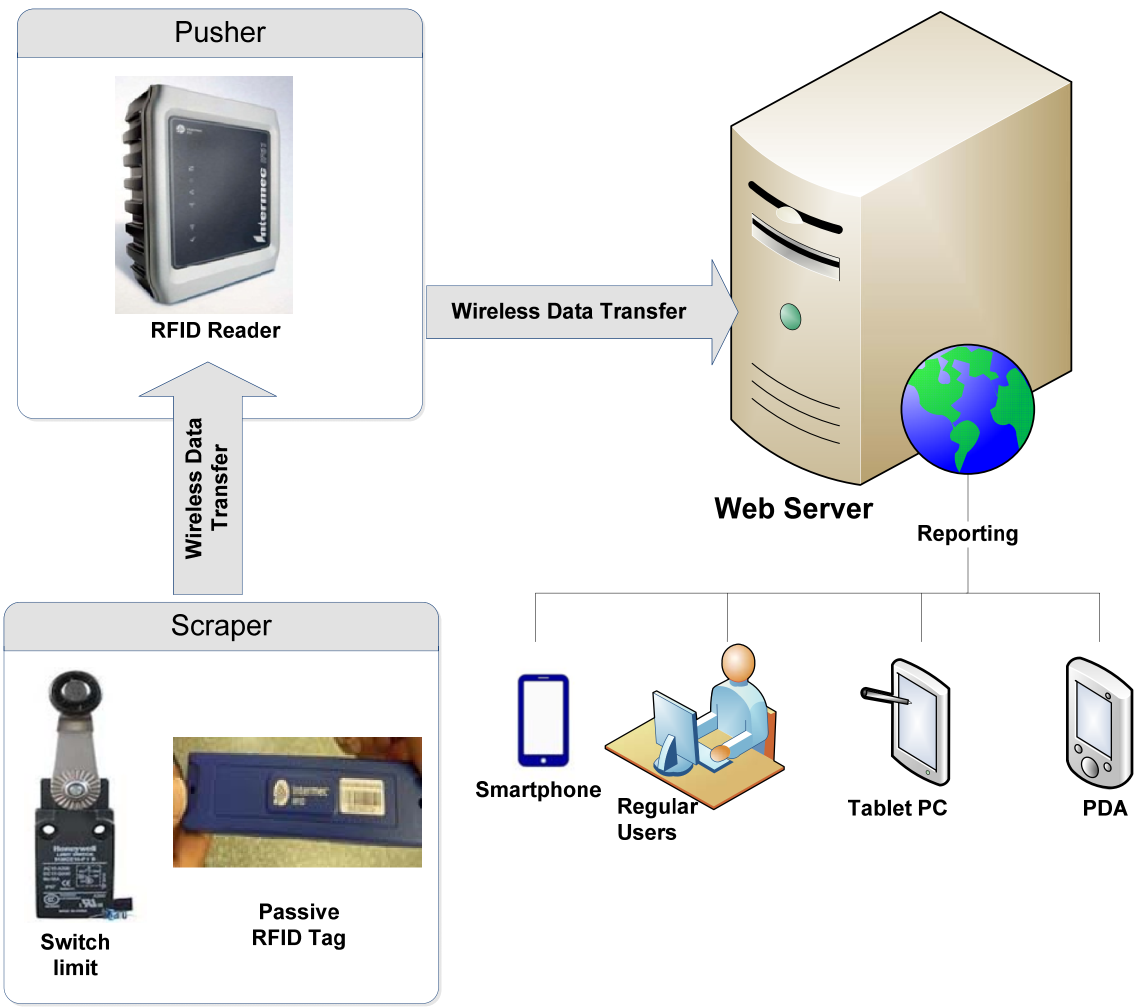

Figure 1: Schematic diagram for the proposed methodology and its components

The main RFID hardware components used in the developed method are RFID fixed reader attached to the pusher and low cost RFID encapsulated passive tags attached to scrapers. RFID components and switch limit hardware are capable of collecting data in dusty, harsh, hazardous conditions. For example, the encapsulated passive RFID tag in Figure 1 could work in temperatures ranging from -40^{o} C to 66^{o} C, with read range equal to three meters and could be attached to the scraper rear end using screws, rivets, double-sided adhesive strips or a variety of other methods. Regarding its memory size it has a capacity of 512-bit-on-chip. Also, fixed readers (Figure 1) could work under similar harsh conditions such as could work in temperatures ranging from -25^{o} C to 55^{o} C and protected from dirt, dust, oil, other non-corrosive material and splashing water. Readers' connectivity could be Ethernet or Wi-Fi and can host applications written in Java, JavaScript, VB .Net or C# .Net for communication with other devices such as the scraper micro controller (Intermec, 2011).

Figure (2-b) shows a graphical representation of switch limit captured data when the scraper bowl is opened (Figure 2-a) and closed (Figure 2-c). The change in switch limit status will happen due to the scraper bowl motion, which happens when the scraper loads or dumps. The scraper switch limit captured data are date, time, scraper ID and switch limit status (On or Off). However, the switch limit status and the order of loading and dumping could be used to identify the cycle time. But, the methodology in this case might give inaccurate interpretations especially during loading. For example, during the loading part the scraper bowl could be opened for minor short time check or maintenance. So, the next scraper bowl motion will be interpreted by the methodology as dumping, which is not correct. Hence, another sensor will be needed to ensure that the scraper is actually loading. From the scraper-pusher crew sequence of work, the pusher has to be in contact with the scraper during the loading process. Therefore, this contact could be measured using a proximity sensor, which is the passive RFID in our case. Passive RFIDs have a close read range from couple centimetres till five meters according to the radio waves frequency, which could be utilized effectively in the proposed method.

Figure 3 depicts RFID hardware implementation method, where the passive tag attached to the scraper rear end, which is the nearest location to the pusher contact. RFID reader is fixed to the pusher front with the antenna attached to the pusher blade. This setup in addition to tag read range will allow the RFID reader to receive tag signals when the pusher is pushing the scraper in loading process. The signal will represented by zigzag line to indicate the loading process. RFID reader will generate a file with five fields: a) RFID tag ID, which was read and represents the scraper ID, b) the number of times this tag was read, c) received signal strength, d) date, e) time. The data collected from RFID Reader will transferred using wireless communications to the web server. Figure 4 illustrates the main five events that describe the entire earthmoving process, upon performing the data fusion of the two sensors. These five events depict a complete cycle in the operation being modeled. Event 1 represents the commencement of the loading process. As long as the scraper bowl is opened, which indicated by the switch limit, and scraper in pusher read range, the reader will keep receiving signals from the scraper. When the scraper bowl is closed and the scraper leaves the loading area, RFID reader and switch limit will register Event 2. In the proposed method, it is assumed that the scraper bowl is loaded with its full capacity; according to scraper manufacturer data and soil type. Event 3 is registered from scraper switch limit when the scraper opens the bowl for dumping while the scraper is moving. Upon dumping the excavated material, the scraper will close the bowl then the switch limit will register the commencement of Event 4, which is also while the scraper is moving. A cycle will be completed upon return of the scraper to the loading area (i.e. commencement of Event 5). For each scraper, the method will identify five main events and the corresponding time and they are T1, T2, T3, T4 and T5. By identifying those five events the cycle time component could be calculated as following:

Loading Time = Registered time of Event 2 - Registered time of Event 1

Travel Time = Registered time of Event 3 - Registered time of Event 2

Dumping Time = Registered time of Event 4 - Registered time of Event 3

Returning Time = Registered time of Event 5 - Registered time of Event 4

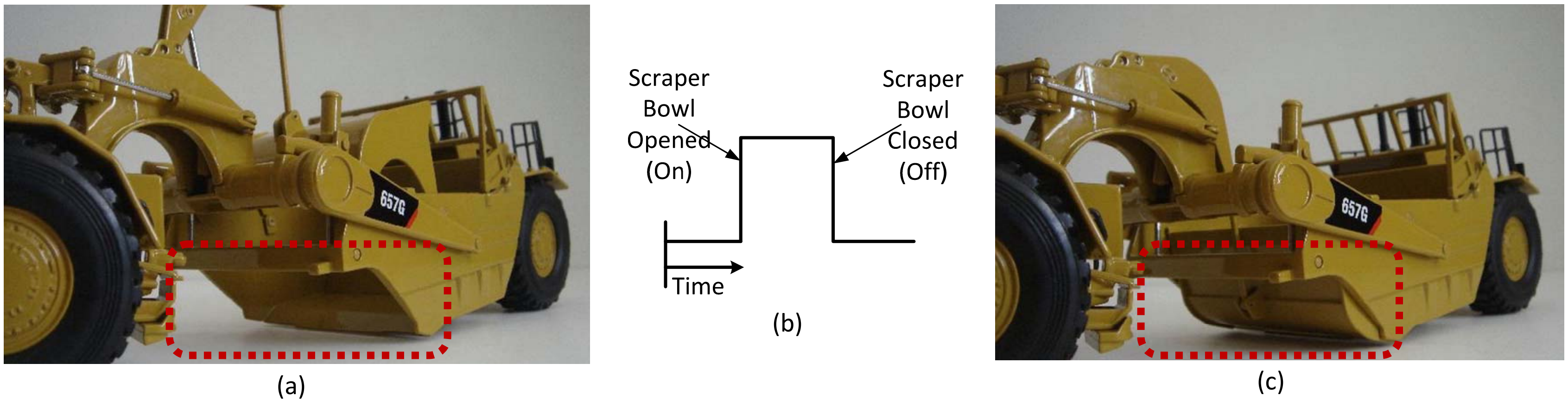

Figure 2: Diagram representing the change in switch limit captured data due to scraper bowl motion

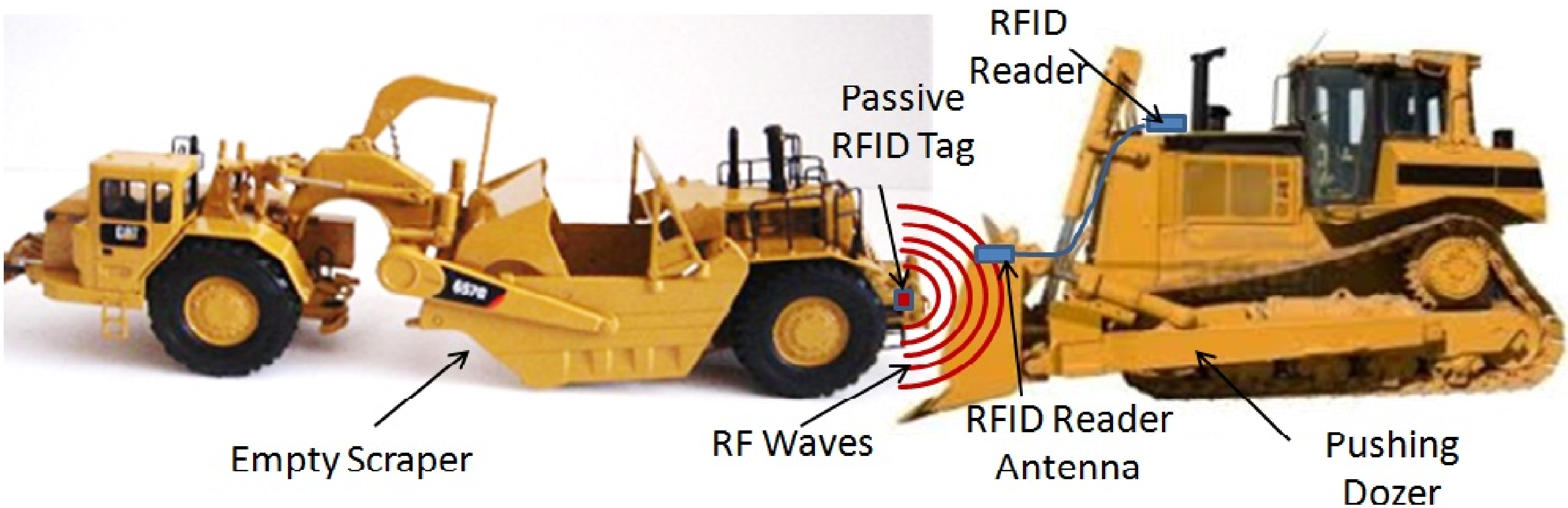

Figure 3: Schematic diagram representing RFID hardware implementation

Then the total cycle time can be calculated too by the summation of loading time, travel time, dumping time and return time and those steps will be repeated for each scraper in the project (Table 1). For each scraper, the number of cycle times, total cycle time duration and its components duration will be identified then will be appended to project database. Figure 5 shows different switch limit and RFID data fusion scenarios that could exist while loading. The arrow indicates the rule in calculating the loading time which is the common time between the switch limit On/Off status and the RFID captured signals. This rule means the scraper bowl is opened and the pusher is pushing the scraper in loading.

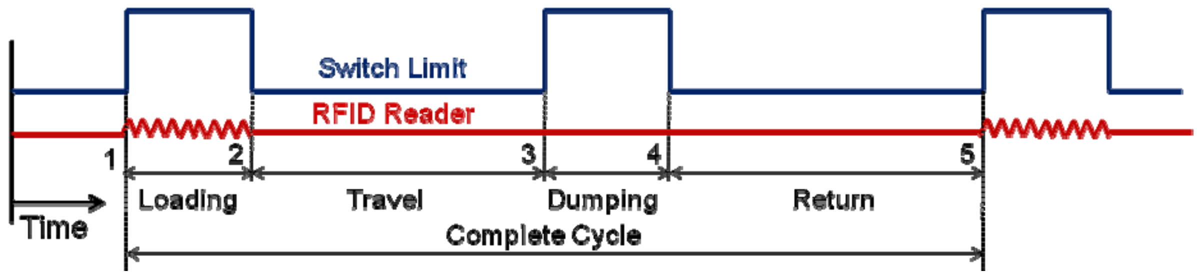

Figure 4: Diagrammatic sketch for RFID and switch limit data integration

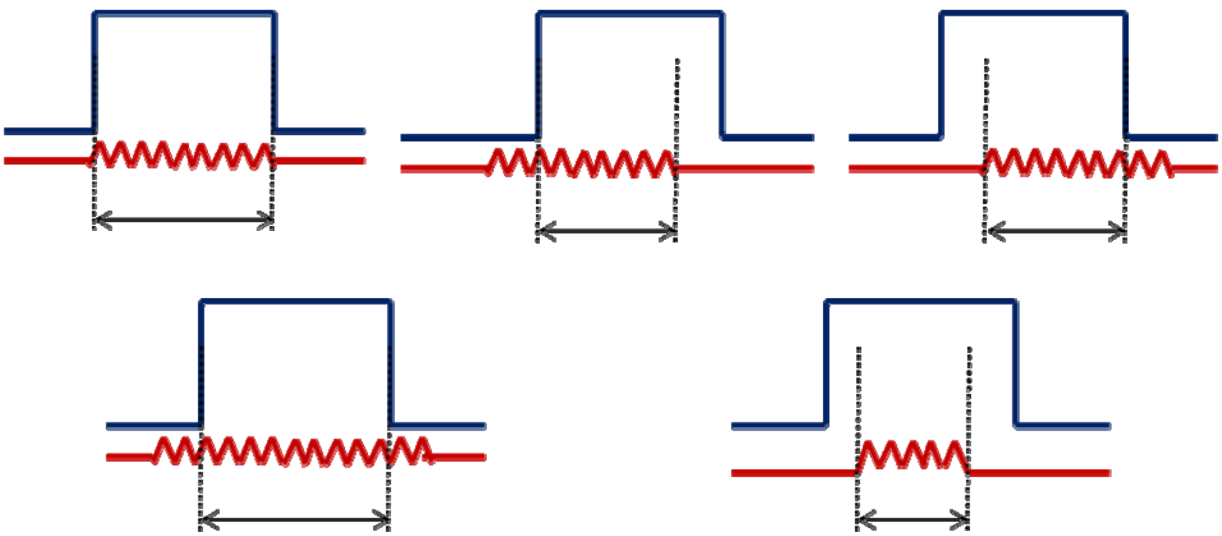

Figure 5: The different scenarios for loading process data integration

For each scraper, the system retrieves its capacity from the database to calculate the fleet productivity. Then, project soil properties will be obtained from the project database to estimate the quantity of hauled excavation. This quantity will be divided to the total excavation to know the actual percentage complete which could be used for earned value analysis for progress reporting purpose to estimate the actual cost and duration. To facilitate data storage, fusion and processing a relational database was developed. The database has 10 entities; interconnected with one-to-one, many-to-one and many-to-many relationships. Due to space limitation, the Entity Relationship (ER) diagram and the algorithm developed are not included. Figure 6 represents a tabular report for one of the fleet scrapers, describing in details the number of cycles and its components. An activity level reports could also be generated utilizing earned value concept to know the activity status regarding time and budget (Figure 7 & 8).

Table 1: Events recognition and cycle time calculations

Serial	Date	Time	Scraper ID	Switch Limit Status	RFID Reader	Event	Time (min)	Type	Cycle Time (min)	Cycle #
1	24.11.2010	.	230		230					
2	24.11.2010	.	230		230					
3	24.11.2010	.	230	On	230					
4	24.11.2010	8:12:06	230		230	1				
5	24.11.2010	.	230		230					
6	24.11.2010	.	230		230					
7	24.11.2010	.	230		230	2	0:03:05	Loading Time		1
8	24.11.2010	8:15:11	230	Off	230					
9	24.11.2010	.			230					
10	24.11.2010	8:40:27	230	On		3	0:25:16	Travel Time		
11	24.11.2010	8:42:38	230	Off		4	0:02:11	Dump Time		
12	24.11.2010	.	230		230					
13	24.11.2010	.	230		230					
14	24.11.2010	9:03:43	230	On	230	5	0:21:05	Return Time	0:51:37	
15	24.11.2010	9:03:47	230		230	1				

The developed method was designed to work on a web-based enterprise level; to facilitate tracking of scraper-pusher not only at the project level but also for the contractor entire fleets. Upon determining the cycle time using the method described above, earthmoving productivity can be estimated deterministically or using computer simulation, where the captured data for loading, hauling, dumping and returning can be used to generate representative probability distribution. Those distributions could be used to evaluate the fleet configuration, highlight the fleet bottlenecks and to experiment and optimize the new fleet configuration if needed (Montaser et al, 2011& 2012). The developed method allows project teams to check jobsite conditions remotely and study the efficiency of the planned operations. It provides them also with tools for detecting potential problems in loading areas, dumping areas and travel hauling and return roads. Near real time control of on-site earthmoving operations, facilitates early detection of discrepancies between actual and planned performances and support project managers in taking timely corrective measures. The developed methodology could be integrated with spatial technologies (GPS/GIS) to provide more information regarding the loading, travel, dumping and return areas. Regarding the assumption of bowl is loaded with it is full capacity, a weighting sensor could be attached under the scraper or a digital camera above the scraper bowl could be used to improve the developed methodology. With the continual development of automated data acquisition sensors and its integration, a significant amount of data can be collected at construction sites. To make informed decisions and objective assessments of the progress on a construction site, data from a number of sources must be fused, since it is not possible for all of the necessary information to be captured using a single sensor.

Resource Name: 233

Cycle#	Loading			Travel			Dumping			Return			Cycle Duratio
	From	To	Duration	From	To	Duration	From	To	Duration	From	To	Duration	
45	4/13/2010 3:20 PM	4/13/2010 3:24 PM	00:03:45	4/13/2010 3:25 PM	4/13/2010 3:47 PM	00:22:30	4/13/2010 3:35 PM	4/13/2010 3:38 PM	00:03:00	4/13/2010 3:25 PM	4/13/2010 3:47 PM	00:22:30	00:51:45
46	4/13/2010 3:49 PM	4/13/2010 3:53 PM	00:04:30	4/13/2010 3:54 PM	4/13/2010 4:20 PM	00:26:15	4/13/2010 4:05 PM	4/13/2010 4:10 PM	00:04:30	4/13/2010 3:54 PM	4/13/2010 4:18 PM	00:24:00	00:59:15

Figure 6: Generated tabular report for scraper # 233 (Resource Level)

Activity Status:

Date	BCWS	BCWP	ACWP	CV	SV	CPI	SPI	EAC1	EAC2	TodayQuantity	QuantitytoDate
10/12/2012	150000	162300	147277	15022	12300	1.102	1.082	160136	161447	204	22610

PrecentageComplete	ForecastedEF	TimeStatus	BudgetStatus
85%	05/02/2013	Ahead of Schedule	Under Budget

Figure 7: Tabular earned value generated reports (Activity Level)

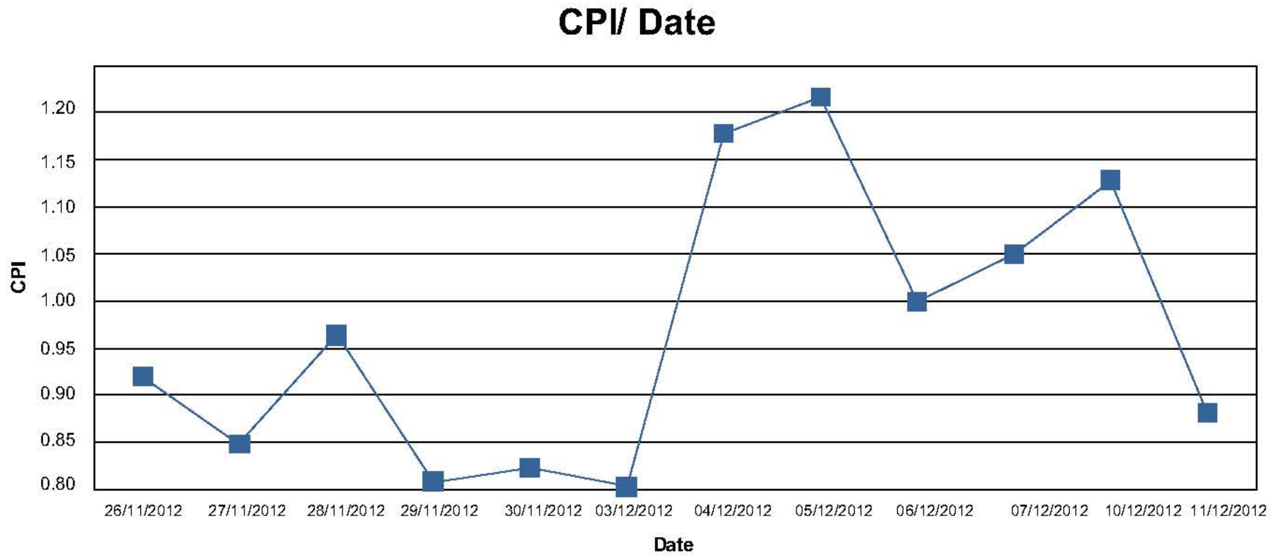

Figure 8: Graphical generated reports for Cost Performance Index (CPI) on daily basis (Activity Level)

3. Summary and Concluding Remarks

Manual site data acquisition in earthmoving operations is time consuming and may result in tardy corrective actions with undesirable cost consequences. Radio frequency identification (RFID) and other technologies such as switch limit have evolved to meet construction industry needs with its lower cost and increased capabilities. The developed method is a step ahead of regular RFID identification applications and expands upon its use in the construction industry. This paper presents an automated method for tracking and estimating productivity of scraper-pusher fleet earthmoving operations in near-real-time utilizing RFID and switch limit technologies. The developed method demonstrated the significance of data fusion between RFID reader and switch limit. It presents practical and easy to use method for estimating productivity of scraper-pusher fleet earthmoving operations in near real-time. The collected data is analyzed and processed automatically without human intervention, to calculate the productivity of the fleet and report it directly to onsite personnel. Entity relationship diagram (ER) is developed to implement and automate the developed method. Near real-time control of on-site earthmoving operations, facilitates early detection of discrepancies between actual and planned performances and support project managers in taking timely corrective measures. Incorporating RFID data in modeling earthmoving operations can be useful in tracking and control of earthmoving operations during execution of the work.

4. References

ABB - Limit Switches - 101 A basic guide to ABB's limit switch portfolio, (2013) < http://www05.abb.com/global/scot/scot260.nsf/veritydisplay/8bb7f20332ba74d5852575d20063da5a/$file/1sxu141184x0201.pdf> (Jan. 02, 2013).

Alkass, S. and Harris, F. 1988. Expert system for Earthmoving Equipment Selection in Road Construction. *Journal of Construction Engineering and Management*, ASCE, 114(3): 426–440.

Alshibani, A. and Moselhi, O. 2012. Least Cost Optimization of Scraper–Pusher Fleet Operations. *Canadian Journal of Civil Engineering*, 39: 313–322.

De la Garza, J. and Howitt, I. 1998. Wireless Communication and Computing at the Construction Jobsite. *Journal of Automation in Construction*, 7 (4): 327-347.

Eldin, N. and Mayfield, J. 2005. Determination of Most Economical Scrapers Fleet. *Journal of Construction Engineering and Management*, 131(10): 1109 –1114.

Ergen, E., Akinci, B. and Sacks, R. 2007. Tracking and Locating Components in a Precast Storage Yard Utilizing Radio Frequency Identification Technology and GPS. *Journal of Automation in Construction*, 16(3): 354-367.

Farid, F., and Husaini, H. 1990. Optimum multi-pusher-scraper fleets for earthmoving. *In Proceedings of the first International Symposium on Uncertainty Modelling and Analysis*, Maryland, 3–5 Dec 1990, 628–634.

Finkenzeller, K. 2010. *RFID Handbook: Fundamentals and Applications in Contactless Smart Cards and Identification.* 3rd edition, John Wiley & Sons, USA.

Goodrum, P., McLaren, M. and Durfee, A. 2006. The Application of Active Radio Frequency Identification Technology for Tool Tracking on Construction Job Sites. *Journal of Automation in Construction*, 15(3): 291-302.

Grau, D. and Caldas, C. 2009. Methodology for Automating the Identification and Localization of Construction Components on Industrial Projects. *Journal of Computing in Civil Engineering*, ASCE 23(1): 3-13.

Hajjar, D., and AbouRizk, S. 1999. Symphony: an Environment for Building Special Purpose Simulation. *31st Winter Simulation Conference*, ASCE, Phoenix, AZ, USA. 998–1006.

Intermec Solutions. Inc., (2011).”RFID.” < http://www.intermec.ca/products/rfid/index.aspx> (Jan. 02, 2013).

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

Marsh, L. and Finch, E. 1998. Attitudes Towards Auto-ID Technologies Within the UK Construction Industry. *Journal of Construction Management and Economics*, 16: 383-388.

Marzouk, M. and Moselhi, O. 2004. Multi-Objective Optimization of Earthmoving Operations. *Journal of Construction Engineering and Management*, ASCE, 130(1):105–113.

McCullouch, B. and Lueprasert, G. K. 1994. 2D Bar-Code Applications in Construction. *Journal of Construction Engineering and Management*, ASCE, 120 (4): 739-752.

Montaser, A. and Moselhi, O. 2012. RFID + For Tracking Earthmoving Operations, *Construction Research Congress (CRC 2012), ASCE Construction Institute and Construction Engineering and Management*, West Lafayette, Indiana, United States, 2012, 21-23 May, 1011-1020.

Montaser, A., Bakry, I., Alshibani, A. and Moselhi, O. (2011) Estimating Productivity of Earthmoving Operations Using Spatial Technologies. *3rd International/9th Construction Specialty Conference*, Ottawa, Ontario, Canada, June 14-17, 3: 2318-2327.

Montaser, A., Bakry, I., Alshibani, A. and Moselhi, O. 2012. Estimating Productivity of Earthmoving Operations Using Spatial Technologies. *Canadian Journal of Civil Engineering*, 39: 1072–1082.

Moselhi, O., and Alshibani, A. 2009. Optimization of Earthmoving Operations in Heavy Civil Engineering Projects. *Journal of Construction Engineering and Management*, ASCE 135(10): 948– 954.

Oglesby, H., Parker, W. and Howell, A. 1989. *Productivity Improvement in Construction*, McGraw Hill Companies, New York, NY, USA.

Rasdorf, J. and Herbert, M.J. 1990. Automated Identification Systems- Focus on Bar Coding. *Journal of Computing in Civil Engineering*, ASCE, 4 (3): 279-296.

Razavi, S.N., Haas, C. 2010. Multisensor Data Fusion for on–Site Materials Tracking in Construction. *Journal of Automation in Construction*, 19(8): 1037-1046.

Rezazadeh Azar, E. and McCabe, B. 2012. Automated Visual Recognition of Dump Trucks in Construction Videos. *Journal of Computing in Civil Engineering*, 26(6): 769–781.

Sacks, R., Navon, R., Shapira, A. and Brodetzky, I. 2002. Monitoring Construction Equipment for Automated Project Performance Control. *International Symposium on Automation and Robotics in Construction (ISARC 2002)*, Washington, DC.

Weinstein, R. 2005. “RFID a Technical Overview and Its Applications to the Enterprise. *Journal of IT Professional*, 7 (3): 27-33.