AUTOMATED SYSTEM FOR PRODUCTIVITY ASSESSEMENT OF EARTHMOVING OPERATIONS

Adel Alshibani
Concordia University, Montreal, Canada
adelshib@enccs.concordia.ca

Osama Moselhi
Concordia University, Montreal, Canada
moselhi@encs.concordia.ca

Abstract

Onsite data collection is essential for estimating onsite productivity, measuring project performance, and tracking large earthmoving operations. This paper presents a web-based system, developed for estimating onsite productivity and tracking earthmoving operations. The paper briefly describes the main components of the developed system and focuses primarily on estimating onsite productivity .The proposed system utilizes spatial technologies including GPS and GIS in addition to Google maps to support its management functions. The proposed system is most suited for large earthmoving projects. GPS is used to automate onsite data collection in near real time and to facilitate information exchange among members of project teams. GIS is employed not only to automate data acquisition, but also to analyze collected spatial data. The developed system has been coded in prototype software using object-oriented programming and Microsoft Foundation Classes (MFC). Real case example of a construction project is analyzed to demonstrate the features of the developed model.

KEYWORDS: earthmoving, automated data collection, GPS, and productivity.

INTRODUCTION

Estimating onsite productivity is always a main concern for project managers (Zhang et al., 2009). The main challenge in estimating onsite productivity is the need to collect large amount of accurate data from construction sites. In earthmoving operations, this challenge is more complex. This is due to the fact that this class of projects involves the use of heavy and costly equipment that operates outdoor, which makes it sensitive to inclement weather. In current practice, estimating onsite productivity relies heavily on company's' historical data and experts' opinions (Christian, and Xie, 1996). The methods used for estimating onsite productivity of earthmoving operations can be clustered into two groups; the traditional methods and knowledge-based methods. Traditional methods commonly use charts and multiple regressions (Han and Halpin(2005)), which are based on data collected manually. As such, these methods require human involvement and they are expensive, time consuming, and may not necessary be accurate (Alshibani and Moselhi, 2007). Knowledge-based methods frequently use artificial neural networks (ANN) (Tam et al., 2002).

The progressive advancements in information technology, however, made it possible for the construction industry to utilize on board instrumentation systems (OBIS) and spatial technologies, particularly GPS in collecting onsite data. OBIS have been used in many applications for earthmoving operations, which include monitoring mechanical status of equipment, optimizing load time for scrapers, and maximizing dozers production (Moselhi and Alshibani, 2008). The use of GPS in such applications, on the other hand, is relatively new and its use is of limited scope. Its application in earthmoving operations includes collision avoidance of moving equipment, detection of compaction error, and monitoring of paving operations (Oloufa et al.,2002).

The main disadvantage of OBIS lies in its high cost while, to the contrary, the main advantage of GPS is its low cost (Kannan et al., 1999). The use of GPS, as well, can offer a number of other advantages including (Kannan et al., 1999): no requirement for format conversion of collected data, its suitability for collecting data of outdoor operations, its capability of collecting sizable amounts of data in a timely manner, no requirement of trained personnel, GPS receivers can be easily mounted on and detached from earthmoving equipment, and GPS provides timely information flow to members of project teams. This paper presents a newly developed system for automated tracking and timely estimating of onsite productivity.

OVERVIEW OF THE PROPOSED SYSTEM

The main components of the developed system are outlined in Figure 1. It consists of four main components: (1) GPS receiver(s) as depicted in Figure 2, (2) web-based graphical user interface module, (3) database module, and (4) reporting module. In addition, it utilizes one algorithm named “Path Finder”, described in an earlier publication (Moselhi and Alshibani 2007). Unlike current systems, the proposed system automates onsite data collection and data processing. As well, it tracks and monitors the construction equipment involved in near real time.

The database module is of a relational type designed using Microsoft Access Database Management System. A relational database management system is used in view of its combination of power, simplicity, and ease of use (Kim et al., 1989). This design allows the developed system modules and the Path Finder algorithm to be integrated easily. The database module stores the data needed for tracking and control. These data are clustered into: (1) equipment data; (2) project data; and (3) soil data. Equipment data includes available equipment and its model, capacity, hourly fuel consumption, ownership, and operating cost. These data were mostly obtained from the equipment manufacturer. Equipment types are chosen based on those that are most often employed in this class of projects. Projects data includes: installed quantities and planned and actual cost and the data collected by GPS receivers (positioning, date, time, and velocity). Soil data includes properties of different types of soil such as shrinkage and swell factors.

The graphical user interface contains a series of dialog windows to support user utilization of the developed system. The user interface incorporates menus, toolbars, and dialog windows, as well as a drawing tool. The implementation of the Graphical User Interface (GUI) is carried out in a way that facilitates data entry and minimizes redundant data input.

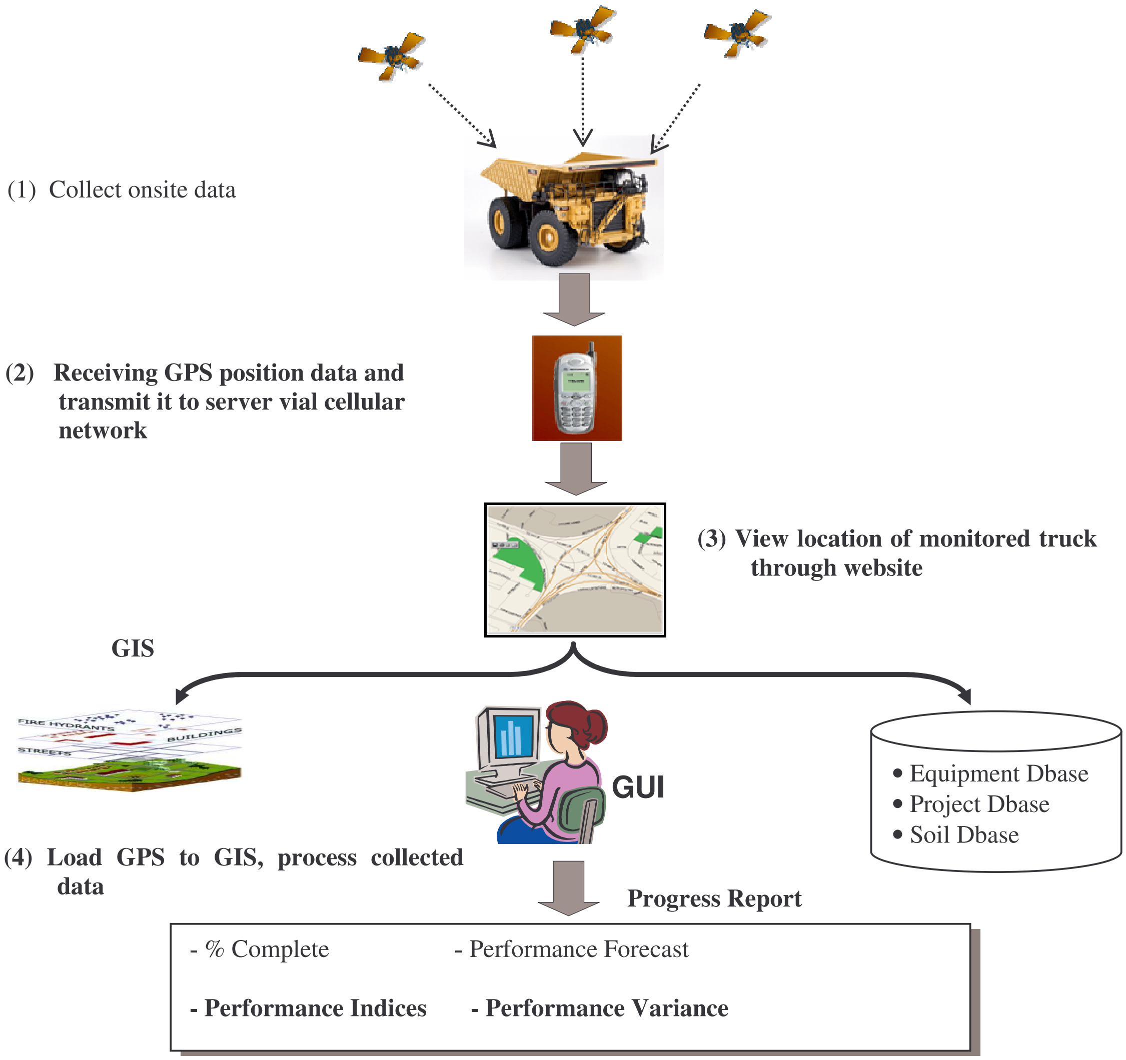


Figure 1: System Overview

Computation Process

As shown in Figure 3, the system starts by collecting data of the hauling unit (i.e. truck) under consideration. This data includes longitude, latitude, altitude, speed, time, and direction. The user then utilizes the developed web-based system to load the collected GPS data into Google map for graphical presentation. In Google map, the moving equipment is presented as dotted line. The user then can map this data directly into the GIS map of the developed system. The user is required to enter additional data interactively using the developed dialog windows. This data include daily indirect cost, tracking technique used, and a set of acceptable ranges of performance indices. Upon the completion of the input data, the system automatically progresses with the crew productivity analysis, determines the project schedule and cost status at the report date, and forecasts time and cost at any targeted future date. The project status is represented by a set of performance indices, and their associated variances

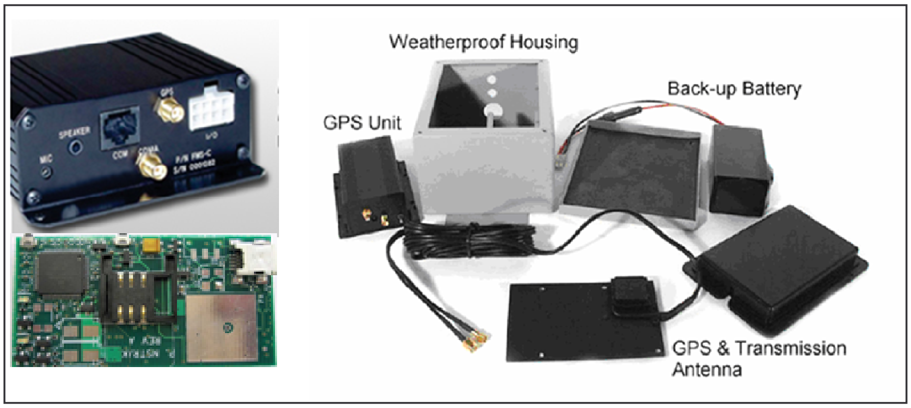


Figure 2: Main Components of the Used GPS Receiver

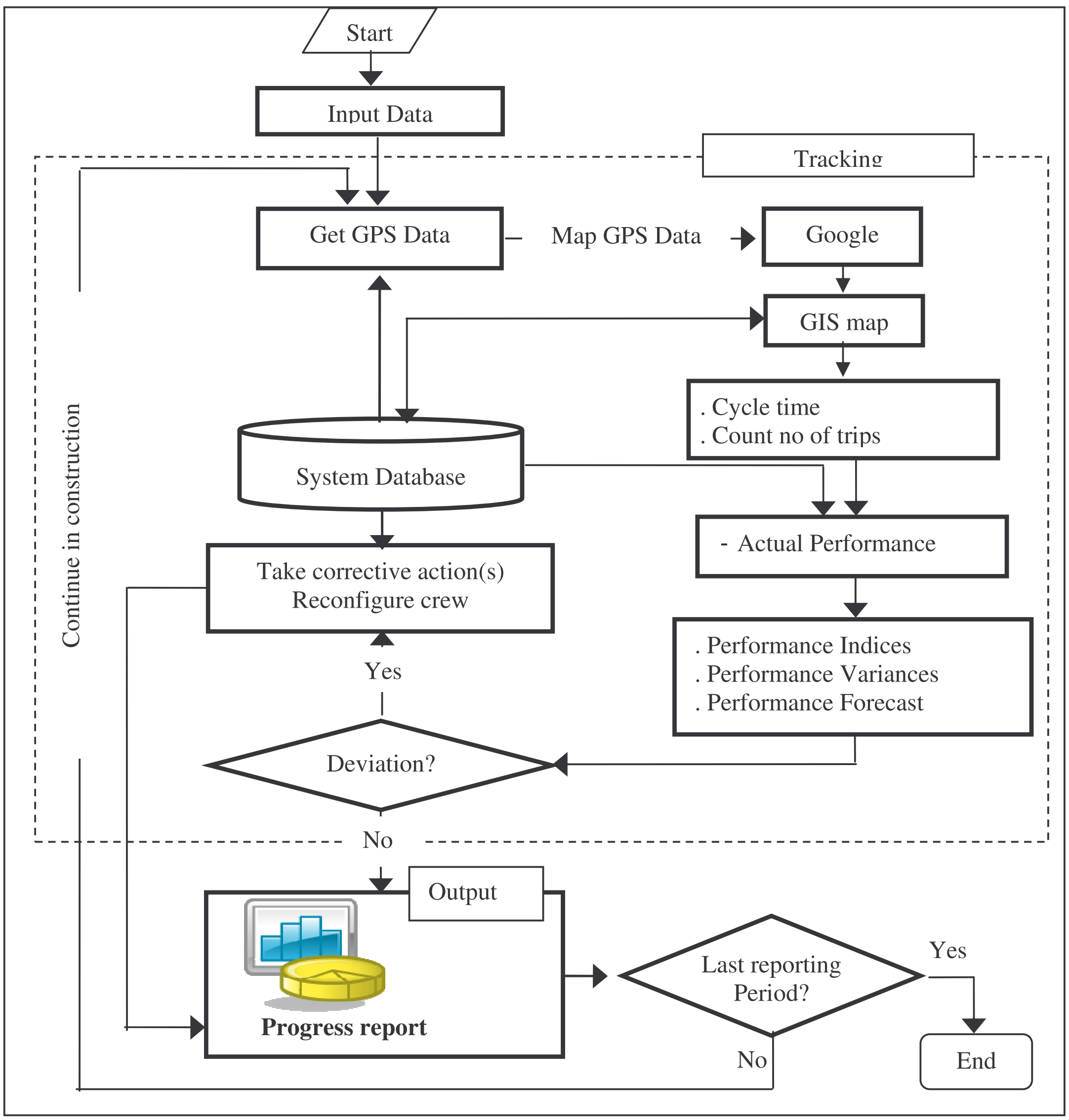


Figure 3: Data Flow in the Developed System

Productivity Estimating

The proposed system estimates onsite productivity using the spatial data collected by GPS receiver(s). The system tracks (counts) the number of cycles (trips) the equipment makes within a particular period of time. The cycle-time equals the summation of loading, travel, dumping, and returning time. The loading time is determined when the equipment is positioned in the loading area. The travel time is determined when the equipment moves from loading to dumping area(s), the dumping time is determined when the equipment is positioned in the dumping area, and the return time is determined as the time required for the equipment to move back from dumping to loading areas. The onsite productivity is estimated considering the type of construction equipment involved. Generally, the onsite productivity for hauling units such as trucks can be estimated as follows:

$$P_a = N_h \times N_t \times C \times C_f \qquad (1)$$

Where P_a is the estimated actual productivity per hour; N_h is the number of hauling units in the crew being considered; N_t is the number of trips the hauling unit made in one hour; C is the hauling unit capacity taking in consideration soil type, which is retrieved from the model's database; C_f is a correction factor, entered by the user, and accounts for the efficiency factor, bucket fill factor; and job and management conditions. It should be noted that N_t is counted automatically using GPS data.

It should be noted that Equation 1 can be easily adapted to suit other equipment such as compactors, graders, and rollers. Having estimated the actual productivity, project performance indices can then be calculated by comparing the actual performance to that planned.

Performance Indices

In order to identify the cause(s) behind unacceptable performance, if any, the proposed system measures project performance indices utilizing project ratio techniques (Eldin, 1992) and/or earned value concept. In view of space limitation, sample of the performance indices are highlighted below:

Productivity Performance Index

This index provides a measure of the likelihood of finishing the project within its targeted schedule.

Cost Performance Index

The cost performance index (CPI) provides a good measure as to how close a project will be completed within its targeted budget.

Queuing Length Index

The index is important when there is a space limitation or when there are obstructions that divide project segments.

Queuing Waiting Time Index

It is the time in which the equipment spends waiting in queue relative to an acceptable range set by the user. It is a good indicator of the crew formations, productivity.

Customer Delay Index (CDI)

Similarly, this index represents the time in which the customer stays waiting for the server. This waiting time can be expressed in relation to the process cycle time involving the equipment being monitored. It should be noted that if the operation is not cycled, then DT is the sum of delays or waiting time in each queue that the customer experiences during the operation, and CT is the total working time of the customer. If (CD)j > the range defined by the user, then the number of customers should be decreased or a change of the server can fix the problem.

Server Quantity Index (SQ)

This index is to account for unused servers that are assigned to the project and left ideal. Although they do not affect the productivity, they affect the project total cost and may lead to cost overrun.

Matching Index (MI)

The Index is used to measure the match between the number of haulers and the number of loaders that leads to maximum efficiency.

Path finder algorithm

The Pathfinder Algorithm was developed in GIS environment and described elsewhere (Moselhi and Alshibani 2007). It supports the following input formats: Satellite and digital images depicting elevation, global positioning system (GPS) data point in addition to the shape file. It has a drawing tool that enables the user to interact directly with the project map (see Figure 4). The pathfinder selects the path that offers the shortest travel and return time. It is not used in the numerical example presented at the end of this paper.

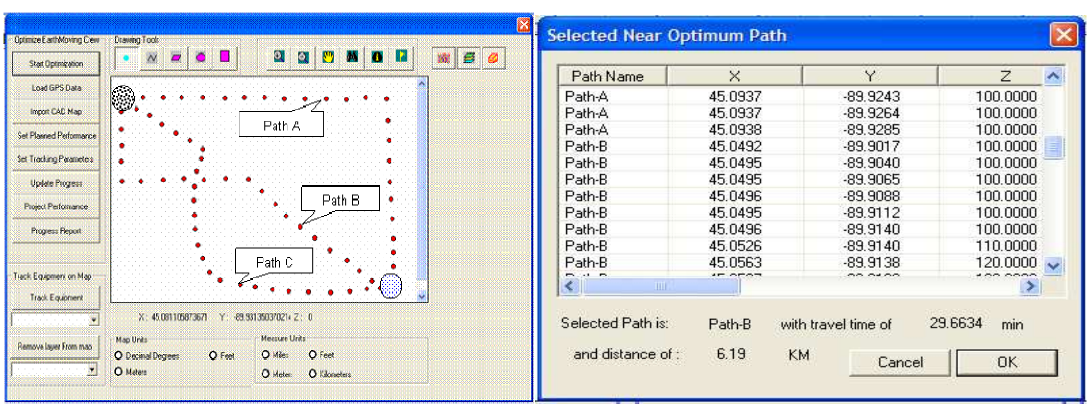


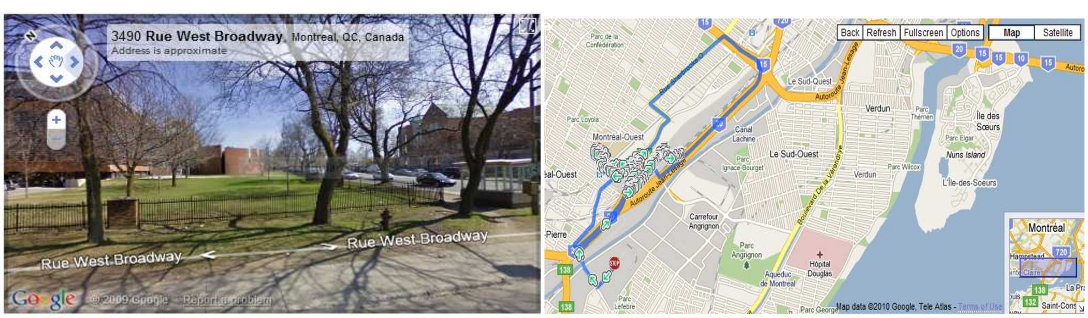
Figure 4: Screen Printout of the Path Finder

COMPUTER IMPLEMENTATION

The proposed system has been implemented in prototype software as proof of concept. The software has been developed using Microsoft Visual C++ by employing Microsoft Foundation Classes (MFC) and ESRI Map-Objects library. The system architecture is designed to allow flexible expansion and change without affecting the rest of the system. Adding a new module for project planning and schedule, however, can be easily integrated within the system. The data required for the use of the developed system can be retrieved from three sources. The first source is the data collected by GPS. The GPS data represents the positioning data of the moving equipment onsite. This data includes positioning data of moving equipment such as altitude, longitude, latitude, date, speed, and time. The second source is the central database of the system. This data contains project data, equipment data, and soil data. The project data includes project actual starting date, planned productivity, planned cost, and installed quantities, etc. The equipment data contains data about equipment used such as capacity, hourly cost, speed, etc. The soil data includes swell and shrinkage factors of different soil type. The third source is the data entered interactively by the user through a set of interface Dialog Windows. This data includes actual cost data, job and management conditions, progress report option, and tracking technique used.

Application Example

The project considered in this paper is of new laboratory facilities currently under construction at Loyola campus of Concordia University. The project site in an urban area; surrounded by main roads and existing building, as shown in Figure 5 (a).The project involves excavating and moving approximately 30,000 m^3 (bank cubic meters) of earth from one location, referred to as borrow pit and haul the excavated material to designated area, referred to as landfill site. The material is common and contaminated soil (B-C). The landfill site is located at a distance of approximately 15.6 km (one ways) from the borrow pit location. The travelled road is in urban area with low-rise buildings in Montreal. The allowed speed on the travelled road is 50 and 60 Km per hour for travelling and returning, respectively. Additionally, the travelled road intersects with other lateral roads. Those interactions force the truck operator to stop at a number of locations along the travelled roads. Figure 5 (a) and (b) shows the construction site and the surrounding area as well as the travelled hauling road as presented in Google map.



(a) (b)

Figure 5: Project Location and Its Surrounding Area

The contractor selects a crew consisting of one excavator and 4 articulated trucks to carry out the work, all in good operating conditions. Figure 6 shows excavation work of the project under consideration. A near optimum crew, however, can be obtained using optimization model described earlier by the authors (Alshibani and Moselhi, 2009). The hourly loader and truck cost is $85 and $185, respectively. It is required to track these operations in near real time without human involvement in data collection and estimating onsite productivity, forecast project time and cost at completion.

Figure 6: Overview of the Excavation Work

Analysis of the Results

Considering the condition of the crew, it was decided to mount only one GPS receiver on one of the 4 trucks, and collect GPS data of the operations involved in time interval of 45 seconds. Table 1 shows a sample of the collected GPS data. The collected GPS data samples were uploaded into the GUI of the developed model. It should be noted that the data collected in different times of the day and in different weather conditions to reflect the actual condition of the construction site. As mentioned earlier, the user uses the server to login into the project and then starts loading the collected data into Google map. The system then analyzes this data to calculate actual loading, hauling, and dumping time and subsequently to estimate onsite productivity. Figure 6 represents the screens printout of one of the collected data samples that has duration of 131.47 minutes. As it can be seen from the figure, the system first calculates actual loading, dumping, and hauling time as described above. The loading time is 4.6 minutes, dumping time is 2.26 minutes, average speed is approximately 12 Km/hr, and the total distance of this data sample is 25.5 Km. Having estimated the cycle time, the number of trips made is then calculated. The number of trips made in 131.47 is 1.4592 trips. Therefore the number of trips made in an hour is 0.68 trips (1/ 1.4592). The crew actual productivity is 542.82 m^3 /hour , comparing with as planned, the productivity performance index is 0.77 which indicates for poor productivity that causing cost overrun and behind schedule status.

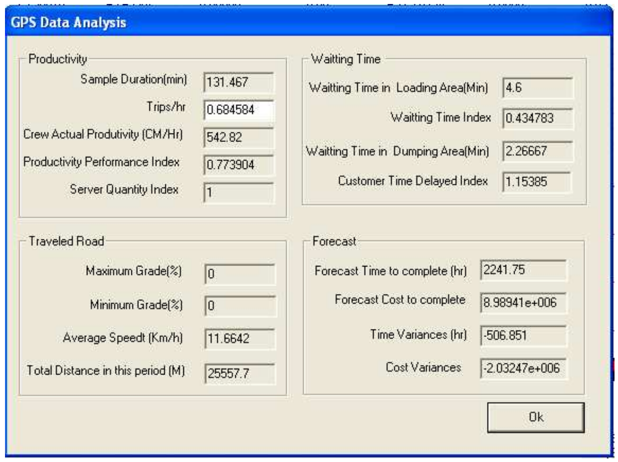


Figure 7: Output of the GUI Module

Table 1: Sample of GPS Data

Latitude	Longitude	Date	Time	Information	Speed (KM/h)	Heading
45.43993	-73.6389	12/04/2010	6:35:13	Moving	25	SW
45.43797	-73.6428	12/04/2010	6:36:43	Moving	19	NW
45.4409	-73.6459	12/04/2010	6:37:28	Moving	17	NW
45.44266	-73.6471	12/04/2010	6:38:58	Moving	12	N
45.44516	-73.6425	12/04/2010	6:39:43	Moving	63	NE
45.45008	-73.6355	12/04/2010	6:40:28	Moving	42	NE
45.45329	-73.6332	12/04/2010	6:41:13	Moving	29	NE

CONCLUSIONS

This paper presented a new web-based system that automates onsite data collection, estimating onsite productivity, measuring project performance, and forecasting project cost and time based on data collected using GPS in real time. The main components of the system and their interconnectivity were described. The applications of spatial technologies including GPS in tracking and controlling have been found to provide a powerful tool to automate tracking and control of earthmoving operations. The integration of GPS with Google map makes easy for the project manager to track construction equipment in real time. Analysis of the results obtained indicates that using GPS facilitates data exchange among project team members so that timely corrective actions can be taken. Displaying GPS data in Google map can help project managers in identifying causes behind unacceptable performance, if any.

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