TRACKING HAULING TRUCKS FOR CUT-FILL EARTHMOVING OPERATIONS

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ABSTRACT

Hauling trucks are important part of equipment fleets for large earthmoving operations such as those encountered in dams and highway construction projects. This paper presents an automated methodology for tracking and estimating productivity of hauling trucks fleet operations in near-real-time. Recent advancement in automated site data acquisition technologies made their use in tracking and monitoring of construction operations feasible. However, these technologies fail to track hauling truck fleets due to the change in the cut and fill locations from one cycle to another; making tracking and progress reporting difficult and inaccurate. In addition, there is very little work done utilizing data sensed directly from equipment, for example sensing when truck dumping bed is raised during the dumping process. The technologies deployed in the developed method are Radio Frequency Identification (RFID) and equipment control sensors. Low cost passive RFID tags are attached to hauling trucks and fixed RFID readers are attached to loaders or excavators. The read range of the used RFID tag is centimeters, to be activated only when a loader with an attached RFID reader is loading a truck. On the other hand, control sensor is connected to the truck control system and operated by the motion of its movable bed. The function of control sensors is to record the signal time when the truck operator gives order to the truck control system to raise or lower truck bed. The captured data is then transferred wirelessly from the RFID reader and control sensor to a computer housed in one of the temporary offices onsite and subsequently to the main server in the contractor's head office. Fusing the data captured from RFID reader and control sensor is used to identify loading, travel, dumping and return time that constitute the hauling truck cycle time. The collected data is analyzed and processed automatically, without human intervention, to calculate the productivity of the hauling truck and to report it directly to onsite personnel. Relational database is developed to support the implementation of the proposed method. The developed database is used to process the data captured by the RFID and the control sensor to calculate the productivity achieved in cut-fill operations in near-real-time. The developed methodology is expected to facilitate early detection of discrepancies between actual and planned performances.

KEYWORDS

Earthmoving Operations, Hauling Trucks, Tracking and Progress Reporting, RFID, Control Sensor

INTRODUCTION

Estimating actual productivity on construction jobsites is essential in forecasting the time and cost required to complete construction operations with good accuracy (Oglesby et al 1989). Manual methods for data collection are time consuming and prone to human error and may result in delayed corrective actions with adverse cost consequences. Failure in effectively tracking construction progress and in retrieving related information can result in schedule delays and cost overruns (De la Garza and Howitt, 1998). Earthmoving operations have received considerable attention from researchers and industry professional (Alkass and Harris, 1988, Hajjar and AbouRizk 1999, Marzouk and Moselhi, 2004, and Moselhi and Alshibani 2009). Hauling trucks 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 (Eldin and Mayfield 2005 and Alshibani and Moselhi 2012).

Recent advancements in automated site data acquisition technologies made it feasible to track and monitor earthmoving operations in near-real-time. Spatial information utilizing 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 trucks actual productivity in near-real-time. However, the use of these technologies alone is not suitable for tracking hauling trucks in cut-fill operations in a dynamically changing environment of cut and fill locations from one cycle to another. Computer vision-based systems could be used to track earthmoving operations but focusing mainly on loading process (Rezazadeh Azar and McCabe 2011). However, 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.

With its lower cost and increased capabilities, Radio Frequency Identification (RFID) gained acceptance in different applications (Ergen et al, 2007 and Grau and Caldas, 2009). RFID technology overcomes most limitations of other tracking technologies such as bar code and magnetic strips (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. RFID tags fall into two broad categories, active and passive, depending on their source of electrical power supply. 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). 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. Control sensor is a type of sensor that detects occurrence of events and report those events. It could be connected to equipment control system via microcontroller. So, when then equipment operator take certain action that triggers the control sensor designated events, It will be registered by the microcontroller memory.

Simulation of earthmoving operations allows construction planners and estimators to predict productivity and to evaluate construction operations before starting site work. The literature reveals considerable work on computer simulation for modeling earthmoving operation (Shi and AbouRizk 1995 and Marzouk and Moselhi 2003). The proposed models lack the capability of fusion of data collected from more than one sensor, which is crucial to the proposed method. In addition, very little work has been done utilizing data sensed from equipment itself and conducting simulation for stochastically productivity forecasting. The development made in this paper makes full utilization of the collected RFID and control sensor captured data to perform near-real-time estimates of productivity for earthmoving operations.

PROPOSED METHODOLOGY

Figure 1 depicts a schematic diagram of the proposed methodology and its components. Low cost Ultra High Frequency (UHF) rugged encapsulated passive RFID tags are attached to hauling trucks and fixed RFID readers are attached to excavators (loaders). The read range of the used RFID tag is centimeters, to be activated only when the excavator (loader) with the attached RFID reader is loading the truck. Then, the RFID reader starts capturing the RF signals from the truck tag. On the other hand, control sensor is connected to the truck control system and operated by the motion of its movable bed. The function of control sensors is to record the signal time when the truck operator gives order to the truck control system to raise or lower truck bed during the dumping process. The control sensor will be sending its data via cable to microcontroller that is attached also to the excavator (loader). Truck microcontroller has a wireless communication module that could send and receive data to/from RFID readers. The data captured by RFID from hauling truck passive tag and control sensor will be transferred wirelessly to a computer housed in one of the temporary offices onsite and subsequently to the main server in the contractor's head office. The collected data will be analyzed and processed automatically, without human intervention. Fusing the data captured from RFID reader and control sensor is used to identify loading, travel, dumping and return time that constitute the hauling truck cycle time and consequently the productivity of the fleet. The results will be reported to project stockholders via web-based reporting system.

The main RFID hardware components used in the developed method are RFID fixed reader attached to the excavator (loader) and low cost RFID encapsulated passive tags attached to hauling trucks. RFID components and control unit hardware could collect data in dirty, harsh, hazardous conditions. For example, the encapsulated passive RFID tag in Figure 1 could work with read range equal to three meters and could be attached to the hauling truck 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 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 hauling truck microcontroller (Intermec, 2013).

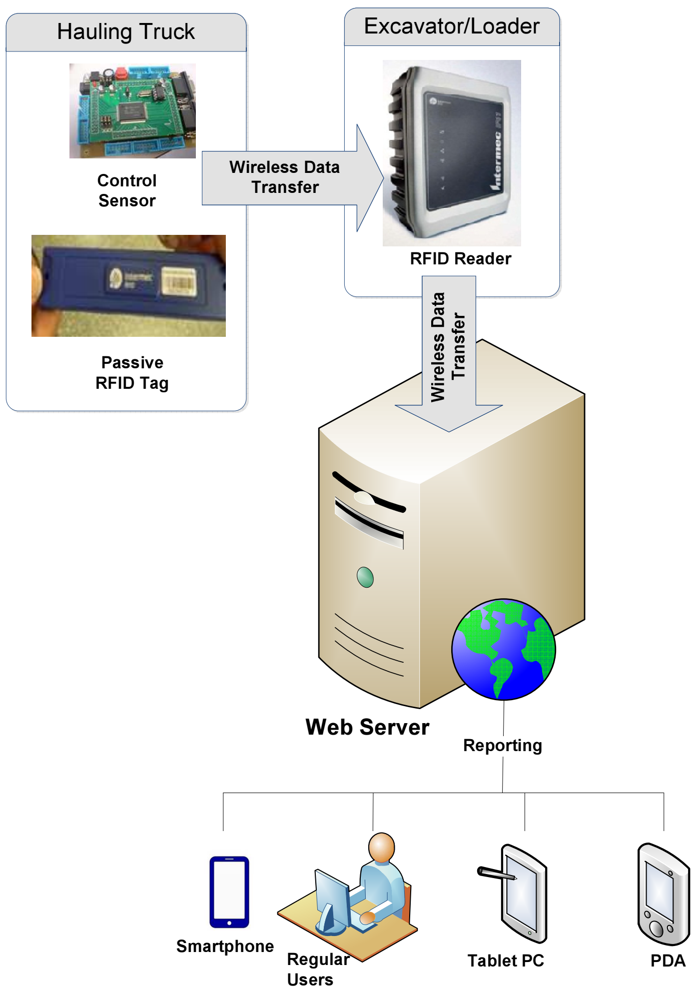


Figure1- Schematic diagram for the proposed methodology and its components

Figure 2 depicts RFID hardware implementation method, where the passive tag attached to the hauling truck bed, which is the nearest location to the excavator during loading. RFID reader is fixed to the excavator front with the antenna attached to the excavator bucket. This setup in addition to tag read range will allow the RFID reader to receive tag signals when the excavator is loading the truck. The signal is represented by a zigzag line to indicate the loading process. The excavator is stationary in its location;

loading its bucket and dumping the soil in the truck bed. This process is repeated until the hauling truck is loaded with its full capacity. In this state, the response of excavator's RFID reader will be continuous zigzag line during the loading process. The time from the beginning of the zigzag line till its end represents the loading time in this cycle.

The same RFID setup is used in case of using loader to load the hauling truck. However, the loader sequence of work is different. As, it moves to the soil stock pile forward and backward for each bucket load. For each loader bucket load, the RFID reader response will be continuous zigzag line then straight line due to the loader movement away from the truck to the soil stock pile till it become in a reading range again. Accordingly, the time from the beginning of the first zigzag line till the end of the last zigzag line represents the loading time in this cycle. In this process, the 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. Figure 4 shows a graphical representation of control sensor's captured data when the hauling truck bed is raised for dumping excavated soil and lowering it after. The change in control sensor status will happen due to the hauling truck bed motion. The control sensor captured data are date, time, truck ID and status (On or Off).

Figure 5 illustrates the main five events that describe the entire earthmoving process, upon performing the data fusion of the two sensors. These five events represent a complete cycle in the operation being modeled. Event 1 represents the commencement of the loading process. As long as the hauling truck is in excavator (loader) read range, the reader will keep receiving signals from the truck. Event 2 registered at the end of the zigzag line in case of the excavator or the end of last zigzag line in case of loader. In the proposed method, it is assumed that the hauling truck is loaded with its full capacity; according to truck manufacturer data and soil type. Event 3 is registered from control sensor when the truck operator gives order for dumping which indicated by raising the truck bed. Upon dumping the excavated material, the operator will give order to lower the truck bed then the control sensor will register the commencement of Event 4. A cycle will be completed upon return of the truck to the loading area (i.e. commencement of Event 5).

For each truck, the developed method will identify five main events and their corresponding times T1, T2, T3, T4 and T5. By identifying those five events, the cycle time component could be calculated as follows:

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

Then the total cycle time can be calculated by the summation of loading time, travel time, dumping time and return time and those steps will be repeated for each truck in the project (Table 1). For each truck, the number of cycle times, total cycle time duration and its components duration will be identified then will be appended to project database. For each truck, 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 explained.

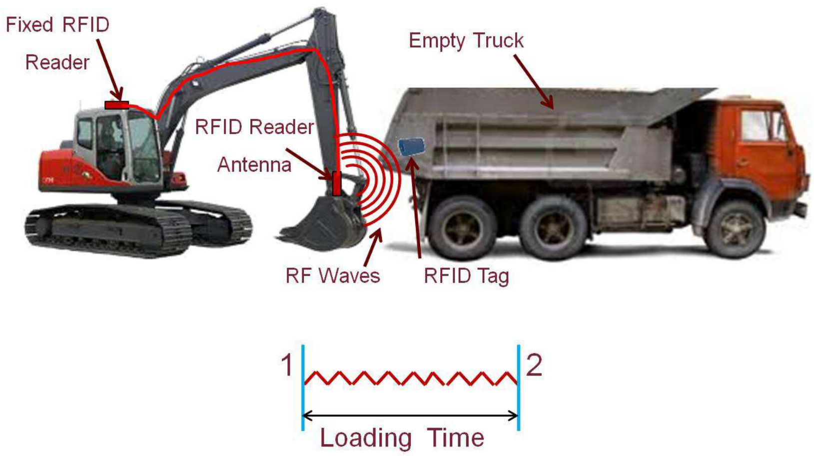


Figure 2 - Diagram representing the change in RFID reader captured data due to proximity to stationary excavator during loading process

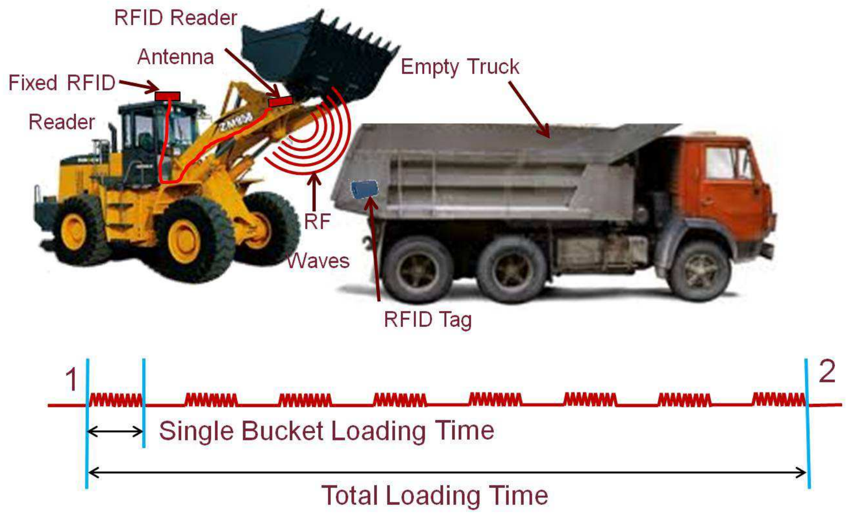


Figure 3 - Diagram representing the change in RFID reader captured data due to proximity to moving loader during loading process

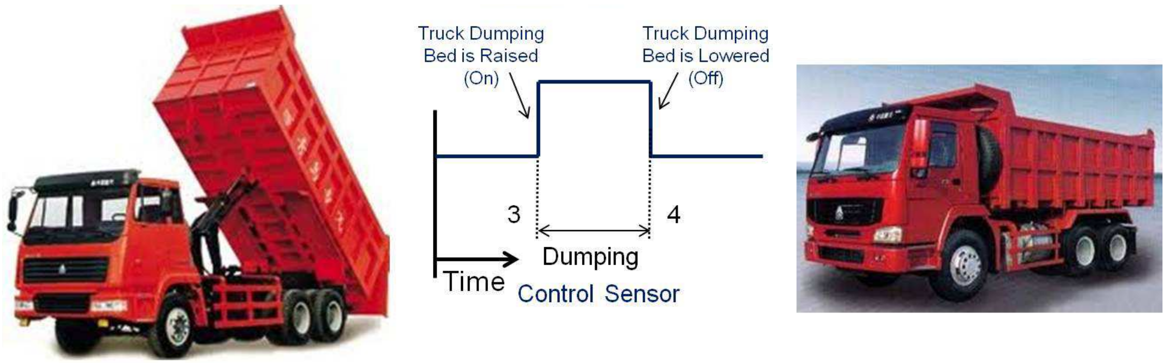


Figure 4 - Diagram representing the change in control sensor captured data due to truck bed dumping soil

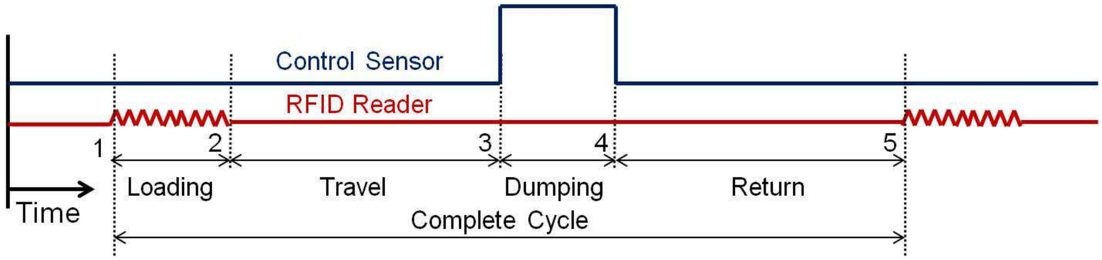


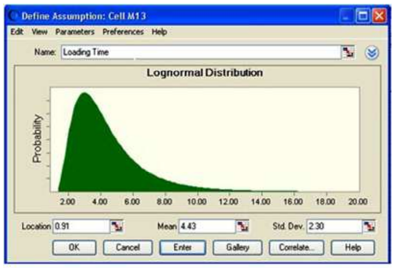
Figure 5 - Diagrammatic sketch for RFID and switch limit data integration

Table 1- Events recognition and cycle time calculations

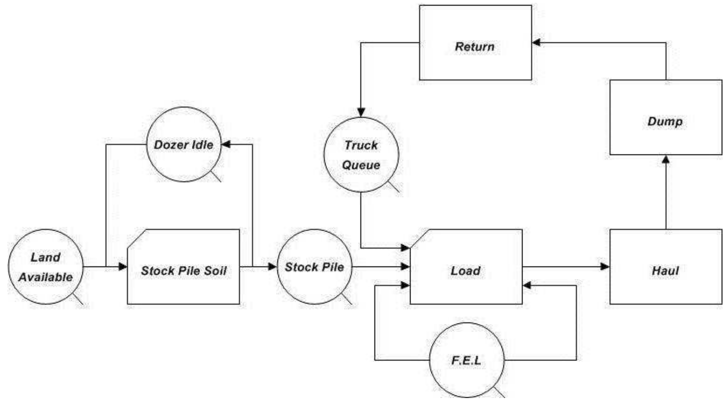
Date	Time	Truck ID	Control Sensor Status	RFID Reader	Event	Time (min)	Type	Cycle Time (min)
24.11.2010	8:12:06	230		230	1			
24.11.2010	.	230		230				
24.11.2010	.	230		230				
24.11.2010	.	230		230				
24.11.2010	.	230		230				
24.11.2010	.	230		230				
24.11.2010	8:15:11	230		230	2	0:03:05	Loading Time	
24.11.2010	8:40:27	230	On		3	0:25:16	Travel Time	
24.11.2010	8:42:38	230	Off		4	0:02:11	Dump Time	
24.11.2010	9:03:43	230		230	5	0:21:05	Return Time	0:51:37
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 hauling truck fleets not only at the project level but also for the contractor entire projects. Upon determining the cycle time using the method described above, earthmoving productivity can be estimated deterministically. Most forecasting techniques for earthmoving operations use deterministic methods estimate productivity based on the historical data. Even for the same project, it may forecast base on the average performance of elapsed periods. These methods do not take uncertainty into consideration and do not show crew configuration different scenarios and its impact on productivity. For example, the cycle time differs as the travel time of trucks can be affected by several dynamic factors, such as weather conditions, operating conditions in the excavation area and traffic on travel roads. Therefore, the proposed method tries to use the actual collected data for the elapsed periods, which takes into account the impact of variables such as weather, to forecast fleet productivity and consequently the forecasted duration and cost. Computer simulation is utilized, where the captured data for loading, hauling, dumping and returning can be used to generate representative probability distributions (Figure 6-a). Those distributions could be used as an input for the simulation model (Figure 6-b) to evaluate the fleet configuration, highlight the fleet bottlenecks and to experiment and optimize fleet configuration; if needed.

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 hauling truck is loaded with it is full capacity, a weighting sensor could be attached under the scraper or a digital camera above the truck bed 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.



(a)



(b)

Figure 6 - a) Loading time probability distribution, b) Loading time probability distribution

CONCLUSIONS

Manual site data acquisition in earthmoving operations is time consuming and may lead to tardy corrective actions with undesirable cost consequences. Radio frequency identification (RFID) and other technologies 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 hauling truck fleet earthmoving operations in near-real-time utilizing RFID and control sensor technologies. The developed method demonstrated the significance of data fusion of RFID reader and control sensor. It presents practical and easy to use method for estimating productivity of dynamically changing earthmoving operations in near-real-time. The collected data is analyzed and processed automatically without human intervention, to calculate fleets productivity and report it directly to onsite personnel. Entity relationship diagram (ER) is developed to implement and automate the developed method. The variations in the captured cycle times are used to model the uncertainty associated with the operation by developing reprehensive probability distribution for cycle time components. Simulation is used to model the uncertainty and to evaluate the bottlenecks of the fleet being analyzed. Simulation is also used to stochastically predict fleet productivity and consequently the project time and cost. 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 performed.

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