

TRUCK+ FOR EARTHMOVING OPERATIONS

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SUMMARY: *This paper presents an automated system that integrates Global Positioning System (GPS) and Geographical Information System (GIS) in a web-based platform named Truck+. It is utilized for estimating, monitoring and forecasting productivity of hauling trucks in earthmoving operations. The developed system consists of GPS for automated site data acquisition, GIS web-based system used as graphical user interface, relational database and Discrete Event Simulation (DES) for stochastic forecasting. The paper also highlights the benefit of utilizing the actual captured data supported by DES for stochastically forecasting productivity of earthmoving operation. DES was applied to forecast productivity in a stochastic approach that makes use of the project's captured data during the operations involved rather than data from past projects. This makes it more capable of capturing relevant factors that impact project conditions. Truck+ consists primarily of two modules: tracking/monitoring module and forecasting module. The developed system has been implemented in prototype software using object-oriented programming, ArcGIS APIs (Application Programming Interface) and deploys Microsoft Silverlight for creating and delivering rich internet web application and media. Truck+ is capable of generating graphical and tabular reports with various degrees of detail to suit the requirements of project teams. The developed system is applied to a construction project in Montreal area to demonstrate its use.*

KEYWORDS: *Earth-moving Operations, Productivity, Progress Reporting, GPS, GIS, Web-Based System.*

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1. INTRODUCTION

Estimating actual productivity of construction jobsites is essential in forecasting time and cost required to complete construction operations (Oglesby et al, 1989). Earthmoving operations are characterized by intensive use of equipment. Therefore, tracking this equipment is essential for tracking earthmoving operations (Alkass and Harris 1988, Eldin and Mayfield 2005, and Alshibani and Moselhi 2012). Hauling trucks are an important part of equipment fleets in earthmoving operations, which demand moving large amounts of soil and long travel distance within relatively short time (Marzouk and Moselhi 2004). Traditionally, site data collection used in earthmoving operations is carried out manually, which is time consuming and not necessarily accurate (Sacks et al, 2002). Consequently, some information ends up being not readily available to project teams to make timely decisions. Failure in effectively tracking construction progress and in retrieving the related information on demand may result in schedule delays and cost overruns (De la Garza and Howitt, 1998). Thus, earthmoving operation needs an automated system for capturing job-site data, with capability of handling a large volume of data in near real time and integrates time and cost for accurate performance measurement and forecasting.

Recent advancements in automated data acquisition technologies made it feasible to track and monitor construction operations in near real time (Navon and Goldschmidt, 2002, Caldas et al., 2006, Goodrum et al, 2006 and Grau and Caldas, 2009). GPS has been used in many aspects of construction operations such as collision avoidance of equipment, calculation of durations of earthmoving activities (John et al, 2005). As well, GPS was used to monitor the compaction level of various layers of road construction (Bouvet et al. 2001). Oloufa et al (1997) proposed an automated system to monitor and record the areas compacted by an asphalt roller. That system used GPS to achieve a high degree of accuracy. The system guides the operator throughout the process so that the necessary passes are carried out. Jaroslaw and Karl (2002) developed a road construction system based on GPS. Their system is designed to detect and correct substantial compaction errors.

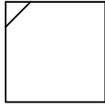
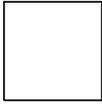
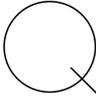
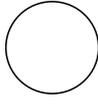
GIS is a combination of computerized mapping and database management system (Hassanien, 2002). It is used to represent and analyze the geographic features present on the earth's surface. GIS database is a collection of information about objects and their spatial relationships to each other. Hassanien and Moselhi (2002) used GIS to develop a model to automate data collection and analysis for planning and scheduling highway construction projects. Their model utilizes GIS to analyze spatial data and to estimate cut and fill quantities. Spatial information utilizing GPS and GIS has proved to be an effective method to track construction operations since it provides data collection and graphical representation. Cheng et al (1996) developed a system by integrating GPS and GIS to track pavement compaction. The system collects data in real time using GPS devices attached to compactors and then transforms this data to a GIS map for graphical presentation. Moselhi and Alshibani (2009) presented a standalone desktop system for the tracking and control of earth moving operations. Their model uses spatial technologies (GPS/GIS) to facilitate automated data acquisition. Their proposed system is designed for highway construction projects. GPS was used to automate data collection, and GIS is used to analyze the collected data. However, their model was built on the assumption that loading and dumping areas are circular, which is not true in most cases. Additionally, did not get any benefit from the previously identified optimum travel and return road from the planning module.

Computer vision-based systems were used also to track earthmoving operations but focusing mainly on loading process (Rezazadeh Azar and McCabe 2011). In addition, such technology has limitations specially in differentiating between hauling trucks if they have the same colour. It also suffers from dust obstruction to camera line of the sight and inability of calculating travel, dumping and return durations, which constitute complete hauling cycle. On Board Instrumentation System (OBIS) is the most widely used automated tracking and monitoring system in earthmoving operations. The system is based on automated data acquisition sensors attached to different parts of the equipment to give an alert in case of any abnormal conditions. Those sensors are responsible for mechanical health monitoring for equipment and measuring physical performance of equipment such as temperature and pressure. In addition, those sensors could be used to estimate onsite productivity (CAT Product Link, 2013). However, those systems are characterized by being expensive in cost. As well, the manufactures catalogues do not disclose its working methodology since it is the manufacturer's Know-How. In addition, those systems could not forecast fleet performance deterministically or stochastically.

Discrete Event Simulation (DES) is the most common type of simulation in construction. It serves as a powerful tool in analyzing and breaking down complex problems. Consequently, it grabbed the biggest share of researchers' attention (AbouRizk, 2010). DES models a system as a network of processes that are sometimes preceded by queues, where state changes occur at discrete points of time. In DES model, each unit flows through the system and reserves resources to complete a job. When, the job is accomplished, the unit releases those resources. Queues temporarily hold units in case resources are not readily available. These actions are

called events (Halpin, 1973 and Hajjar and AbouRizk, 1999). Halpin (1973) developed a powerful modeling element called CYCLONE, which simplified the simulation and modeling process for users with limited simulation background. CYCLONE was later used as a base for other simulation systems. In 1996, Martinez produced a more evolved simulation tool (STROBOSCOPE). This tool is capable of handling uncertainty not only in time, but also for different resource quantities.

Table 1: common used DES modeling elements (Halpin 1973)

Element Name	COMBI	NORMAL	QUEUE	FUNCTION	COUNTER	ARROW
Modeling Element Symbol						

Simulation of earthmoving operations allows construction planners and estimator's prediction and assessment of operations productivity (Halpin and Riggs 1992). The literature reveals considerable work on simulation for modelling earthmoving operation (Shi and AbouRizk 1995 and Marzouk and Moselhi 2003). Despite the advantages of computer simulation, it requires trained staff for model development and data entry, specialized simulation software and past historical data to generate operations probability distributions. In order to rectify the limitations of the current systems, a new system is developed. This paper presents automated web-based system (Truck+) that has two modules, tracking/monitoring module and forecasting module, for estimating and forecasting productivity of earthmoving operations. The system uses spatial technologies (GPS/GIS) for automated site data acquisition, graphically display onsite data and supported by earned value analysis to measure actual performance. As well, Truck+ utilizes DES in forecasting module making use of captured data from tracking/monitoring module to take into account the uncertainty associated in the operation. The paper focuses in detail on the system overview and the tracking/monitoring module. This paper builds on earlier work and related developments made by the authors (Montaser et. al., 2011).

2. PROPOSED SYSTEM

Truck+ is an integrated web-based system. It consists of two main modules for estimating and forecasting productivity during the execution of earthmoving operations as shown in Fig. 1. The first module is designed for automated tracking/monitoring of the operations involved, while the second is used for stochastically forecasting productivity and evaluating different fleet configurations. GPS units are mounted on hauling trucks to identify its locations during the earthmoving operation cycle. The data captured using GPS is automatically transferred to onsite server and subsequently to a central database. The central database is in the heart of Truck+. It is responsible for receiving, storing and data exchange with the two modules of the system and its simulation engine. The GIS web-based graphical interface is the shell of Truck+, where the user interacts and defines the spatial boundaries of the earthmoving operation and the type of performance reports. The data is processed automatically, without human intervention, to calculate total cycle time for each truck and its respective loading, travel, dumping and return durations. Truck characteristics and excavated soil properties are retrieved from the central database to calculate the productivity of hauling trucks. Then total productivity for the entire fleet is estimated.

The cycle time information for each truck is added to the central database and is considered as truck current data. This current data is used afterward in the forecasting module where it is analysed stochastically to generate probability distribution for the cycle time four components. DES engine is linked to the central database to extract its respective data and use it subsequently to simulate earthmoving operation in order to stochastically forecast future productivity based on the actual collected data. The actual captured data inherits all the uncertainties encountered during the construction elapsed period and depicts operation bottlenecks. For example, the daily collected data via the tracking/monitoring module could be used at the end of the week as an input to the forecasting module to predict the fleet productivity and its performance for the next week. The collected data can also be used to evaluate the performance of trucks and its operator. The results will be reported to members of project teams via web-based reporting system.

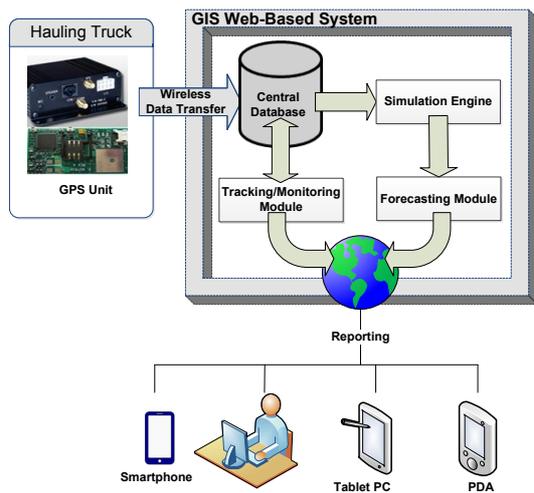


FIG. 1: Truck+ system components

1. Tracking & Monitoring Module

This module is automated and works in near real time to track and monitor hauling trucks. It is capable of capturing large volume of data on daily basis; processing and analysing the captured data; calculating onsite productivity; measuring actual performance based on earned value concept and comparing the actual versus planned to derive variances if any; and deterministically forecast time and cost for the operation. Actual productivity is a function of the number of trips hauling trucks made over a certain period, which requires calculating the different cycle time durations for each truck. Consequently, calculating cycle time accurately is key element for estimating onsite actual productivity. The developed module estimates the fleet's onsite productivity using the spatial data captured by GPS receivers mounted on the hauling trucks Fig. (2-a). The GPS unit consists mainly of GPS chip and antenna for receiving the satellite signals. The GPS is connected to a microcontroller that has a processor that converts the signals into truck ID, date, time, longitude and latitude along its route as shown in Fig. (2-b). The GPS starts reporting the hauling truck location and its route related data stated above. GPS data are in the form of truck positions in over short time intervals such as 45 seconds. Then, the data is transferred to the main server in the contractor's head office, where the central database resides.

Truck cycle time consists of four main components, which are loading, traveling, dumping and return. The loading time is the time when the truck is inside the loading area. Travel time is the time spent between and from loading area to dumping area. Dumping time is the time when the truck is inside the dumping area. Return time is the time required for the truck to travel back from dumping area to loading area to start new cycle. The user defines using the GIS web-based interface the spatial boundaries of the earthmoving operations. In order to allow the user to add layers to the GIS map, a drawing tool has been developed for each cycle component (i.e. loading, travel, dumping and return). Using the drawing tools, the user draws the polygon around the loading area. The drawing tool is flexible to enable the user to draw regular, irregular and circular shapes. If the GPS data point resides inside this polygon, it means that the truck is in the loading process. Similar procedure is done for the dumping area. For the travel and return road, the user draws poly line. This poly line represents the travel and return roads. If the drawn poly line inside streets, it will automatically retrieve the street dimensions (centreline and width) from the GIS map. Otherwise, the poly line is on unpaved roads, an offset with predetermined value will be applied to the poly line to form a polygon. Figure 3 shows a diagrammatic sketch of the data capturing scheme and classification of the components of the earthmoving operation. The user defines the polygons and poly lines one time at the beginning of the project and its corresponding data will be saved automatically in the central database.



FIG. 2: (a) Main components of the used GPS device (b) GPS raw captured data

Each GPS data point is mapped on the GIS map, which is used to display geographically as a separate layer the moving truck. The system classifies the truck as it crosses from one polygon to another and the time that polygon was crossed is identified. Then, it is classified as loading, travel, dumping, or return. Truck+ starts identifying the cycles that the truck has done through a series of decisions, as shown in the flow chart (Fig. 4 & 5). The five main events in each cycle are identified to be used afterwards for cycle time calculations. Table 1 shows the GPS data after system processing.

For each truck, Truck+ identifies five main events and its corresponding time. They are T1, T2, T3, T4 and T5. By identifying those five events the cycle time component could be calculated as following:

Loading Time (L) = Registered time of Event 2 - Registered time of Event 1

Travel Time (T) = Registered time of Event 3 - Registered time of Event 2

Dumping Time (D) = Registered time of Event 4 - Registered time of Event 3

Returning Time (R) = Registered time of Event 5 - Registered time of Event 4

Truck loading time provides a clear picture of the number of trucks inside the loading area and whether it matches the number of loaders (excavators). It assists in identifying whether there are trucks queue or not. Similarly, dumping time could help in detecting dumping area congestion. Such information supports project managers in detect causes behind any unacceptable performance. It should be noted that loading (dumping) time include the exact direct loading (dumping) time in addition to the truck manoeuvring time in loading (dumping) area. Accordingly, the total cycle (C) time is calculated by the summation of loading time, travel time, dumping time and return time. If the truck is outside the optimum travel and return roads, another rule is applied to calculate the travel and return time. The rule is based on the truck direction. If the direction is from the loading area to dumping area, it is classified as travel and vice versa for return. The system calculates the times spent outside the optimum travel and return roads and considers it as cycle time inefficiencies of the operation and reports this to the project manager. The system provides for the user a capability to define if-then rules in the central database, which could help in situations such as driver break time or to fuel the truck.

The productivity of the truck is determined knowing the number of trips and the cycle time of each trip that each truck makes within a particular period. For each hauling truck, Truck+ retrieves its capacity and project soil properties from the central database to calculate the truck productivity and to estimate the quantity of hauled excavation. In this module, it is assumed that the truck is loaded with its full capacity; according to truck manufacturer data and soil type. Those steps are repeated for each cycle and each truck and the total cycle time and its components is identified and appended to the central database as shown in Fig. 6. As this system works at company enterprise level, the first step is to identify the desired project. Central database provides the list of project working hauling trucks and retrieves all respective data. Since, the number of hauling trucks, the number of trips per truck and the capacity of each truck are known; the daily-excavated quantity could be calculated. This quantity is divided by the total excavation quantity to identify the actual percentage complete. Percentage complete is used afterwards in earned value analysis for progress reporting purpose and to estimate the actual cost and duration.

According to earned value method, three main indicators are used for performance analysis; namely as: Budget Cost for Work Scheduled (BCWS), Actual Cost for Work Performed (ACWP), and Budget Cost for Work Performed (BCWP) (Moselhi, 1993). BCWS for earthmoving operation is known from the planning stage and saved in the central database. BCWP is calculated according to the percentage complete calculated on daily basis. The user enters ACWP from the actual on-site expenditures related to earthmoving operation. Upon the completion of estimating the BCWS, BCWP and ACWP, this module proceeds to calculate the activity performance indexes Cost Variance (CV), Schedule Variance (SV), Cost Performance Index (CPI) and Schedule Performance Index (SPI). Then, the system indicates whether the earthmoving operation status for time (behind schedule or on schedule or ahead of schedule) and cost (over budget or on budget or under budget). The system deterministically forecasts the cost Estimated at Completion (EAC) using two assumptions: (1) the established performance at the report date will continue until completion (EAC1) or (2) the remaining work will be performed as planned and the previous performance was exception (EAC2). These assumptions are providing practical scenarios for the project manager to select from. This module also generates progress reports in tabular and graphical format. The developed module 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.

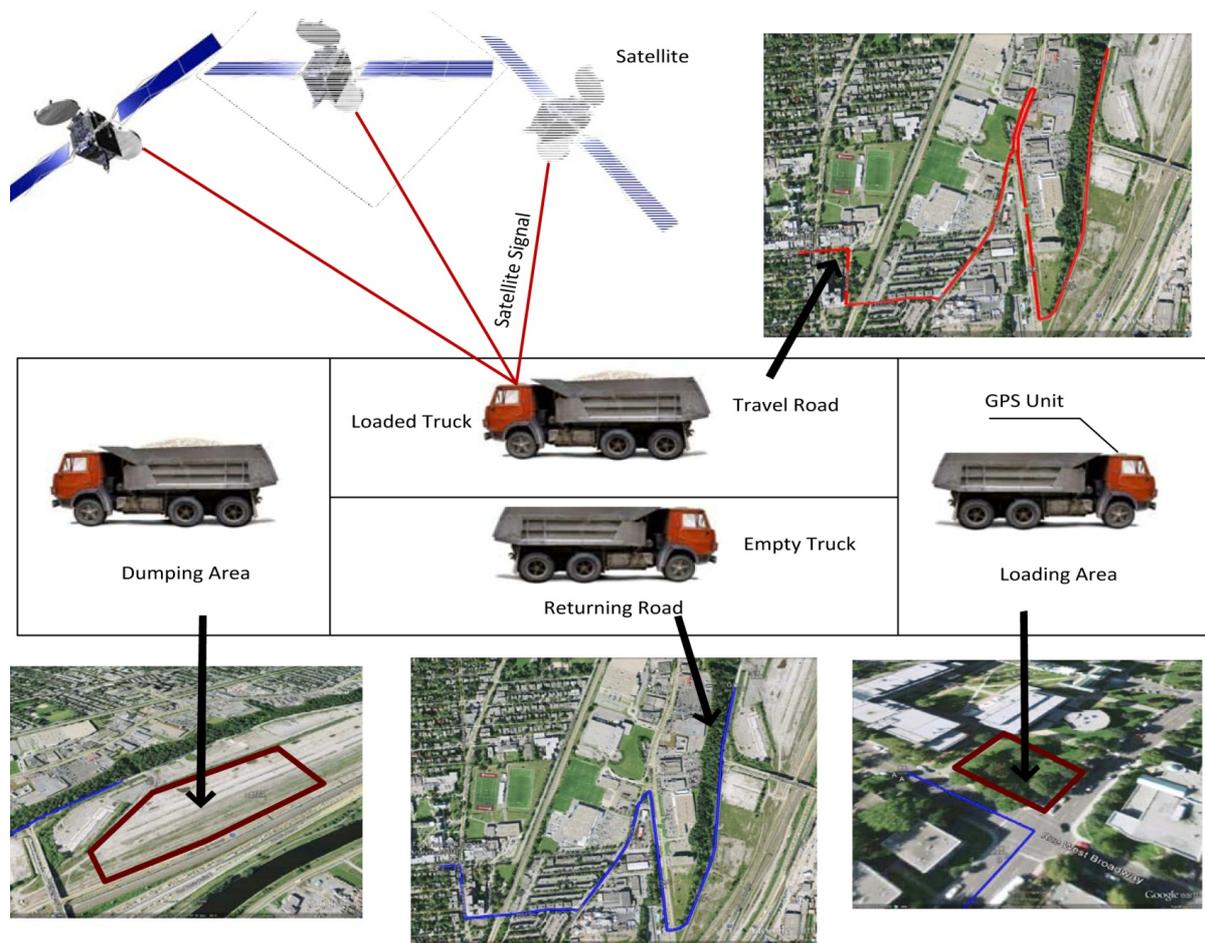


FIG. 3: Diagrammatic sketch for the GPS/GIS interaction

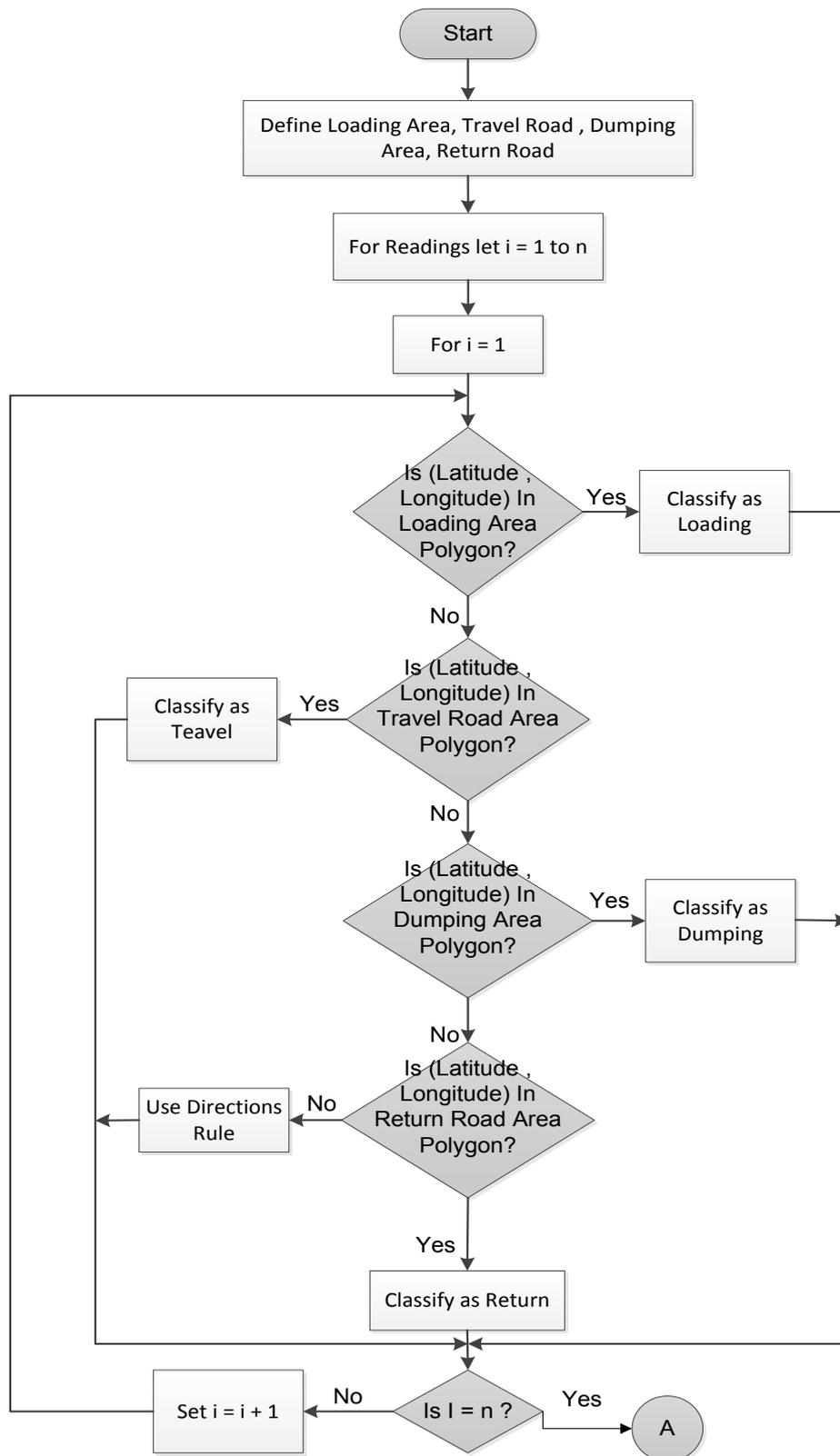


FIG. 4: Flowchart for GPS captured data classification (part 1)

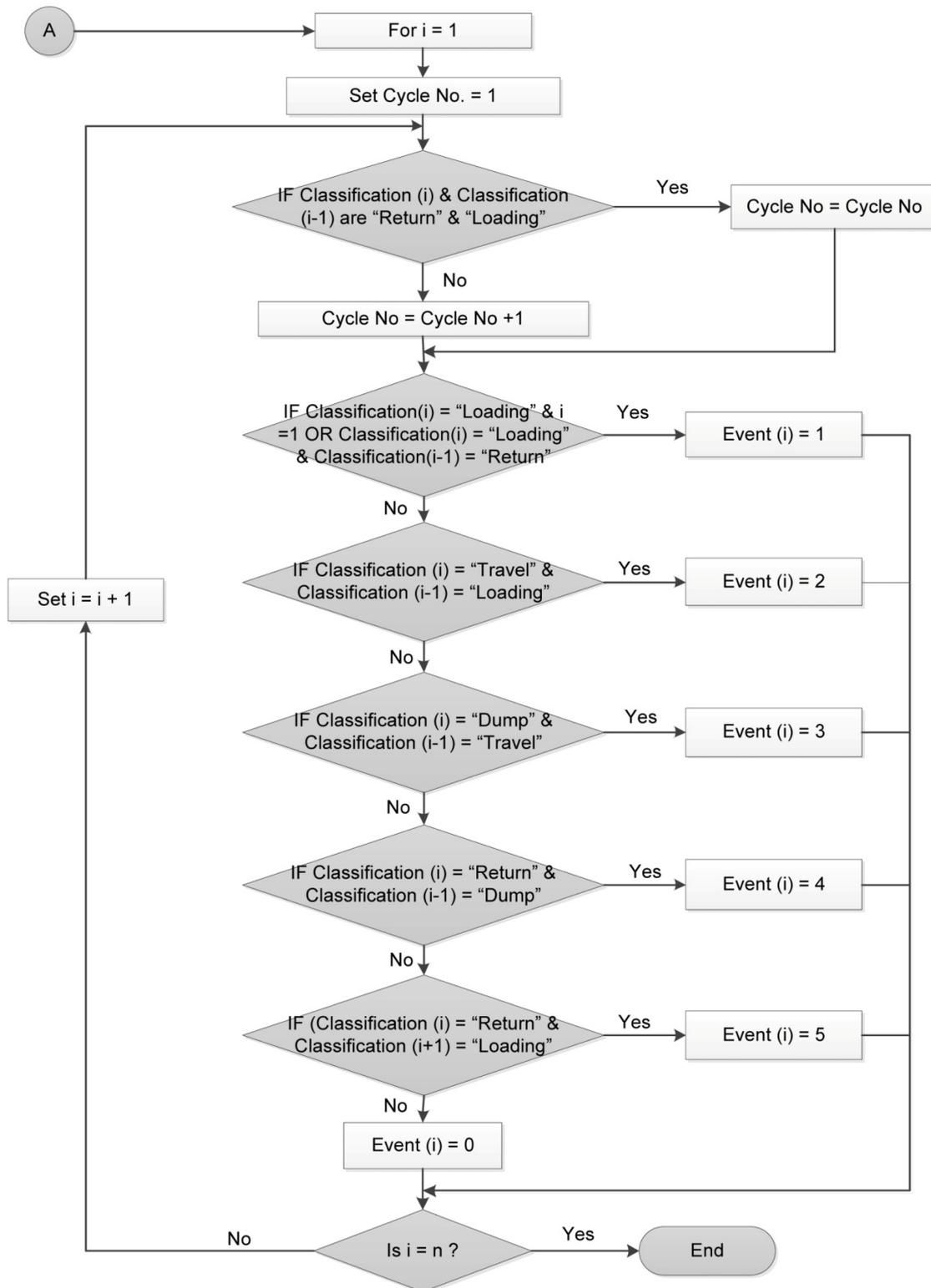


FIG. 5: Flowchart for GPS captured data 5 events identification (part 2)

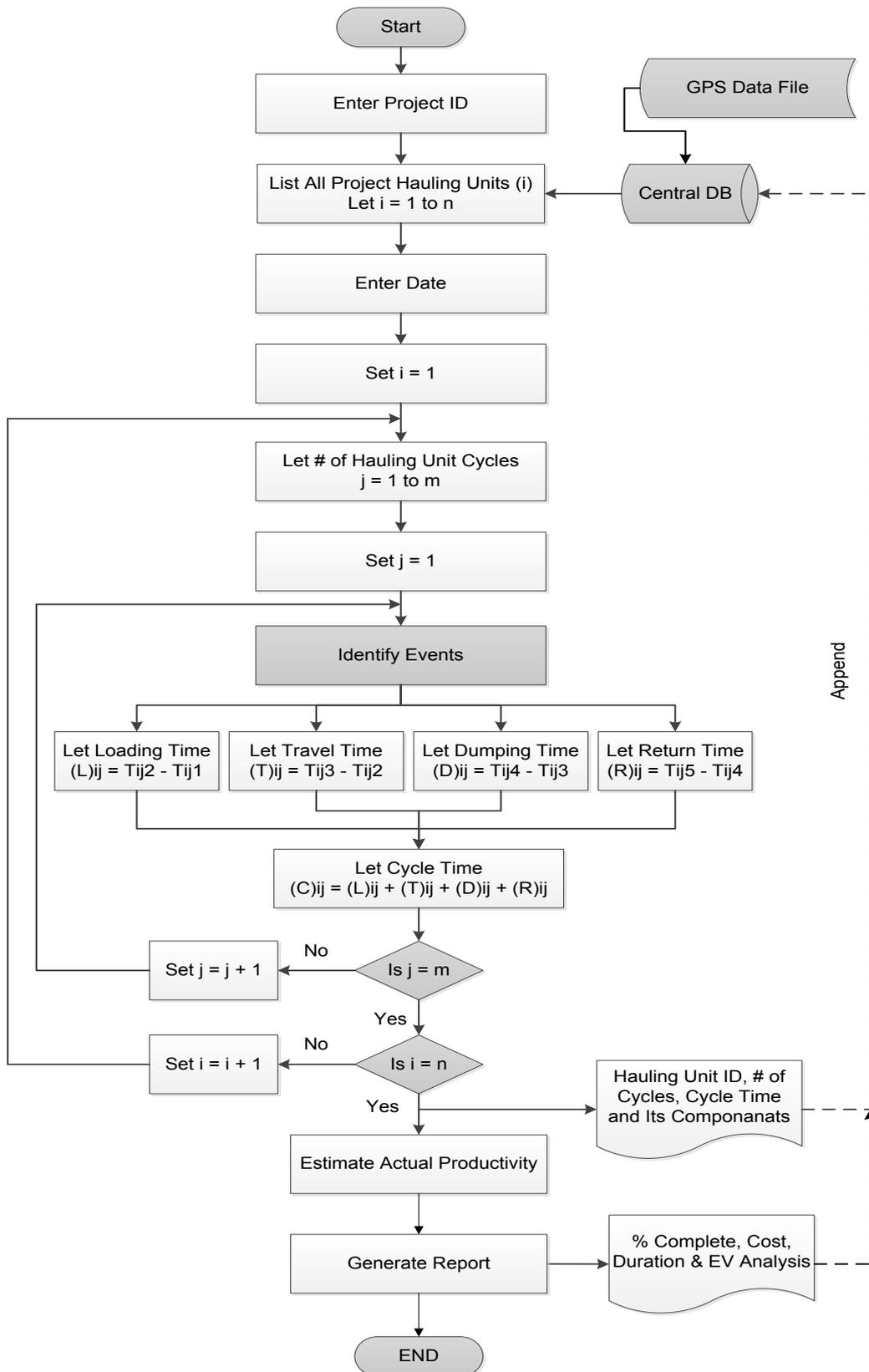


FIG. 6: Flowchart for data flow in the tracking/monitoring module

Table 2: GPS data an its system processing

Date	Time	Latitude	Longitude	Classification	Event	Time (min)	Cycle #	Cycle Time
08/04/2010	8:12:06	45.45667	-73.64062	Loading	1		1	0:25:05
08/04/2010	8:15:05	45.4566	-73.64045	Loading				
08/04/2010	8:15:11	45.4543	-73.63966	Travel	2	0:03:05		
08/04/2010	8:17:11	.	.	.				
08/04/2010	8:21:11	.	.	.				
08/04/2010	8:26:11	45.45729	-73.62556	Travel				
08/04/2010	8:26:20	45.45602	-73.62363	Dump	3	0:11:09		
08/04/2010	8:26:11	.	.	.				
08/04/2010	8:27:58	.	.	.				
08/04/2010	8:28:06	45.45634	-73.62273	Dump				
08/04/2010	8:29:11	45.45738	-73.62531	Return	4	0:02:51		
08/04/2010	8:30:11	.	.	.				
08/04/2010	8:37:46	.	.	.				
08/04/2010	8:37:11	45.45532	-73.64124	Return	5	0:08:00		

2.Forecasting Module

Most forecasting techniques for earthmoving operations use deterministic approaches based on the average performance of elapsed period for the same project. However, those methods do not consider uncertainty or take into consideration fleet configurations different scenarios and its impact on productivity. For example, the cycle time varies from one cycle to other due dynamic factors such as weather conditions and operating conditions in the excavation and dumping areas. Additionally, the traffic on travel roads is another factor, which affects the travel and return durations. The other forecasting techniques are stochastic in nature but rely on historical data of similar past projects. Utilizing such data is an obstacle for accurately simulating the current earthmoving operation. Since, every project is unique in nature even with similar conditions. Also, current literature does not reveal systems that could integrate DES and near real time data acquisition for stochastic forecasting purpose.

Therefore, this module demonstrates the stochastic value of hauling trucks captured data in elapsed period of the current earthmoving operation to forecast productivity of the fleet and consequently the duration and cost. In addition, if the elapsed period were suffering from delay, a corrective action would be taken based on generating different scenarios and fleet configurations using computer simulation. This module is automated but requires human intervention in selecting different scenarios such as the number of hauling units and capacity. It is built based on the interaction between the system and the central database where the past period cycles time and its component has been stored. Fig. 7 shows the module general flowchart, starting by generating the Probability Density Function (PDF) for cycle time components from the captured data retrieved earlier. PDF should be generated for each cycle time component (i.e. loading time, travel time and dumping time) that best fits the process including its associated parameters (e.g. mean value and standard deviation) as shown in Fig. 8. The fitted functions are then used as an input for the simulation model to generate and evaluate different scenarios.

In this module STROBOSCOPE discrete event simulation engine was utilized, where it is installed on the web server. Specially designed simulation model for earthmoving operations is deployed as depicted in Fig. 9. This DES model will be the typical model used for data manipulation and processing to calculate the stochastic forecasted productivity and to experiment fleet different configuration in case of any corrective action. The DES model will retrieve the earthmoving operation data such as total quantity of earth work, number of hauling trucks and excavators, hauling truck capacity and PDF for different cycle time components from the central database. The system will report to the user the forecasted fleet productivity and its associated cost and time. The user could interact with the system to change the fleet configuration only. Then, a different scenario will be generated for the user, which could help in time or cost optimization and making informed decisions.

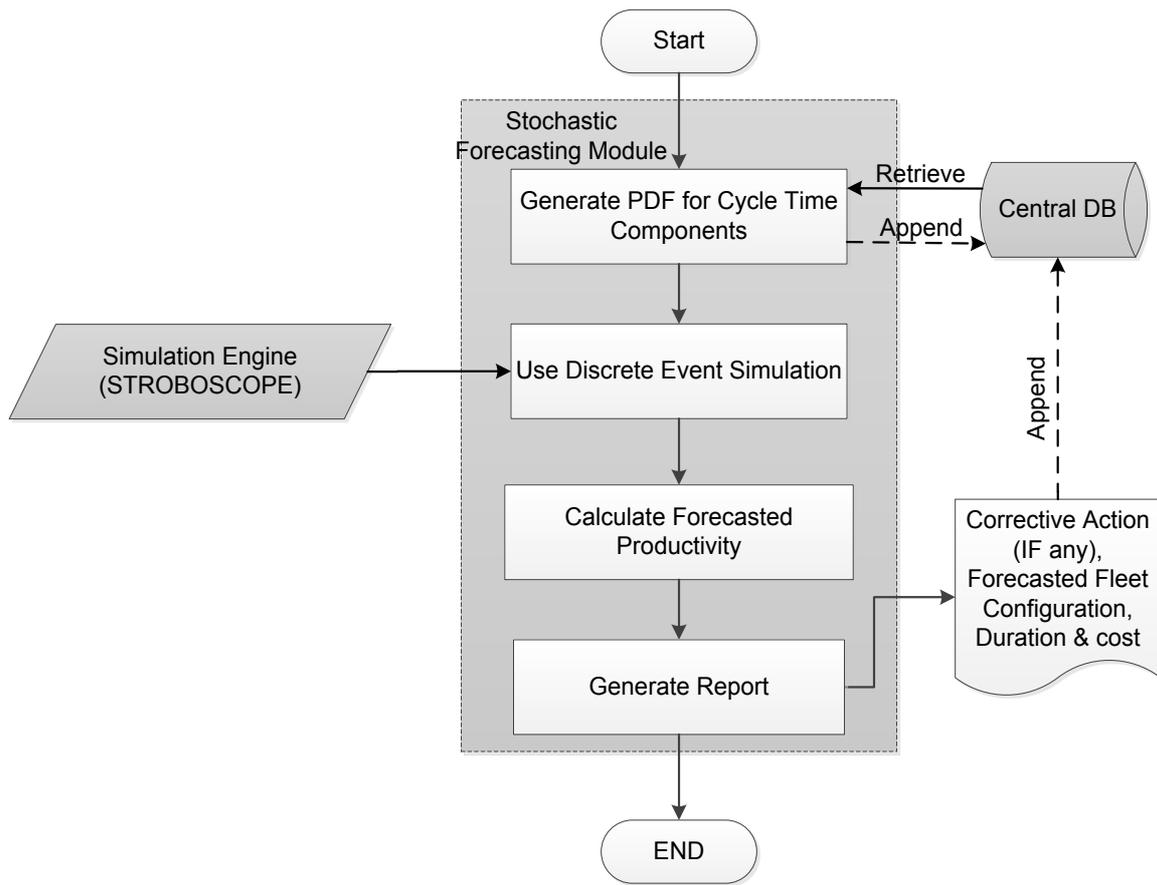


FIG. 7: Flowchart for forecasting module

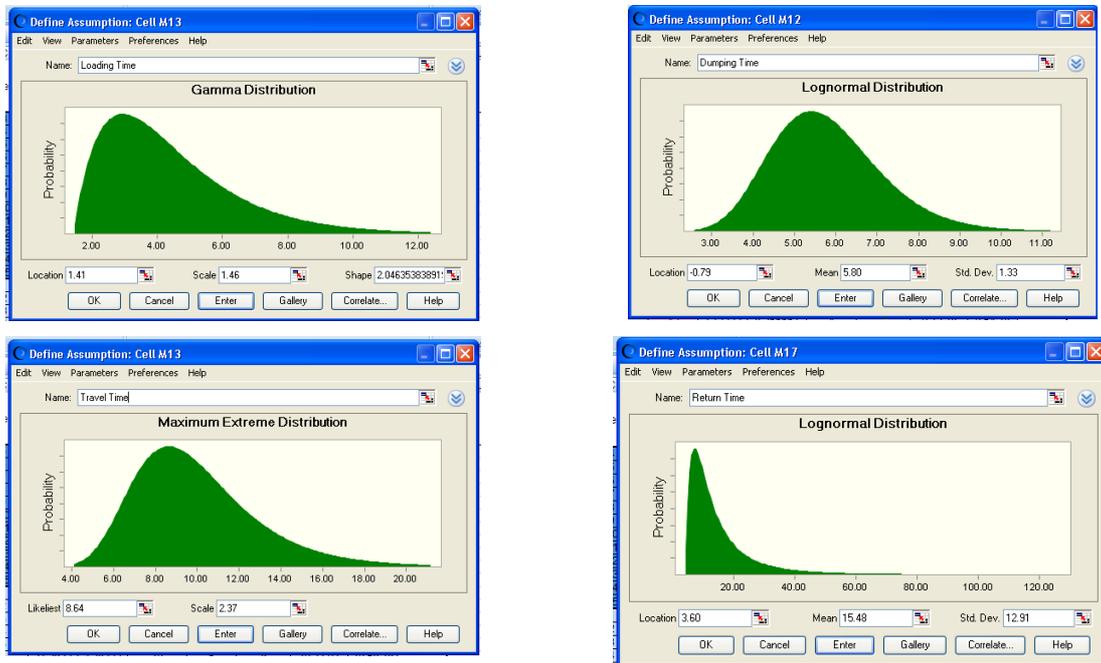


FIG. 8: Cycle time components probability distribution

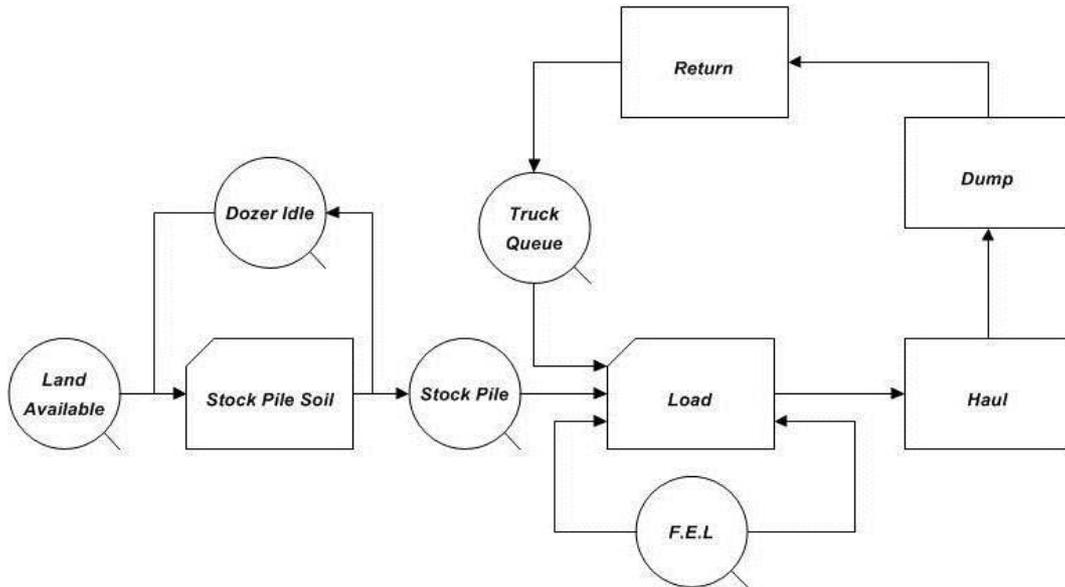


FIG. 9: Specific purpose earth moving operation simulation model

The simulation model equations are as following:

- Excavator Idle Ratio = The time weighted average of the content of Excavator Queue / Number of Excavators
- Excavator Utilization = 1 – Excavator Idle Ratio
- Truck Idle Ratio = The time-weighted average of the content of Truck Queue / Number of Trucks
- Truck Utilization = 1 – Truck Idle Ratio
- Time of operation in hours = Simulation Time / 60
- Production rate (m³/hr) = The current content of Dumped Soil Queue / Time of operation in hours
- Total cost of operation = [Truck cost (\$/hr) * Number of Trucks + Excavator cost (\$/hr) * Number of Excavators] * Time of operation (hr)
- Unit cost (\$/m³) = Total cost of operation / The current content of Dumped Soil Queue

3. System Database

Earthmoving operations are equipment intensive operations. The optimum monitoring of such equipment requires storing and retrieving a large amount of data. Therefore, a central database has been designed to support the management functions of the system and to minimize the user interaction. The system interacts with the central database specially designed to organize, store and manage GPS captured data from construction sites and other respective earthmoving operation data. The proposed system focuses on capturing data from the construction jobsite storing it in databases and then providing queries to retrieve the information needed for reporting the project status. Relational database management systems are better suited for this type of application (Fig. 10). Because it contains relatively structured data, relationships and schema design. The database consists of nine main entities. Resources entity consists of the main three resources in any construction projects that are equipment, labour and material. The main scope of this paper is the equipment entity that resembles the fleet configurations such as excavator and truck fleet. Both entities have the main attributes for the fleet configuration such as capacity. GPS entity has eight attributes, connected to the truck entity with one to one relationship, and in case of tracking all equipment this relationship could be connected to the equipment entity instead of only trucks. Project entity considered the central entity as it connects to the other five entities. Soil entity represents project soil characteristics as reported in the project geotechnical report. It is necessary for tracking modules and this entity has five main attributes. Soil entity is connected to the project entity with one to many relationship based on an assumption that each project has one soil type only. Road entity is created to represent travel and return road for the truck. In addition, it is essential for the GPS based tracking module to identify the travel and return polygons.

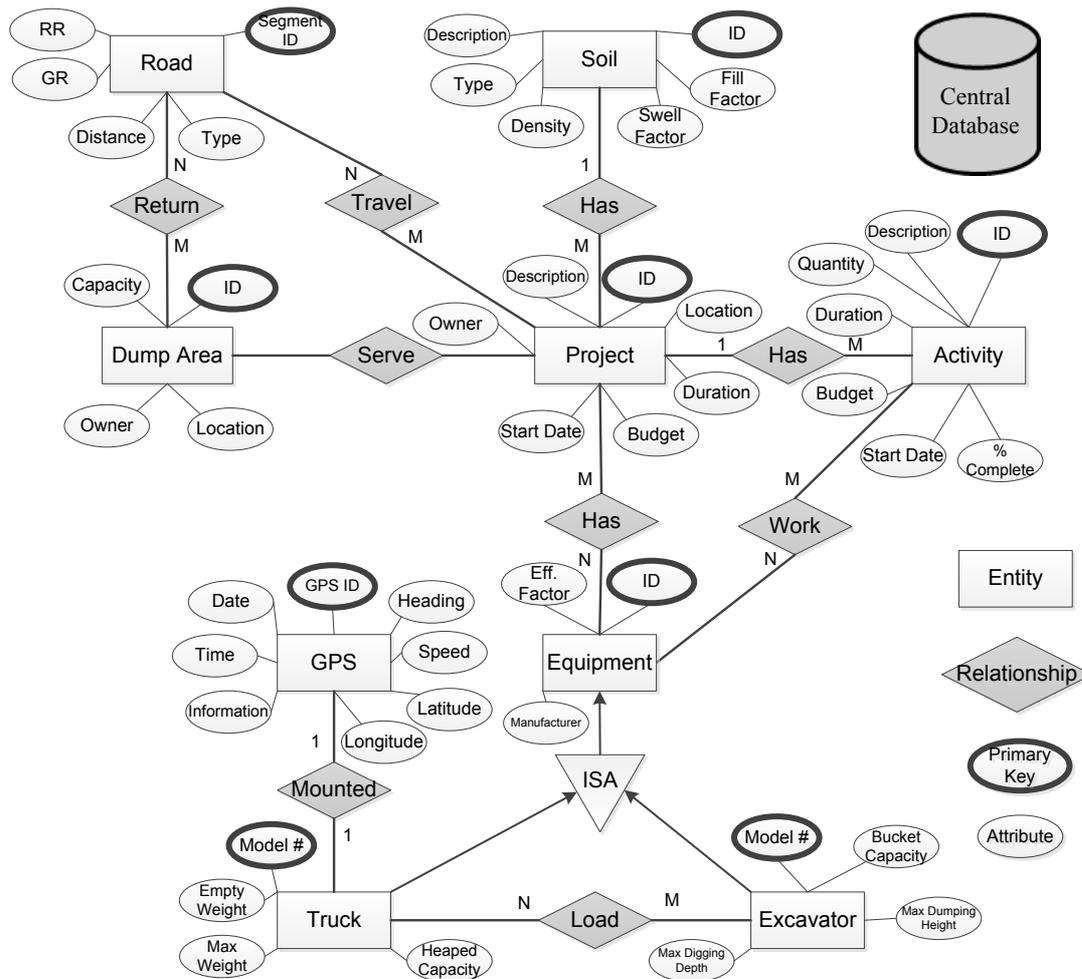


FIG. 10: Entity Relationship (ER) diagram for system database

3. COMPUTER IMPLEMENTATION & CASE STUDY

Prototype software has been developed to automate the process of estimating, monitoring and forecasting productivity of hauling trucks as proof of concept. The software allows simultaneous use and easy mutual data exchange between the system modules, central database and other software such as DES engine. In this research, truck+ was implemented as web-based service. This web-based service is accessible over standard Internet protocols with two main roles, which are independent of platforms and programming languages. The first role is the service provider, which is the web server. The web server creates a web service and publishes its interface and access information over the World Wide Web. The components of the web server are the central database, tracking/monitoring module, forecasting module and the DES engine. The second role is the service consumer, which is the software user. The user could access the software via internet using desktop computer or mobile device such as smartphone, tablet PC or Personal Digital Assistance (PDA). Windows Communication Foundation (WCF) technology is deployed as a runtime and a set of APIs (Application Programming Interface) in the Microsoft .NET framework. WCF is a tool used as intermediate level between the web application and the web server. It also processes the main functionality of system.

Microsoft Access is used as database management system to store and retrieve project respective data and GPS data as shown in Fig. 11. The GIS component of the software consists of ArcGIS bas map, ArcGIS template for Silverlight and ArcGIS APIs for Silverlight. ArcGIS Base Map is free map service provided by ESRI (Economic and Social Research Institute) containing the street and satellite layers. ArcGIS Template for Silverlight is a free template created using Silverlight technology and contains all basic functionality for any map viewer system such as map panning, zooming and navigation at any part of the selected GIS map. ArcGIS APIs for Silverlight is many DLLs (Dynamic-link library), which add many controls such as map controls that contain the base map (street and satellite map) and scale bar. It utilizes the powerful mapping, geocoding, and

geoprocessing capabilities provided by ArcGIS server (ArcGIS, 2013). It is also used to facilitate communication with GPS spatial data and graphically representing them in the GIS map. In addition, Microsoft Silverlight is used as a web plug-in to give the web browser more functionality. This tool is implemented to enable ArcGIS APIs provide the mapping functionality of GPS points. Finally, Crystal Reports technology is used to develop and generate custom reports layout. It facilitates graphically design data extraction from different data sources such as MS Access database, ArcGIS base map and user inputs. The software was coded using Microsoft Visual C# programming language for the integration and development of various modules and algorithms.

For validating the proposed system and demonstrating the use of its components, case study was conducted. Case study made use of the construction of the Centre for Structural and Functional Genomics at Concordia University (CSFG) at Concordia's Loyola campus located in the west end of Montreal (Fig. 12). The fleet used in this project consists of an excavator serving a number of hauling trucks. The soil to be excavated is sandy clay with density of 2900 lb/CY and a swell factor equals to 0.81 according to the geotechnical report. The total quantity of excavated soil is 14 000 bCY. The system Graphical User Interface (GUI) is designed to be user friendly, straightforward data entry and eliminate redundancy of data. GUI accepts both graphic and non-graphic data entry. The graphic data entry will be through the GIS provided drawing tools. The non-graphic data entry will be through a set of buttons, dialog windows and radio buttons.

The main screen of Truck+ web page layout consists of one main view in the centre displaying the world map as depicted in Fig. 13. The top right corner of the screen displays magnifying glasses button, overview map button, map legend button and hide/display map visualization options button. The lower right corner of the screens shows the scale bar and display-navigation controls. When the user press open project button, a dialog box appears. It requests the user to enter the project number. Upon entering the project number, the GIS interface start automatically contacting the web server to load the project respective data. Then, the system extracts the GPS data from the central database and displays it in the GIS map as a separate layer (blue points) for graphical representation. In addition, Truck+ zooms automatically to the extents of the GPS points as shown in Fig. 14. Under change project button, there are four buttons (L, D, T and R), which is the drawing tools for drawing loading polygon, dumping polygon, travel poly line and return poly line respectively. So, the user pushes the button and starts drawing it respective layer. Each layer will be added to map legend in lower right corner. These layers are utilized to classify each GPS point according to the algorithms mentioned earlier. At this stage, the user should select one of the radio buttons, which to choose whether reporting for specific data or reporting from project start to specific data. The project start data is extracted from the central database. According to the user selection, a calendar will appear to select dates. Then the user required entering the ACWP for each day, which represents the actual earthmoving operations expenditure to perform earned value analysis.

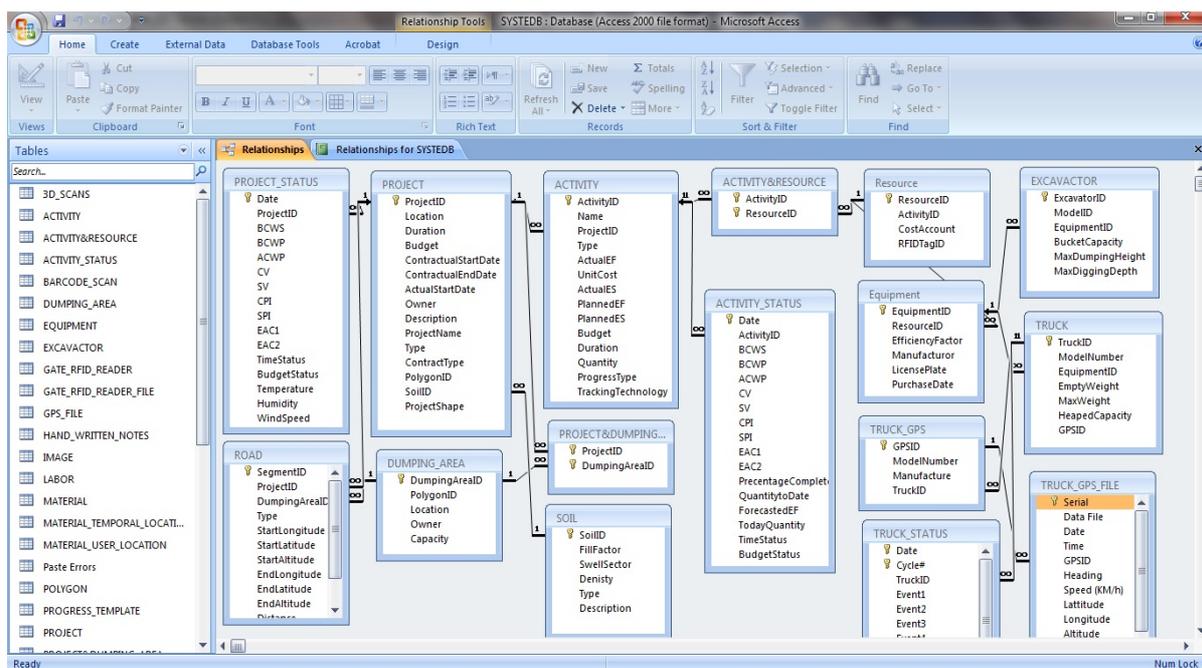


FIG. 11: Entity Relationship (ER) diagram for the designed Microsoft Access central database



FIG. 12: Construction of CSFG building (Case Study)

The reporting module provides the user with online tabular and graphical reports. Tabular format reports have been used to present each truck cycle time and its respective components as shown in Fig. 15. Fig. 16 depicts the number of cycles each truck did in front of each date, which is utilized in conjunction with the truck capacity to calculate the excavated material percentage complete. Then, earned value analysis is conducted to determine the operation performance indices, variances from planned and different deterministic forecasts scenarios for the operation as shown in Fig. 17. Graphical format reports are developed to display information at varying degrees of detail such as CPI per day as shown in Fig. 18.

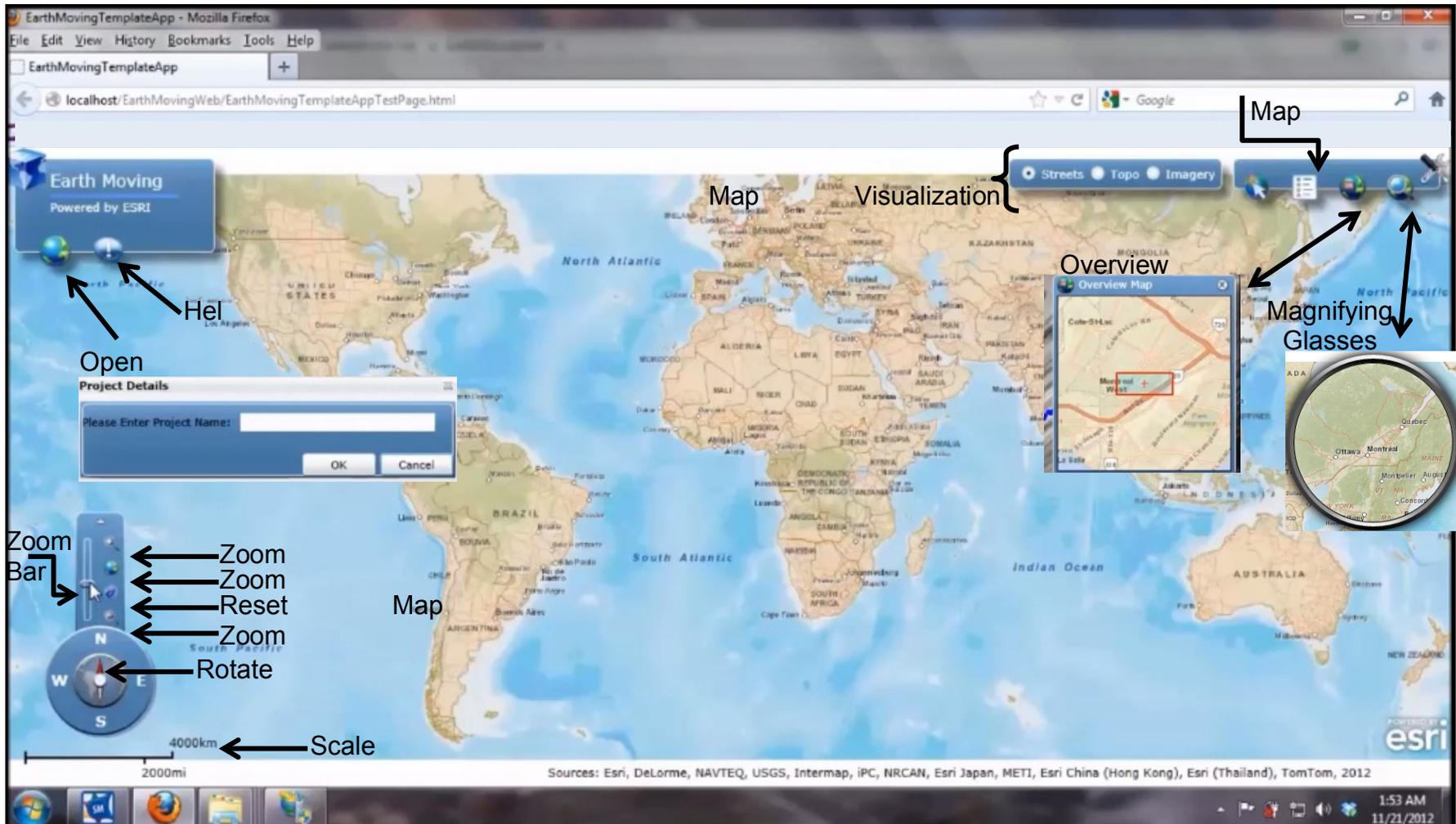


FIG. 13: Developed software web page layout (Part 1)

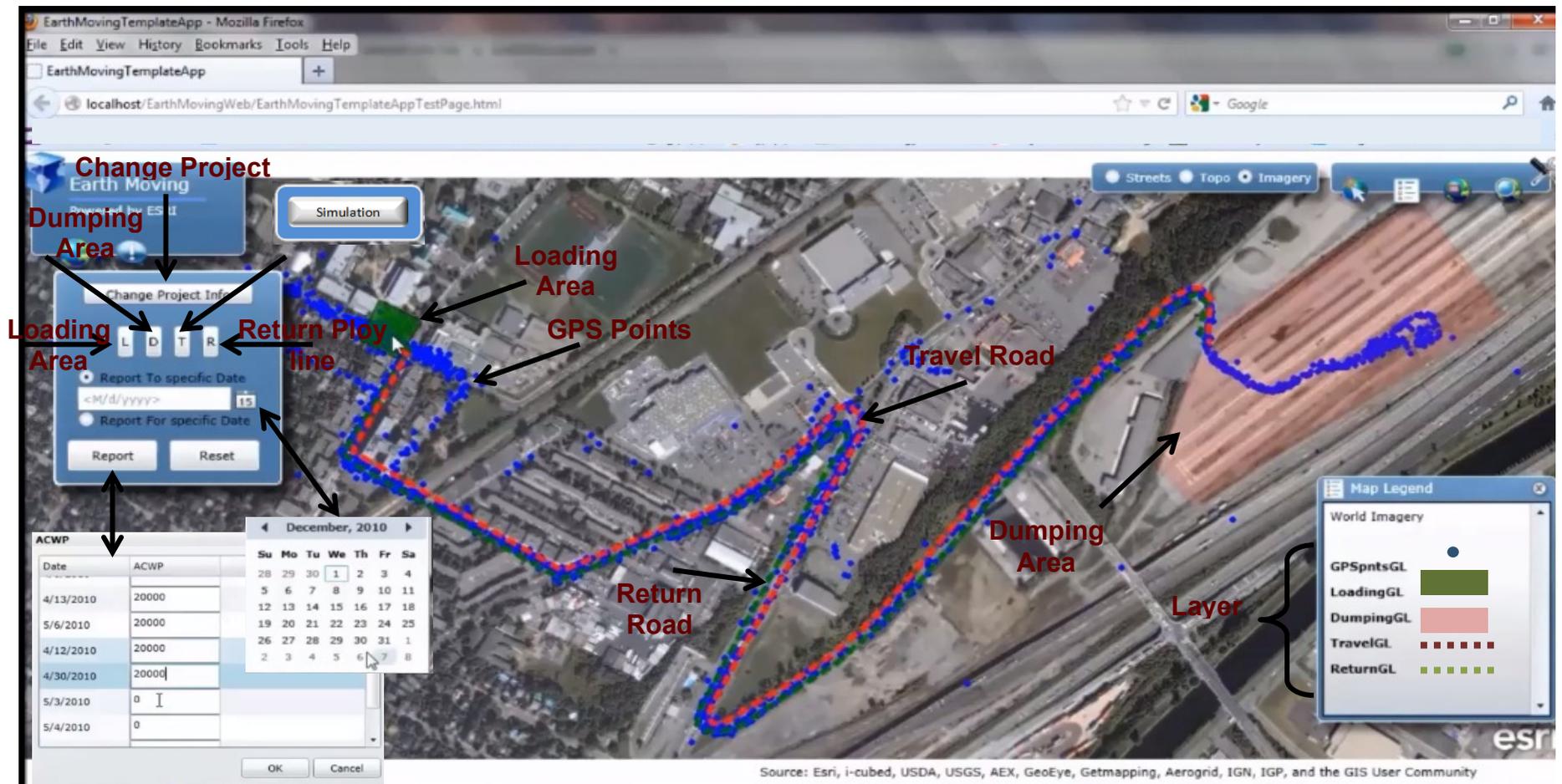


FIG. 14: Developed software web page layout (Part 2)

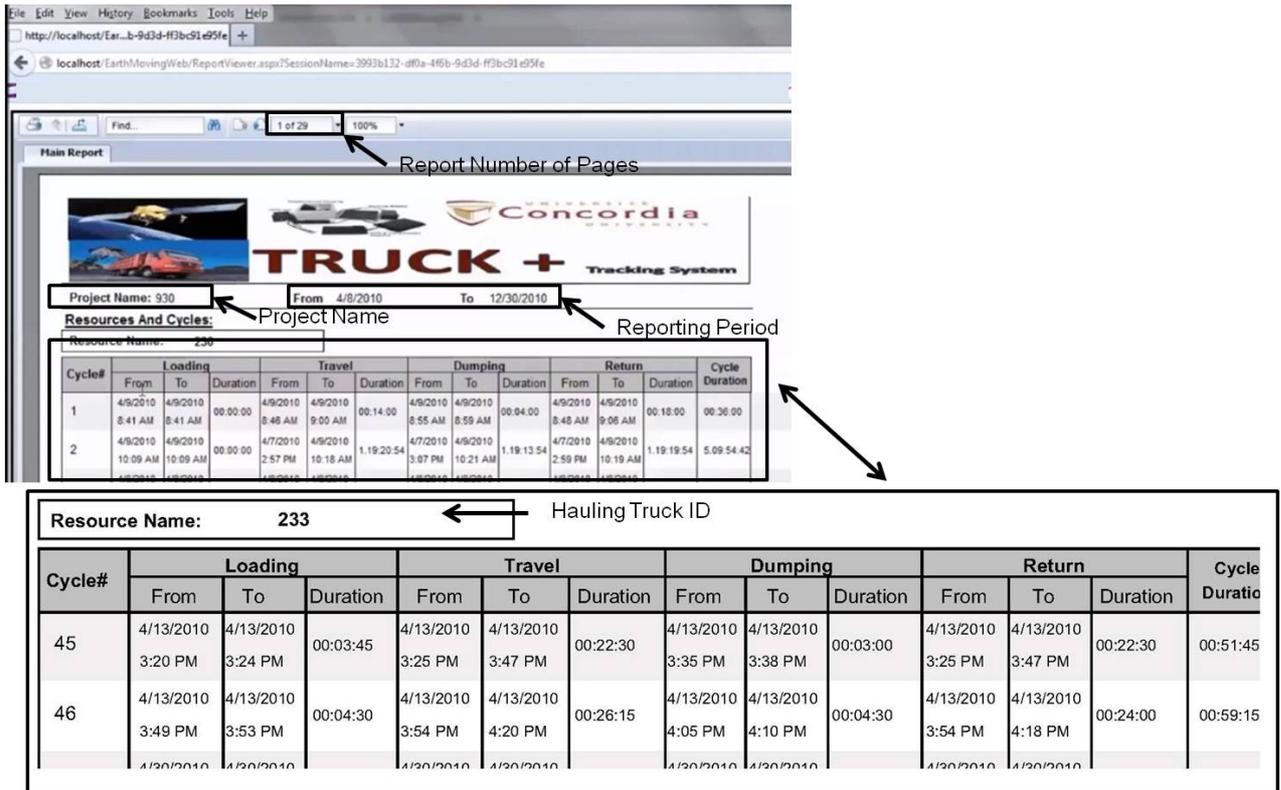


FIG. 15: Generated tabular report

Date	230	231	232	233	234	235
4/12/2012		11	10	11	11	11
5/12/2012		13	13	13	13	13
6/12/2012		10	10	9	10	10
7/12/2012		2	2	2	2	2
10/12/2012		10	9	9	10	10
11/12/2012		10	10	10	10	10
12/12/2012		2	2	2	2	2
13/12/2012		1	1	0	0	0
14/12/2012		5	5	5	5	5
17/12/2012		9	9	9	9	9
18/12/2012		16	15	15	15	15
19/12/2012		12	12	12	12	12
Total # of Cycles		101.00	98.00	97.00	99.00	99.00

FIG. 16: Generated tabular report for hauling trucks cycles

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

FIG. 17: Generated tabular report for earned value performance indices

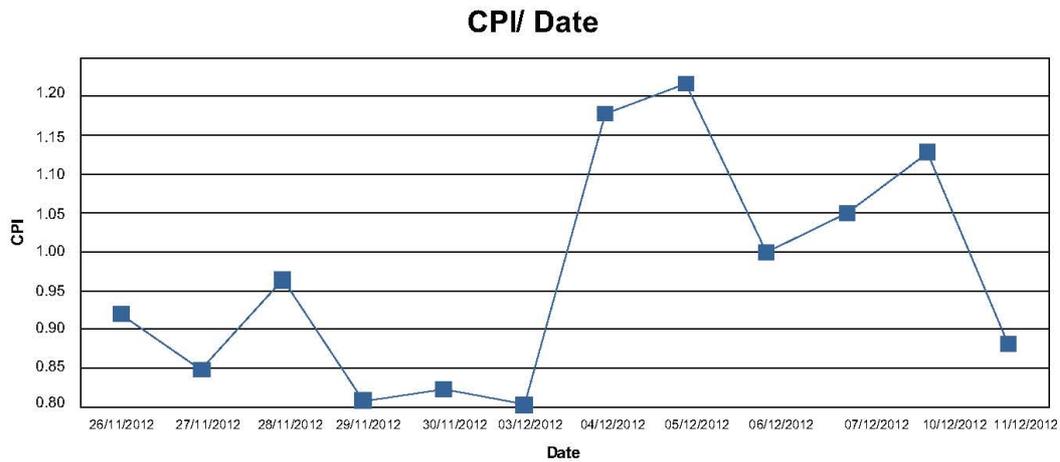


FIG. 18: Generated graphical report for Cost Performance Index (CPI) on daily basis

The variables in the DES model are the number of hauling trucks, truck capacity, number of loaders, the quantity of remaining excavation, truck cost per hour and the loader cost per hour. The system retrieves all this data from the database. To generate PDF for each cycle time component, the user specifies the data range (i.e. start date and finish date). Then, the system extracts the cycle time components from the database and filters it to the specified data range. In addition, there is an option to exclude dates from this data range. This enables removing specific time periods during which exceptional conditions are known to have prevailed and are not likely to be repeated. Oracle Crystal Ball is utilized afterwards to generate best fit PDF for each cycle time component based on the captured data specified date range, as shown in Fig. 19. When the user presses simulation reporting, the results is send to an excel file on the user computer desktop. The results are the operation forecasted loader utilization, truck utilization, production rate, time, total cost and the unit cost of excavated material. Since, the forecasting process was done stochastically through PDFs. Then, the results is not crisp values, it is in the form of average, standard deviation, maximum and minimum values, as shown in Fig. 19. In case, the user wants to experiment with the different fleet configuration but with the same PDFs. Then the user could enter the minimum and maximum number of trucks and loaders in the form. Similarly, the same procedure is followed but with different scenarios.

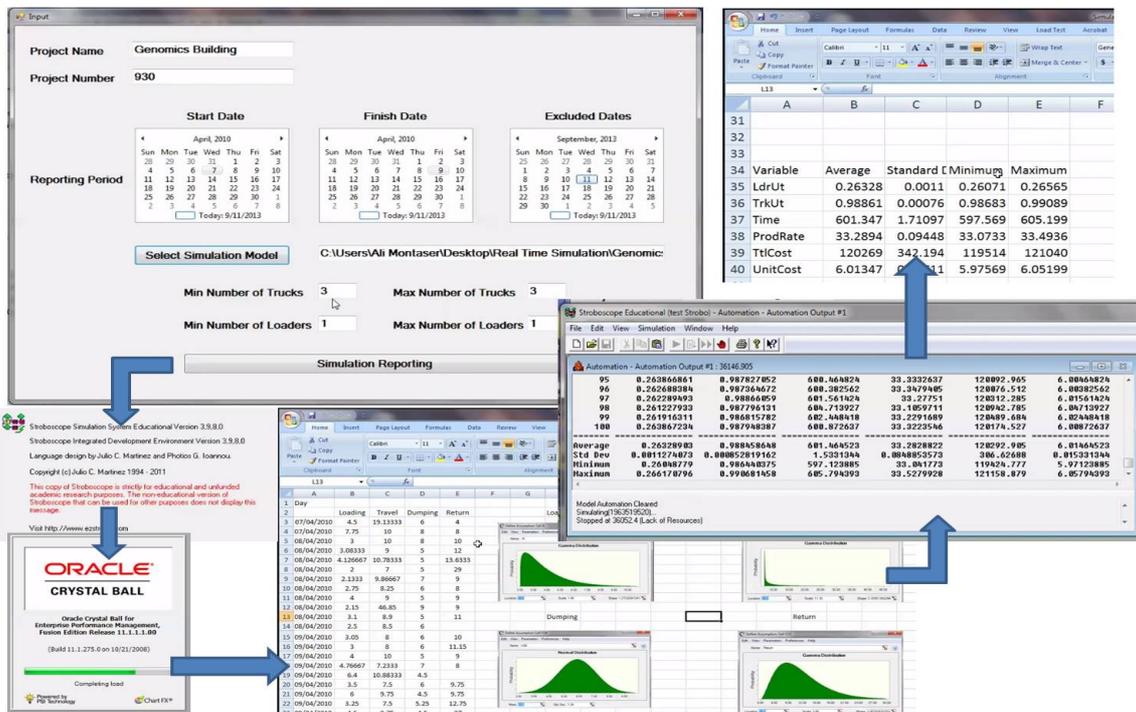


FIG. 19: Stochastic forecasting overview

With the continual development of automated data acquisition technologies and its integration, a significant amount of data can be captured 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. Truck+ could be integrated with other technologies 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 hauling truck to estimate the weight of soil in truck. Also, a digital camera could be used at the project gates to take picture for the truck and estimate the volume of excavated material in truck. The other assumption is regarding the loading and dumping times; both are calculated once the truck enters/exists the loading or dumping areas. This assumption adds to exact direct loading or dumping time additional time for truck manoeuvring. Other sensors such as low range passive RFID could be utilized to detect truck proximity to excavator for loading, which will improve system accuracy for loading time. Also, switch limit could be utilized to detect the movement of truck bed in dumping process to calculate the exact dumping time. The system accuracy will be enhanced considerably if integrated with other proximity-based and motion-based systems (Montaser and Moselhi, 2012 and Montaser and Moselhi 2013). Other machine-based sensors could be integrated with Truck+ to identify idle time and broken equipment time, which will provide alerting system for project team. The proposed system is part of an undergoing research that integrates diverse data acquisition technologies. It also automates the process of data collection from construction sites comparing it to the planned ones. Subsequently, progress reports are generated.

4. CONCLUSION

The paper presents an integrated web-based system to calculate hauling truck productivity. The system consists of two main modules interacting with central database. In addition, construction computer simulation was used to account for uncertainty and to forecast the productivity based on actual captured data. Manual site data acquisition in earthmoving operations is time consuming and may result in tardy corrective actions with undesirable cost consequences. Therefore, in tracking and monitoring module, GPS/GIS spatial technologies were introduced to capture the hauling truck data and to report captured data in near-real-time. Data storage, processing and reporting, are done by the system without human intervention. The developed method utilizes automated site data acquisition in a step ahead of regular GPS tracking and expands upon its use in the construction industry. The proposed system presents practical and easy to use method for estimating productivity of earthmoving operations during planning stage and construction stage. In addition, Truck+ uses computer simulation to demonstrate the fleet configuration bottlenecks. The developed system will facilitate productivity estimation and predication during construction. Near-real-time, control of on-site earthmoving operations facilitates early detection of discrepancies between actual and planned performances to assist project managers in taking appropriate corrective measures.

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