

Optimizing and Controlling Earthmoving Operations Using Spatial Technologies

Adel Alshibani

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ABSTRACT

Optimizing and Controlling Earthmoving Operations Using Spatial Technologies

Adel Alshibani, Ph.D.

Concordia University, 2008

This thesis presents a model designed for optimizing, tracking, and controlling earthmoving operations. The proposed model utilizes, Genetic Algorithm (GA), Linear Programming (LP), and spatial technologies including Global Positioning Systems (GPS) and Geographic Information Systems (GIS) to support the management functions of the developed model. The model assists engineers and contractors in selecting near optimum crew formations in planning phase and during construction, using GA and LP supported by the Pathfinder Algorithm developed in a GIS environment. GA is used in conjunction with a set of rules developed to accelerate the optimization process and to avoid generating and evaluating hypothetical and unrealistic crew formations. LP is used to determine quantities of earth to be moved from different borrow pits and to be placed at different landfill sites to meet project constraints and to minimize the cost of these earthmoving operations. On the one hand, GPS is used for onsite data collection and for tracking construction equipment in near real-time. On the other hand, GIS is employed to automate data acquisition and to analyze the collected spatial data.

The model is also capable of reconfiguring crew formations dynamically during the construction phase while site operations are in progress. The optimization of the crew formation considers: (1) construction time, (2) construction direct cost or (3) construction total cost. The model is also capable of generating crew formations to meet, as close as possible, specified time and/or cost constraints.

In addition, the model supports tracking and reporting of project progress utilizing the earned-value concept and the project ratio method with modifications that allow for more accurate forecasting of project time and cost at set future dates and at completion. The model is capable of generating graphical and tabular reports. The developed model has been implemented in prototype software, using Object-Oriented Programming, Microsoft Foundation Classes (MFC), and has been coded using visual C++ V.6. Microsoft Access is employed as database management system. The developed software operates in Microsoft windows' environment. Three example applications were analyzed to validate the development made and to illustrate the essential features of the developed model.

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Chapter 1: Introduction

1.1 Introduction

Earthmoving includes operations such as site preparation, excavation, embankment construction, backfilling, compaction, surfacing, etc. These operations represent a sizable portion of civil infrastructure projects such as highways, mines, and dams. This class of projects is equipment-intensive, characterized by deployment of large fleets (Hassanien 2002). Such equipment is expensive and operates under unexpected conditions including equipment breakdown, inclement weather, and unexpected site conditions (Marzouk 2002). The owning and operation of such equipment represents significant portion of yearly spending for large contractors engaging in heavy civil engineering projects (Fan et al 2008). Clearly, the optimum use and suitable selection of equipment throughout construction stages of these projects is essential for their successful delivery.

Optimizing earthmoving operations poses a major challenge to engineers and contractors. This challenge is demonstrated in two main tasks (Marzouk 2002): the first is to satisfy all constraints that are imposed by specific job conditions, such as project constraints, equipment availability, its date of availability, and contractors' requirements; the second challenge is to select the best crew configuration that satisfies the previously stated constraints and to complete the project with the least cost. The literature indicates that current models,

unfortunately, do not account fully for these factors (Marzouk 2002). Therefore, contractors still rely on their experience in optimizing planning of these operations.

On the other hand, tracking these operations is also essential for completion of projects within its budget and on time. Naturally, tracking earthmoving operations requires close monitoring of equipment involved. It requires collecting large amount of data from construction sites in a timely manner. Such data is necessary for estimating onsite productivity and for reporting on the project status so that corrective actions can be taken, if needed. Formerly, onsite data is collected, manually, where observers record data on paper for subsequent analysis (Navon 2007). Unfortunately, although different techniques have been used to automate data collection, the cost of such techniques is still high. Clearly, automated data collection in a cost-effective fashion is needed. It can improve productivity, minimize cost, and increase profit to contractors (Moselhi and El-Omari 2006).

1.2 Optimizing Earthmoving Operations

Optimizing earthmoving operations always represents a major challenge to project managers. In fact, it is corner stone of effective planning of these operations. More precisely, the main goals of optimizing earthmoving operations are: (1) selection of the best crew configuration to carryout the work at hand with least cost (Farid 1994, Alkass et al 2003); (2) optimization of the use of available resources throughout the project duration and/or its development stage (Moselhi

and Alshibani 2007-a); (3) selection of suitable equipment for the job; taking into consideration construction site conditions and the mechanical specifications of equipment to maximize productivity and consequently maximize profit to contractors; (4) determination of the quantities of earth to be moved from different borrow pits and placed at different landfill sites so as to minimize project cost (Easa 1988); and (5) completion of projects with the least cost and within the given targeted duration. Taking into account these goals, effective planning can result in considerable savings in time and cost (Farid 1994, Marzouk 2002, Alkass et al 2003).

The optimization process should account for factors that greatly affect the optimization of earthmoving operations. These factors include site conditions, travel roads surfaces, indirect cost, capacity and setup cost of landfills and borrow pits sites (Moselhi and Alshibani 2007-a, Moselhi and Alshibani 2007-c). In current practice, selecting crew configuration is usually based on the quantities of the material that must be moved and the production rates of available equipment (Farid 1994, Alkass et al 2003). It depends greatly on human experience (Christian and Xie 1996). The use of simple deterministic methods can provide satisfactory results for small projects requiring a single loader and several trucks. However, for large projects containing many borrow pits, landfill sites, and requiring multi-loader-truck fleets, the selection process can be more complicated, and the cost can change widely (Alkass et al 2003).

The literature indicates that over the years, many models were developed for modeling and optimizing earthmoving operations, including: (1) queuing theory

(Halpin and Woodhead 1976, Farid 1994, Alkass et al 2003); (2) linear programming (Mayer and Stark 1981, Easa 1988, Jayawardane and Harris 1990; Son et al 2005); (3) expert systems (Christian and Xie 1996, Alkass and Harris 1988, Eldin and Mayfield 2005); (4) commercial software model (Caterpillar Inc. 1998); (5) computer simulation (e.g., Oloufa 1993, Shi and AbouRizk 1998, Hajjar and AbouRizk 1999, Marzouk and Moselhi 2003, Marzouk and Moselhi 2004); and (6) simulation optimization (Shi and AbouRizk 1995, McCabe 1998, Marzouk 2002). However, these models do not account for all the previously stated factors.

1.3 Tracking and Control of Earthmoving Operations

The tracking and control of large-scale earthmoving operations consists of collecting data from the construction site, measuring actual performance, comparing actual performance with that planned, forecasting project time and cost, and taking corrective actions if needed (Hassanein 2002). Presently, the complexity of construction projects has increased due to the extension of the project scope, the fragmentation of parties involved (Alshawi and Ingirige 2003), and the application of a new contracting strategy that requires completing such projects expeditiously. This complexity places severe pressure on entire project teams to complete the project with the least cost and in the shortest time. Unfortunately, few studies carried out on automating the tracking and control of earthmoving operations (Navon 2007). Furthermore, the existing methods and models tend to focus more on integrated cost and time control and automation of

construction operations rather than on automating the tracking and control themselves (Moselhi and Alshibani 2007-b).

Overall, the tracking process depends primarily on the nature, accuracy, frequency, and time required of collecting onsite data about construction operations. Traditionally, onsite data collection is commonly conducted based on manual methods, in which the collected data is recorded on paper by human observers (Navon 2007). Such manual methods are costly, time consuming, and not necessarily accurate (Navon 2007). Automating data collection in a cost-effective manner, can improve the speed and accuracy of data acquisition and the response to any unacceptable performance (Moselhi and El-Omari 2006). Literature reveals that despite the need for automating onsite data collection and the progress in the communication industry, little has been done to reduce data collection time and to provide construction managers with timely and accurate information (Navon et al 2004, Navon and Sacks 2007).

In addition to onsite data collection, tracking construction operations requires measuring onsite performance, which thereafter is compared with the as-planned progress to determine the project status and to assist in the identification of possible cause(s) behind unacceptable performance so that corrective action(s) can be taken (Moselhi and Hassanien 2003). At present, measuring actual performance is still carried out manually. According to this method, the data is first collected from the construction site, then analyzed, and finally used to calculate actual performance. This method may delay taking corrective action when it is needed.

Further to the above functions, forecasting of project time and cost is a basic function of tracking and control. It gives the project managers a clear picture of the project status at future set date if a certain scenario has occurred. Different techniques are used to develop many methods to forecast project time and cost with different degree of success such as earned value, project ratios, simulation, etc. In summary, an effective tracking and control system relies on the following:

1. The accuracy of the data collected from the construction site
2. The speed and timing of the information exchange between the project team members on the construction site, the head office and the parties involved such as the owner, designer, contractor, and material suppliers. Delay in data exchange among these parties can result in reporting progress with very long time-lags, thereby leading to tardy corrective actions with cost consequences(Sacks et al 2002)
3. The accuracy and efficiency of forecasting the project cost and time method (Alshibani and Moselhi 2007)
4. The speed and timing of responding to any unacceptable performance

It is clear that automating tracking systems improves efficiency for the project teams, reduces the time spent on paperwork, allows more time for monitoring the progress and quality at the project site, and ultimately allows the completion of the project within its budget and time.

1.4 Scope and Objectives

The main objectives of the present research are:

1. To study the application of spatial technologies (GIS, GPS) in the planning, tracking, and control of earthmoving operations
2. To develop a model that supports efficient management of earthmoving operations circumventing a number of limitations associated with current practice. This involves the following sub-objectives:
 - A. Develop a cost effective methodology to automate data collection and acquisition for earthmoving operations using spatial technologies.
 - B. Develop a methodology to optimize earthmoving operations throughout the project construction duration and/or its development stage.
 - C. Develop a methodology to estimate onsite productivity and measure project progress automatically using global positioning system (GPS).
 - D. Develop a methodology to forecast project cost and time at completion and at any future set date.
 - E. Implement the developed model in an automated system as a proof of concept.

To fulfill these objectives, the following steps have taken:

- A. An in-depth review of the literature on current planning, tracking, and control of earthmoving operations to highlight their advantages and limitations
- B. Exploration of the potential application of spatial technology (GIS,

- GPS) in planning, tracking, and control of earthmoving operations
- C. Study modeling issues pertinent to earthmoving operations and subsequently design and develop a suitable model for the efficient management of these operations.
 - D. Testing the individual functions of the developed model, validating the model and demonstrating its capabilities

1.5 Research Methodology

The methodology adopted in the present research is based on review the literature of current practice in project planning, tracking and control of construction projects that involve earthmoving operations in particular. It also covers onsite site data collection, performance evaluation, and forecasting methods with emphasize on the use of spatial technologies.

In the second stage, an efficient methodology is developed for optimizing, tracking, and control of earthmoving operations to overcome a number of identified limitations of current models and software systems. The last stage involved the implementation of the developed methodology in prototype software and testing its performance and validating its functions.

1.6 Thesis Organization

The present thesis consists of seven chapters. Chapter 2 presents a comprehensive literature review of planning, tracking, and controlling techniques used currently in earthmoving operations. Included also in this chapter is a review of different methods of onsite data collection for tracking and control

purposes. Applications of spatial technologies including Global Positioning System (GPS) and Geographic Information System (GIS) in construction are also described with emphasis on earthmoving operations. Chapter 3 presents an overview of the proposed methodology. The developed optimization module is described in Chapter 4. Chapter 5 describes the developed tracking and control module. Chapter 6 focuses on the computer implementation, validation, and limitations of the developed model. Research contributions and recommended future work are presented in Chapter 7.

Chapter 2: Literature Review

2.1 Introduction

This chapter presents a review of the literature on optimizing, tracking, and controlling earthmoving operations. It describes different methods and techniques used in estimating productivity and optimizing earthmoving operations. The review also focuses on onsite data collection methods in practice and highlights their essential features and limitations. The use of spatial technology, including geographic information systems (GIS) and global positioning systems (GPS) in construction projects is discussed with an emphasis on their applications in earthmoving operations. It also describes methods of measuring and forecasting a project's performance. This chapter concludes with a review of the desired characteristics of an optimizing and control system.

2.2 Productivity Estimation of Earthmoving Operations

Estimating the productivity rate of construction equipment is an important task in modeling earthmoving operations and in selecting the best crew formations. It is considered a challenging task due to the factors associated with it. The literature reveals that accurate estimation of the productivity of earthmoving operations has intrigued researchers for many years (Ok and Sinha 2006). Estimating productivity relies heavily on a company's historical data and experts' opinions (Christian and Xie 1996). The literature indicates that there are two classes of methods commonly employed for estimating earthmoving productivity: traditional

and artificial intelligent methods. The traditional methods use a performance chart, multiple regressions, and simulation, whereas the artificial methods are mainly comprised of artificial neural networks (ANN).

Formerly, equipment productivity was calculated mainly on the basis of performance charts published by equipment manufacturers and the characteristics of travel roads. However, manufacturer's information has been criticized as being more a marketing tool rather than a true guide to estimate productivity (Lambropoulos et al 1996). Further limitations of performance charts are that they do not account for acceleration and de-acceleration, and they do not consider actual conditions and uncertainties associated with the duration of activities. They have also been found to include overestimations (Han and Halpin, 2005). To overcome these limitations, multiple regression models were developed (Smith 1999; Edwards and Holt 2000; Han and Halpin 2005). Smith (1999) developed a multiple regression model to estimate the actual productivity of earthmoving operations. The model is based on data collected from four earthmoving projects using 141 observations. Smith concludes that there are strong linear relationships between productivity and operating conditions. Edwards and Holt (2000) also developed a multi-regression model that predicts the productivity of excavators. The optimal variables of hydraulic excavator cycle time were first identified, and were then used to develop a multiple regression model. Because of the nonlinear relation between the dependent and independent variables, the model's degree of accuracy was not high. Han and Halpin (2005) developed a methodology to establish a productivity estimation

model. The model's input data is generated through experimental designs and multiple regression analysis using WEBCYCLONE. The model allows project planners to estimate productivity by simply entering input data that reflect actual site conditions. In order to account for the uncertainty in productivity estimation, simulation models were developed.

Recently, ANN has been used to estimate the productivity of different construction equipment, such as dozers (Tam et al 2002) and excavators (Ok and Sinha 2006). Tam et al (2002) developed a quantitative model for estimating the productivity of excavators using a Multilayer Feed Forward (MLFF) neural network with back-propagation. The authors first identified the factors that affect the productivity of excavators. These factors are then used to train and test the network. The actual cycle time of an excavator is the output of the model. The output of their model was then compared with that of a multiple regression model, developed by Edwards & Holt (2000). Tam et al (2002) concluded that using ANN could reduce the uncertainty in predicting excavators' productivity. They also pointed out that both multi-regression and ANN models could be used to predict excavator productivity, although the MLFF neural network approach is superior to multiple regression models.

2.3 Modeling Earthmoving Operations

Modeling earthmoving operations has attracted considerable attention in research and practice. The literature indicates that optimizing earthmoving operations has witnessed the development of different models using various

techniques, which include: (1) queuing theory (e.g., Halpin and Woodhead 1976, Farid 1994, Alkass et al 2003); (2) linear programming (Mayer and Stark 1981, Easa 1988, Christian and Caldera 1988, Jayawardane and Harris 1990, Son et al 2005); (3) expert systems (Alkass and Harris 1988, Touran 1990, Christian and Xie 1996, Haidar et al 1999, Eldin and Mayfield 2005); (4) commercial software model (Caterpillar Inc. 1998); (5) computer simulation (Halpin 1977, Paulson 1978, Chang and Carr 1987, Martinez 1998, Shi and AbouRizk 1998, Hajjar and AbouRizk 1999, Marzouk and Moselhi 2003, Marzouk and Moselhi 2004); and (6) simulation optimization (Shi and AbouRizk 1995, McCabe 1998; Marzouk 2002).

Queuing theory was one of the first techniques utilized to model earthmoving operations. Alkass et al (2003) developed a computer model "FLSELECTOR" for selecting an equipment fleet for earthmoving operations based on the queuing theory. The model accounts for the uncertainties associated with the equipment selection process. "FLSELECTOR" is capable of determining the size and number of trucks and excavators, while considering haul road lengths and surface conditions, etc. It provides the user with a list of the ten best alternatives for fleet configuration. However, it does not consider multiple borrow pit and landfill sites.

Linear programming is one of the most widely used techniques in optimizing earthmoving operations, due to its simplicity and effectiveness. Mayer and Stark (1981) developed a model to minimize the transportation cost of moving earth from different borrow pits to different landfill sites. They divided the unit

transportation cost into three parts: excavation, haul, and embankment unit cost. The unit cost for hauling was considered as a function of haul distance without any reference to the impact of soil type and topography (grade and rolling resistance) of the travel roads. The model accounts for the cost of borrowing earth but does not consider indirect cost as a decision variable. Easa (1988) developed a model to optimize earthmoving operations by minimizing the operations' total cost. The model takes into consideration the compaction costs and the use of waste sites. Christian and Caldera (1988) introduced a model for optimizing earthwork operations with multiple excavation and embankment areas. They concluded that the entire cost of moving earth from one roadway location to another, including compaction, should be included in the optimization. Jayawardane and Harris (1990) developed another model using the same technique. Their model integrates project duration and accounts for: (1) swell/shrinkage factors, (2) equipment availability, and (3) soil strata. More recently, Son et al (2005) developed a mathematical optimization model for determination of the minimum haul distances and directions of moving earth using linear programming. The model determines the quantity of moved earth, the minimum haul distances, and the locations to haul the moved earth to. The model neither considers the resources available to contractors nor different scenarios of crew formations. Site conditions and the topography of the travel roads are also not considered. The model assumes that the travel roads are flat surfaces, which may not be a true representation of real world construction conditions.

With expert systems, the selection of the best crew configuration is based on the user data entry. Alkass and Harris (1988) developed a system that permits the user to enter the information necessary for computation, including: (1) identification of the task and defining the job conditions, (2) selection of equipment by category; (3) estimation of output and equipment matching, and (4) selection of the equipment to perform the task. To benefit from the advantages of simulation, Touran (1990) developed a simulation-integrated expert system. The system does not require the user to be proficient in simulation, as the system guides the user by posing different questions to define the job conditions. The system then provides the user with the most suitable type of equipment to conduct the work at hand, the estimated daily production rate, and the estimated unit cost of operation. Christian and Xie (1996) developed a prototype knowledge-based expert system for crew formation. The authors first determined the factors that have an impact on the crew selection process, by conducting a survey among earthmoving contractors in Canada and the United States (20 contractors). These factors were thereafter grouped into three categories: (1) equipment selection, (2) production, and (3) unit cost of operation. The prototype user goes through three different steps: (1) selecting the appropriate equipment; (2) obtaining the production rates and costs; and (3) comparing the alternatives. The selection of the appropriate equipment is based on the following factors: owned or rented equipment; haul distances; and types of material. The production factors include schedule constraints, conflicts with other activities, and obstructions. The cost factor includes the historical hourly cost data for the

equipment. Haidar et al (1999) have used GAs and a hybrid knowledge-based system to optimize crew selection, consisting of loaders and trucks in opencast mining operations. The model, however, does not account for indirect costs. Eldin and Mayfield (2005) introduced an application, comprised of seven spreadsheets, to select the most economical option among the scrapers that are available for a specific project. This system, which determines the crew unit cost and selects the crew with the least cost is, is comprised of nine steps.

Simulation is the process of designing a model of real system on computer and conducting experiments for these models to understanding the system behaviour and / or evaluating various strategies for operation of the system. During planning stage, simulation has been used to (Brenda and AbouRizk 2001):

1. Optimize construction operations
2. Compare methods
3. Evaluate risks

The literature indicates that considerable efforts have been made in modeling earthmoving operations using simulation (Marzouk et al 2008). Halpin (1977) introduced the CYCLONE modeling framework, which consists of five basic modeling elements. Soon after, a number of construction simulation tools were developed which follow the CYCLONE methodology, such as INSIGHT system (Paulson 1978), and RESQUE (Chang and Carr 1987). Due to the significant differences between the simulation model's representation and the real world construction system, the concept of special purpose simulation (SPS) was introduced (e.g. AbouRizk and Hajjar 1998, Hajjar and AbouRizk 1999, Hajjar

and Abourizk 2000, Marzouk and Moselhi 2000, Hajjar and Abourizk 2002, Marzouk and Moselhi 2003).

Marzouk and Moselhi (2003) developed a model for earthmoving operations that uses object oriented features to design the model engine. It selects a near-optimum fleet configuration while considering different realistic scenarios and it accounts for various uncertainties in earthmoving operations. Their model considers only a single borrow pit and landfill site. Shi and AbouRizk (1998) developed an automated modeling system to simulate earthmoving operations. In this system, the user only needs to select the required equipment from the model database and to specify the project information. The main advantage of this system is that it does not require the user to be proficient in simulation.

Although simulation is a promising tool for construction engineering and management applications, its use is still limited to large contractors' organizations who can afford to employ dedicated simulation professional (Hajjar 1999, Hajjar and AbouRizk 2002). Chung (2007) stated that the main reasons behind the limited use of simulation in real world construction projects are: (1) many industries personal believes simulation models are expensive and they require considerable time to develop; (2) expert opinions are commonly utilized as input to simulation due to the lack of numeric data for various construction activities duration. This input is a subjective and inaccurate, which generally lead to inaccurate simulation results.

Beyond simulation, simulation optimization has also been introduced (e.g. AbouRizk and Shi 1994; Shi and AbouRizk 1995; McCabe 1998). Simulation optimization can be defined as the process of finding the best values of the decision variables for a system where performance evaluation is based on the output of a simulation model of this system (Marzouk 2002). Ólafsson and Kim (2002) stated that although a considerable number of models have been developed that combine simulation and optimization, simulation optimization has not received a similar attention in the construction industry. Figure 2-1 depicts the interaction between simulation and optimization (Marzouk 2002).

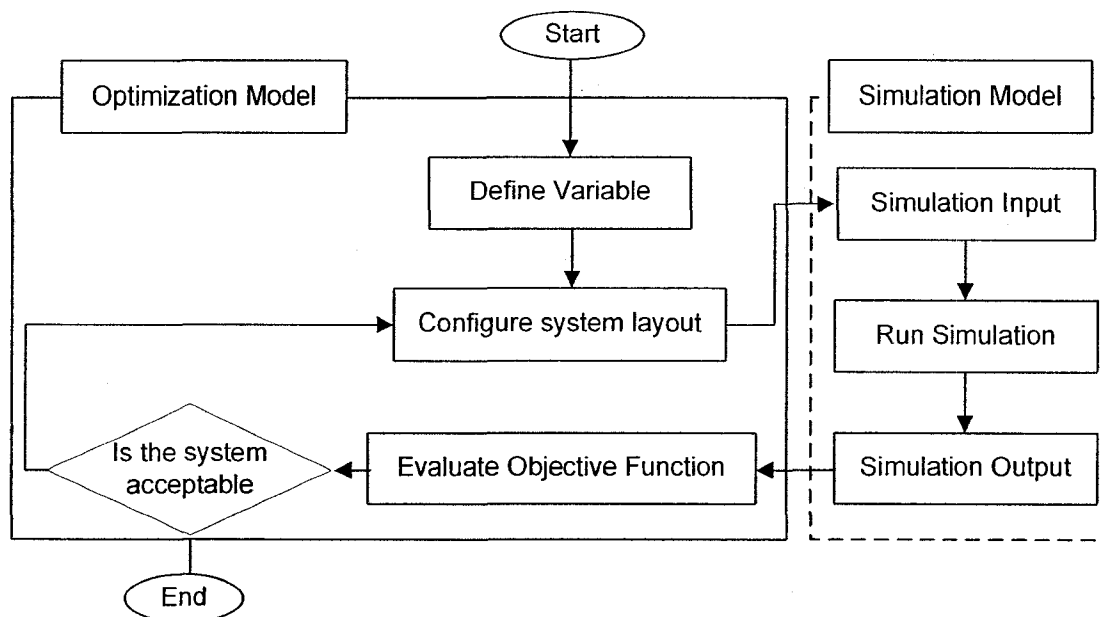


Figure 2-1: Interaction between simulation and optimization (Marzouk 2002)

In summary, the previously stated models, individually and/or collectively, do not adequately: (1) consider the interaction among the individual pieces of equipment in a fleet, as in the case of Fleet Production and Cost Analysis (FPC) software (Caterpillar Inc. 1998)(Marzouk 2002); (2) optimize earthmoving operations that

involve multiple landfill and borrow pit sites, as shown with Marzouk and Moselhi (2004) and Alkass et al (2003); (3) evaluate, concurrently, different fleet scenarios, as is the case with the model developed by Son et al (2005), and (4) dynamically reconfigure crew formations while site operations are in progress. As for simulation, more work is required to convince the construction industry of its advantages in planning and control.

2.4 Site Data Collection

The efficiency of tracking and control systems of large-scale earthmoving operations depends primarily on the nature, accuracy, frequency, and time required for collecting the onsite data of these operations (Moselhi and El-Omari 2006). The collection of onsite data is essential for the measurement of actual performance and the subsequent forecasting of project time and cost. The literature indicates that the methods of onsite data collection can be divided into two main categories: manual and automated. The manual methods are those that require the involvement of a human in a construction site, whereas the automated methods do not. The manual methods most widely in practice are: (1) stopwatch studies; (2) time-lapse motion pictures/photography; and (3) video recording. Stopwatch study requires direct human involvement and its result depends on the efficiency of the observers (Parker and Oglesby 1972). It is the cheapest and fastest method to record duration of an activity on site (Kannan 1999). Oglesby et al (1989) also pointed out that the stopwatch is the most widely used manual method of site data collection for monitoring time and estimating productivity. The main limitations of the stopwatch method include the

following (Parker and Oglesby 1972): (1) the method can only give a general picture of the observed job; (2) an observer has to decide when one cycle stops and the next one begins; (3) a single observer has difficulty watching several components of an operation at the same time. Therefore, the data gathered is restricted to data that is available within the view of the observer; (4) this method cannot be performed when construction equipment is off of the construction site; and (5) the information provided is restricted to the information recorded.

Time-lapse photography consists of a camera taking pictures of a subject with an interval of time between each picture. Using this method, a single camera can replace several observers with stopwatches and it requires less labour. The main disadvantage of time-lapse pictures is that (Parker and Oglesby 1972): the method can be expensive if the operation last for several hours and the available information is limited to the information that is recorded. As an alternative to a time-lapse picture, a Time-Lapse motion picture is introduced. It has proved very successful in reducing the cost of films (Parker and Oglesby 1972). The reported advantages of this method over the stopwatch include the following: (1) it simultaneously records the activities in different construction operations; (2) the process is relatively inexpensive; and (3) it is able to provide an easy way to understand the permanent record. Recognizing the limitations of the stopwatch method, a video recording method has been launched. It involves the use of cameras; tapes, and computer programs to record activities for a certain period. The main purpose of using video recording is to monitor actual productivity by a continuous record of the movements of the observed equipment. Oglesby et al

(1989) concluded that, on the one hand, due to the advantages of instant replay, besides being less expensive and more reliable, video-recording techniques could replace photographic methods. On the other hand, the main disadvantage of this method is that the period required to review the tape is equal to the time required for recording.

Due to the fragmentation of the construction industry and the complexity of current construction projects, tracking and control systems report progress with very long time lags, which results in tardy corrective actions with undesirable cost consequences (Sacks et al 2002). In order to improve the ability of project managers to respond to any unacceptable performance, the construction industry, in recent years, has benefited from newly introduced automated field data collection tools. The most widely-used automated systems for site data collection in earthwork projects are: (1) On-board Instrumentation Systems (OBIS) and (2) Global Positioning Systems (GPS). OBIS are a powerful tool for equipment management. They provide the project manager and equipment operators with information on equipment functions. The system relies on the placement of sensors on the tracked equipment at various locations, which are meant to detect abnormal conditions in any of the equipment system. The main function of these sensors is to (Kannan 1999): (1) diagnose the mechanical health of tracked equipment to improve productivity and (2) measure physical parameters such as temperature; pressure; etc. Such a monitoring system improves the productivity rate and reduces maintenance costs. The OBIS has attracted researchers to deploy it in many applications of earthmoving operations

(Chironis 1987). For example, Sotoodeh and Paulson (1989) have developed a system using OBIS to optimize the load time for a scraper in highway projects. While deterministic methods were used to calculate activity times, the calculated load time was compared in real-time with the actual load time. Schexnayder et al (1999) has used a Vital Information Management System (VIMS) to study the relation between truck payload and the productivity of hauling units. Kannan and Vorster (2000) have used the same OBIS data to investigate the relationship between load time and payload. The authors used the data collected with OBIS to build experience database. Sacks et al (2002) have developed a system to monitor lifting equipment used in construction. The system has the potential to provide significant data for automated project performance control. The sensor is installed on board as a black box, and records data on a daily basis. This data includes load weights and crane hook location coordinates that are gathered from the equipment through its working day. This information is then used to update the project schedule and to estimate the percent of work completed. The main disadvantages of the OBIS are: (1) its inability to determine the time that a hauler unit spends in loading and dumping area and (2) that the system is expensive. Figure 2-2 represents the output of the Computer Aided Earthmoving System (CAES) developed by Caterpillar.

Timestamp	Payload (t)	Loader Pass Count	Load Time (HH:MM:SS)	Total Cycle Time (HH:MM:SS)	Loaded Travel Dist. (m)	Empty Travel Dist. (m)	Fuel Used (l)	% Travel Distance Loaded
01-Sep-02 12:16:58 AM	238.2	4	00:01:59	00:32:57	3862.4	3862.4	116.2	50.0%
01-Sep-02 12:49:56 AM	242.4	5	00:02:40	00:36:50	4023.4	4667.1	125.9	46.3%
01-Sep-02 01:26:49 AM	233.0	5	00:02:40	00:33:21	4023.4	3862.4	115.8	51.0%
01-Sep-02 02:00:11 AM	228.6	3	00:02:12	00:32:09	3862.4	4667.1	122.0	45.3%
01-Sep-02 02:32:23 AM	239.9	4	00:02:29	00:29:47	4667.1	3862.4	126.1	54.7%
01-Sep-02 03:02:13 AM	232.3	5	00:02:25	00:30:38	3862.4	3862.4	120.7	50.0%
01-Sep-02 03:32:52 AM	225.5	4	00:02:50	00:29:50	4506.2	3862.4	115.7	53.8%
01-Sep-02 04:02:43 AM	221.6	3	00:02:10	00:30:56	4184.3	4506.2	120.5	48.1%
01-Sep-02 04:33:41 AM	233.2	4	00:01:55	00:30:36	4184.3	4184.3	123.2	50.0%
01-Sep-02 05:04:18 AM	229.1	4	00:01:51	00:38:14	3862.4	5954.6	127.4	39.3%
01-Sep-02 05:42:33 AM	223.8	4	00:02:09	00:29:15	4345.2	3862.4	113.6	52.9%
01-Sep-02 06:11:49 AM	230.9	4	00:01:52	00:30:30	4184.3	4345.2	122.9	49.1%
01-Sep-02 06:42:21 AM	230.7	4	00:02:07	00:28:40	4184.3	4184.3	119.3	50.0%
01-Sep-02 07:11:03 AM	239.1	5	00:02:27	00:32:47	4184.3	4184.3	123.4	50.0%
01-Sep-02 07:43:51 AM	219.3	10	00:08:25	00:41:30	4023.4	4506.2	118.3	47.2%
01-Sep-02 08:25:22 AM	211.1	5	00:03:09	00:21:47	2735.9	2414.0	76.5	53.1%

Figure 2-2: Sample of CAES output

As for the global positioning system (GPS), it is recognized as an accurate system in determining the position of objects on earth by calculating the time that a signal takes to travel from satellites in the sky to receivers on the ground (Kannan 1999). The literature indicates that since 2000, when the Selective Availability feature was removed, the accuracy of GPS receivers has increased from approximately 100 meters to approximately less than 10 meters. This improvement in accuracy makes GPS a trustworthy technology not only for site data collection but also for tracking construction equipment. Compared to the above described data collection tools, GPS is more efficient, as long as there is an open sky without any obstruction effect. The most important feature of GPS as a data collection tool is its cost effectiveness.

GPS can offer a number of benefits and improvements to earthmoving operations (Rauno and Mike 2003). The collected GPS data can be used to estimate onsite productivity (Alshibani and Moselhi 2007). Han et al (2006) have reported that in earthwork projects with a short haul distance, a GPS-based system for managing earthmoving operations can increase productivity by 21% and can costs saving by 12.97%, whereas in projects with a long haul distance, it can increase productivity by 5.57% and costs saving by 4.79%. Based on the stated advantages of GPS, the present study uses GPS for tracking and controlling earthmoving operations, as a new method. It is envisaged that this new method can overcome the limitations of the contemporary methods in practice and facilitate project management teams' tasks. The advantages of GPS can be summarized as follows: (Kannan 1999):

1. It provides complete information needed for the tracking and control of earthmoving operations.
2. The data collected by using GPS (time, speed, and XYZ coordinates) is very accurate.
3. GPS is a free-of-charge system, with the exception of inexpensive receiver units.
4. GPS does not require any maintenance costs except for the cellular transmissions.
5. The GPS receiver is a removable device that can easily be transferred between equipment.
6. The gradient profile of a travel road can be obtained using GPS data.

7. The travel, return, and idle time of equipment can be easily extracted from the collected data.
8. The use of GPS for data collection does not require any special training.

There are, as well, some limitations in the use of this technology in tracking and controlling construction projects. The reasons attributed are as follows (Kannan 1999):

1. There is a lack of an industry-wide standard protocol and format, which makes it difficult for instruments from different vendors to communicate with one another.
2. The data cannot be collected if there is any obstruction that blocks the open sky.
3. There is some difficulty in manipulating and reducing the collected data.

The literature reveals that GPS has been used in many applications for earthmoving operations, including the following:

- Monitoring of asphalt compaction operations (Oloufa and Thomas 1997; Pampagnin et al 1998);
- Detecting and correcting major compaction errors (Jaroslaw and Karl 2002);
- Avoiding collisions at construction sites (Lothon and Akel 1996; Oloufa et al 2002);
- Planning and control for the efficient routing of construction equipment (Tserng and Russell 1997);

- Tracking of pavement compaction (Cheng et al 1996);
- Monitoring of productivity in construction (Navon and Sacks 2007);
- Monitoring of paving operations (Peyret and Tasky 2002, 2004);
- Estimating activities duration of earthmoving operations (John et al 2005);
- Grading control.

Oloufa and Thomas (1997) proposed an automated system to monitor and record the areas compacted by an asphalt roller. They used real-time differential GPS techniques to achieve a high degree of positional accuracy. In order to track the roller's position accurately, two receivers are attached to the roller, one in the front and the other in the back. The developed system guides the operator through the process so that the necessary passes are carried out.

Similarly, Pampagnin et al (1998) have developed a system called "CIRC" (Computer Integrated Road Construction). CIRC automatically tracks and monitors the compaction of road layers using the GPS and CAD data on the machines. The system assists the operator in performing the exact number of passes at the right speed, everywhere on the surface to be compacted. Jaroslaw and Karl (2002) conducted a field study using low-cost differential GPS (DGPS) receivers to monitor compacting operations. They concluded that since most errors in a compacting operation are caused by omission, the use of low cost DGPS receivers could be as effective as the use of a modern DGPS receiver. Using GPS, Lothon and Akel (1996) proposed a system to alert operators of excavating equipment when the equipment is in danger of collision with a

pipeline network. The system works by comparing the current position of the equipment with the known location of pipelines. If there is any danger of collision, the system sends a message to the operator. Oloufa et al (2002) also developed a system to avoid collisions among construction equipment in construction sites in the event of poor visibility. The system sends the necessary information through a central server, which evaluates collision scenarios and sends back cautionary messages to the roving vehicle(s) if a collision is impending.

Tserng and Russell (1997) have developed a planning and controlling system for the efficient routing of construction equipment based on real-time kinematic GPS methods. The system is used to provide equipment travel path data. The paths are evaluated to identify potential collisions and to determine the shortest collision-free path. Cheng et al (1996) developed a system based on GPS and GIS for tracking pavement compaction. The system collects data in real-time using GPS receivers attached to compactors and then transforms this data to a GIS map for graphical presentation. The required number of passes can then be accounted for and the result saved as historical data.

Jaroslawa and Karl (2002) have developed a computer-integrated road construction system using low-cost GPS. The system is designed to detect and correct major compaction errors. Based on GPS data, John et al (2005) developed a system to identify the key records required for the calculations of activity durations for earthmoving operations. The captured data includes date, time, speed, and position (X, Y, and Z coordinates). A spreadsheet engine is used to automate the data reduction process.

Peyret and Tasky (2002) have developed a system to electronically connect paving operations with an asphalt mixing plant. The system is based on the electronic tagging of the trucks hauling asphalt and a GPS positioning of the asphalt pavers. The system utilizes Radio Frequency Information Data (RFID) to store the data in electronic tags and uses the Global Positioning System (GPS) to position the material parameters with respect to the road-building project. The data related to a batch of materials are retrieved from both the quality-monitoring computer and the weighing table computer that measures the load of each truck as it leaves the plant. The data is transferred to the tag through an interfacing box connected to an antenna. The data are conveyed to the site by the tag while the truck is loading asphalt into the pavers' hopper. A similar system called "OSYRIS" (Open System for Road Information Support) was developed by the same authors (2004) for road construction and maintenance. Figure 2-3 represents a pavers' on-board computer and GPS antenna.

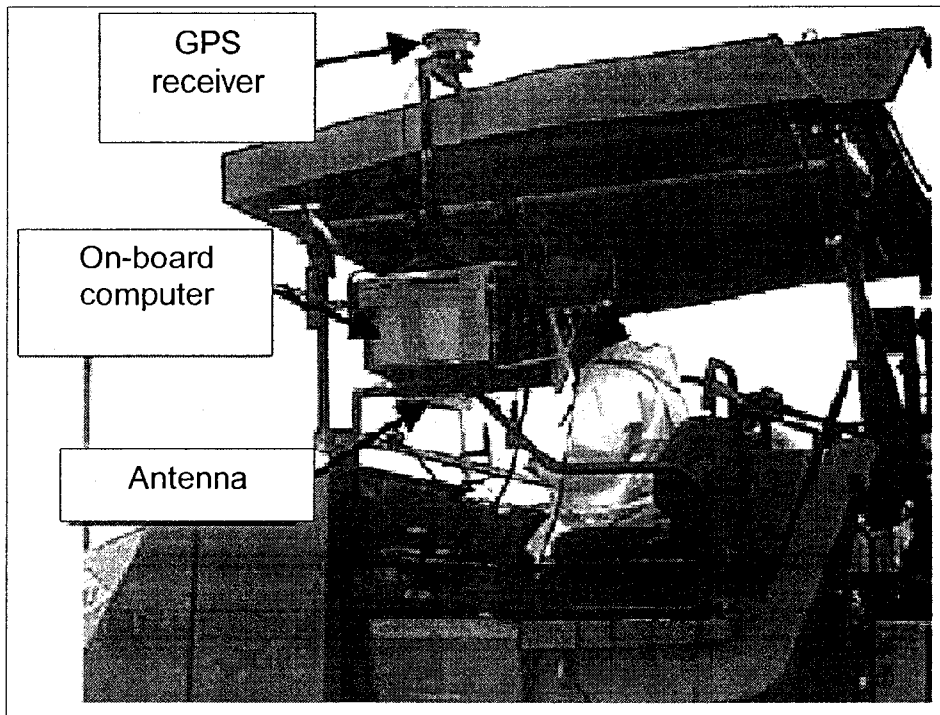


Figure 2-3: A pavers' on-board computer and GPS antenna (Peyret and Tasky, 2004)

In 2002, Trimble Navigation introduced a GPS-based system called SiteVision. This system is designed for the grading control of earthmoving. It is a machine guidance and control system designed for excavation equipment. The system allows machine operators to perform earthmoving operations accurately by placing the site design in the cab and using Global Positioning System (GPS) technology. The system provides contractors with measurable benefits and a quick return on investment by reducing re-work and allowing them to complete their jobs more quickly and accurately. Figure 2-4 depicts the standard form of the Site Vision system.

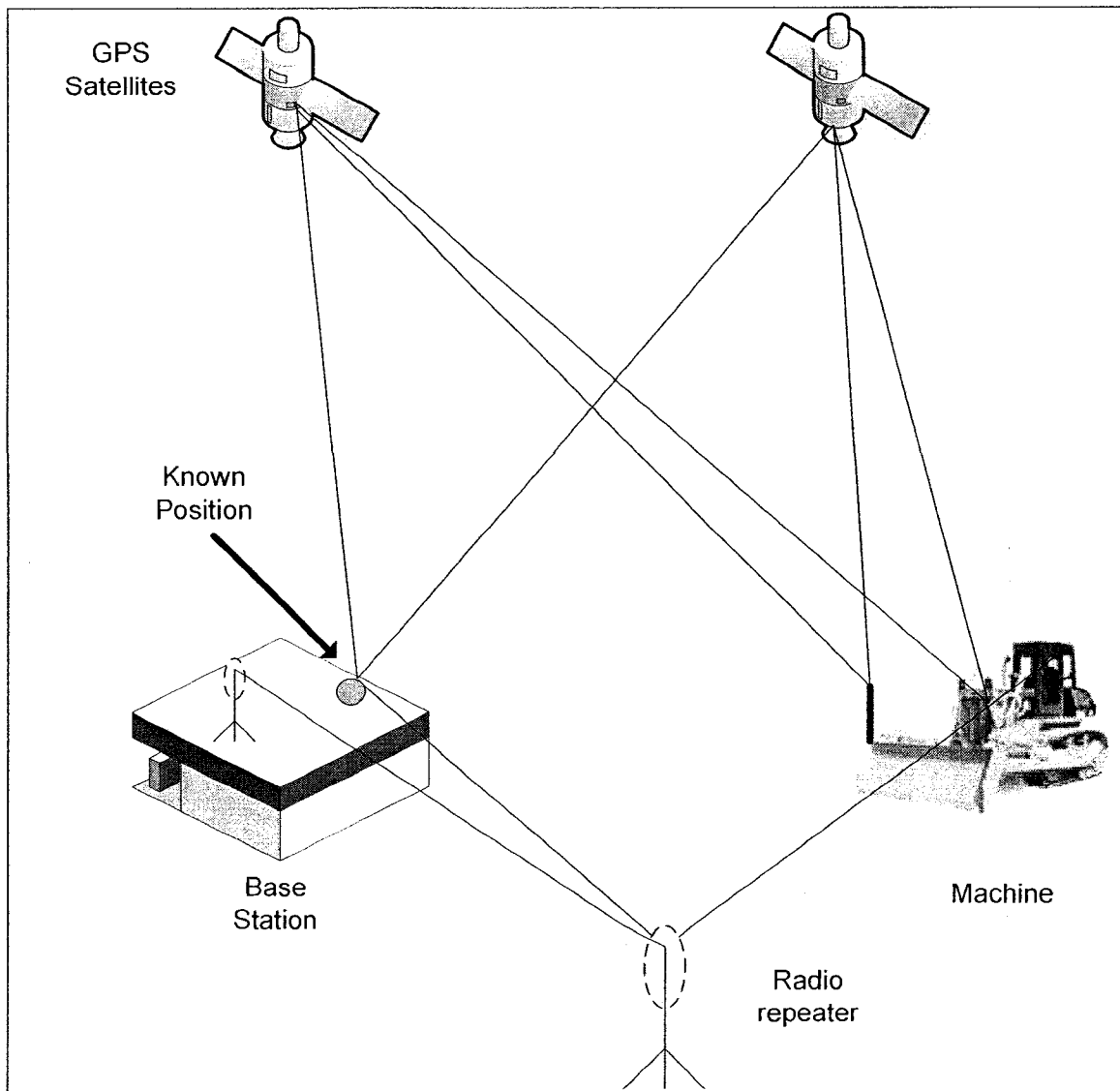


Figure 2-4: Standard SiteVision system

Kannan (1999) compared the data collected by GPS and that collected by the OBI system in estimating cycle time duration. The author stated that if OBI is used to collect data, then the loading time of a truck could be measured accurately, while the time spent in the loading area is only estimated if GPS is used. He also added that determining the load time requires having physical sensors on the truck. The OBIS can only record the aggregate time to haul,

whereas the global positioning system is able to calculate the haul time for each segment. This finding makes the GPS more suitable than OBIS in tracking and control of earthmoving operations. Table 2.1 summarizes the features of OBI and GPS.

Table 2. 1: OBI vs. GPS (Kannan, 1999)

Feature	On-board Instrumentation Data	Global Positioning Systems
Extent of Automation	Almost complete automation; Calibration required on a daily basis	Full automation possible
Activity time	Directly available	Can be calculated based on proximity rules
Load time	Yes, sensors are available	No, only time in load area is possible
Load time from each pass	Not with the systems investigated; possible by others	No, physical sensors are needed to collect this data
Waiting time	Yes, using speed as a criterion, waiting time can be separated from activity time	Yes, if speed is used as an input, waiting time can be incorporated into the rules
Dump time	Not with the systems investigated; possible by others	No; time in dump area
Individual haul segments	No, only aggregate information is available	Yes, can be computed on the server
Communication		
Individual unit to base	Cell phone / radio link possible, one way in most instances	Cell phone / radio link possible, two way in most instances
Individual unit	Integrated with machine instruments; almost all internal	Communication with satellites depend on weather
Buffer	Can store records temporarily until refreshed	Can store records temporarily until refreshed
Availability		
Types of machines	Available only from some manufacturers on selected trucks	Independent of truck manufacturers
Mobility : Fixed or portable	Fixed, completely integrated with machine electronics	Portable, can be easily detached and mounted on any machine

Other Features and Applications	Load as a output	(a) Haul road profile (actual vs. theoretical speed) (b) Haul road maintenance (accelerometer) (c) Load counting (d) Actual-built simulation
Cost		
Equipment	Varies with manufacturer; usually ranging from \$40,000 to \$ 50,000 / truck; software extra.	Receiver = \$1000 / Truck Base station = \$20000 or can be substituted with coast guard beacon or community base station; Software extra.
Training		
Training	Operator training required	Operator training not required

Based on the preceding review of the literature relating to onsite data collection, the following characteristics should be found in any effective data collection system and should be incorporated in the development of any new one (Kannan 1999):

1. The system should be an independent mode of data collection and be capable of handling a large volume of data.
2. The system should integrate data collection and extraction.
3. The system should be cost effective.
4. The system should collect data in an electronic format to provide an excellent opportunity for analysis and storage.
5. The system should be capable of collecting data in near real time.

2.5 Geographic Information System (GIS)

GIS is a computer system tool (including both hardware and software) capable of storing, retrieving, transforming, and displaying geographically-referenced

information. GIS is essentially a combination of computerized mapping and database management systems (Hassanien 2002). It is used to digitally represent and analyze the geographic features present on the Earth's surface. The database of the GIS is a collection of information about objects and their relationships to each other. It includes a wide variety of information: geographic, environmental, political, social, etc. The GIS allows maps to be drawn from the database and data is referenced from the maps. When a database is updated, the associated map can be dynamically updated also. The primary purpose of a GIS is to display, query, and analyze spatial data. The GIS is used in many industries as a problem-solving and decision-making tool. GIS has retained considerable attention in research and practice in many areas. In the construction industry, considerable work has been done using GIS for various purposes including: monitoring schedules (Min and Jiann 2002); automate data acquisition (Hassanien and Moselhi 2002); and remote controlling of earthmoving equipment (Marco and Fioerenzo 2003). Min and Jiann (2002) have developed an automated schedule monitoring system for pre-cast building construction. The system integrates a barcode, GIS, and a database management system to assist engineers in controlling and monitoring the erection process on a real-time basis. The erection process was selected because it is the most critical activity in pre-cast building construction. Hassanien and Moselhi (2002) used GIS to develop a model to automate data acquisition and analysis for planning and scheduling highway construction projects. Their model utilizes GIS to analyze spatial data and to estimate cut and fill quantities. It generates a digital map of the terrain to

represent the ground topography and underlying soil strata. Marco and Fioerenzo (2003) developed a remote control system for a fleet of earthmoving and road construction equipment. Their system consists mainly of three segments: positioning, control, and transmission. The system uses GIS, CAD, and GPS for controlling and monitoring operations that involve heavy equipment. The system tracks neither the cost nor the schedule of these operations or activities. It should be noted that in the literature, as yet there has been no reported use of GIS in optimizing earthmoving operations.

2.6 Project Tracking and Control

Tracking and control is an essential management function for successful delivery of engineering, procurement, and construction (EPC) projects. It includes three aspects: (1) collection of data from the construction site; (2) monitoring progress; and (3) comparison of actual performance to planned, and determination of any existing variations (Moselhi 1993). Integration of time and cost control is a difficult and complex process (Moselhi et al 2004). Traditionally, the S-Curve with its many variations has been used to report individually on the project control status and its physical progress (Moselhi and Hassanien 2003). Despite the improvement achieved by using an S-Curve for a project's control purposes, this effort is of little or no value as long as the project cost and progress are tracked independently. Recognizing these difficulties, the US Department of Defence (1967) introduced the earned value concept. Since then, several other researchers have adopted it and some modifications have been introduced with respect to: (1) the level of detail associated with the work breakdown structure

(WBS); (2) the structure used for measuring work progress (Moselhi and Hassanien 2003); and (3) forecasting of the project cost and time at completion (e.g. Alshibani 1999; Li et al 2006; Alshibani and Moselhi 2007). In order to achieve the desired integration of time and cost, the differences in the level of detail between the cost breakdown structure (CBS) and the work breakdown structure (WBS) must be recognized (Alshibani 1999). Hegazy and Kassab (2003) developed a model using genetic algorithms for tracking and control. The model is designed to store resource data and to use it to perform estimating, scheduling, and controlling. Their model was developed to carry out dynamic project monitoring and control by using an overall optimization of a project's intermediate schedule. The model integrates the use of the Critical Chain Method in addition to the well-known earned-value technique. Although several tracking and control models have been developed using network schedule techniques (e.g. Moselhi and Hassanien 2003; Alshibani 1999; Li 2004), little effort has been made for the tracking and control of earthmoving operations. Moselhi and Hassanien (2003) have developed a system designed to eliminate the limitations of resource-driven scheduling and to obtain a more reliable forecast of cost and time at completion. Navon et al (2004) have developed a tracking and control system for linear projects. The system uses GPS and onboard instrumentation to monitor, in real-time, the activity of major construction site equipment, such as tower cranes, concrete pumps, etc. The system enhances the ability of construction managers to respond quickly to project performance problems.

2.6.1 Measuring Project Performance

In addition to the automation of site data collection and the integration of cost and time control, the problem of measuring construction performance has been widely recognized and documented (Bassioni et al 2004). Measuring a project's performance takes the form of comparing the actual performance with the as-planned performance. This comparison enables identification of the cause(s) behind unacceptable performance so that corrective action(s) can be taken to bring the project back on track (Alshibani 1999). Alarcon and Ashley (1996) presented several factors to improve construction performance measurement. Handa and Barcia (1986) pointed out that several methods to evaluate actual progress have been developed; including those based on the units completed, incremental milestones, start-finish, supervisor's opinions, the cost ratio, and weighted units. Barrie and Paulson (1992) reported that the weighted-units method is the one most capable of quantifying construction progress. Alarcon and Ashley (1996) presented a methodology for modeling project performance by combining the experience captured from experts with that from the assessment carried out by the project team into a general performance model (GPM) for application to individual projects. Robert et al (2003) putted together quantitative and qualitative performance indicators that are presently used in the construction industry (key performance indicators). They recommend that, for the task to be measured, simplified methods should be used to gather only the data that is directly used to predict performance. The performance indicators, however, can be either the quantitative results of the construction process, i.e., \$/unit (Eldin

and Hughes 1992), or qualitative measures such as worker motivation on the job and client satisfaction. Robert et al (2003) have also concluded that there are differences between heavy civil engineering and industrial construction projects with respect to the key performance indicators (KPI). These differences are due to the level of details. McCabe and AbouRizk (2001) introduced standard performance indices in automating the experimentation process of a computer simulation during the planning stage. The system uses five developed indices: the queue length index, the queue wait index, the customer (trucks) delay index, the server (loader) index, and the server quantity index. These indices have been adopted in the present thesis, as presented in Chapter 5.

Despite the progress over the past 20 years in communication technologies and project information management software, little work has been done in automating control performance (Navon and Sacks 2007). "Automating control performance enables construction activities to be controlled and managed in a real-time and in a closed loop" (Navon and Sacks 2007). Navon (2005; 2007) presented a variety of research projects whereby the measurement of the actual performance is fully automated, including measuring labour productivity by measuring the location of workers at regular time intervals.

2.6.2 Forecasting Project Performance

Forecasting project time and cost is a basic function of tracking and control of a construction project. It is essential for the evaluation of the project status. Forecasting project time and cost accurately is a difficult task. This difficulty is

due to the impact of many factors on project time and cost such as weather conditions, cost changes, and equipment breakdown, etc. Over the years, many forecasting models have been developed using different techniques. Each is based on its own assumptions (e.g., Moselhi et al 1991; Eldin and Hughes 1992; Diekmann and Al-tabtabi 1992; Shtub et al 1994; Fleming and Koppelman 1994; Christensen et al 1995; Robinson and Abuyuan 1996; Al-tabtabi 1996; Alshaibani 1999; Hassanien 2002; Moselhi et al 2004; Gabriel et al 2004; Li 2004; Christensen 2004; Li et al 2006; Alshibani and Moselhi 2007). These models are based on one or the other of the two following assumptions (Li 2004): (1) the established performance at the report date will continue until completion; or (2) the future work after the report date will be performed as planned. The first assumption does not correlate the past and future performance. Under this assumption, the cost at completion is forecasted by adding the cost variances at report date to the budgeted cost at completion. The second assumption correlates the future and past cost performance. The cost at completion is forecasted by dividing the budgeted cost at completion by Cost Performance Index (CPI). The cost variances at completion are then determined by subtracting the forecasted cost at completion from budgeted cost at completion. The previous stated methods lack the ability to: (1) block out previous reporting period in which exceptional conditions are known to have prevailed except for that of Moselhi and Hassanien (2003); (2) account for changes over the project time; and (3) they provide a single value for forecasting project cost and time, except for that of Gabriel et al (2004) and Eldin and Hughes (1992).

Hassanien (2002) has developed an alternate methodology in which his model enables blocking out certain periods during which exceptional conditions are known to have prevailed. However, blocking out certain periods completely may not be accurate because it does not consider the inefficiency of the contractor. Instead of blocking out the entire period, determination of the performance index for this period can be based on the level of productivity achieved by the contractor during normal conditions and before such unusual conditions had arisen. This concept has been adopted in the forecasting method developed in the present research as presented in Section 5.5.4. Moselhi and Hassanien (2003) developed a model to: (1) monitor the progress of a linear construction project, (2) identify the source of an unacceptable performance at the crew level, and (3) forecast the time and cost at completion utilizing the earned value technique. The model uses the relative weight of an activity to measure the total work completed. The relative weight is calculated as $((\text{man-hour of activity} / \text{total man – hours required for project}) * 100)$. The model forecasts the time and cost at the crew level. This is significant when there is more than one crew on an activity. Alshibani and Moselhi (2007) developed a forecasting method based on data collected by GPS. In this method, instead of blocking out an entire period in which exceptional conditions are known to have prevailed such as a strike, the performance index for this period is determined based on the level of performance achieved by the contractor during normal conditions just before the occurrence of such unusual conditions.

Eldin and Hughes (1992) criticized models that provide a single number for forecasting project cost and time. They recommended that different deterministic methods should be used in forecasting project's performance providing a range of possibilities rather than using a single rigid number. The same authors (1992) developed forecasting model using deterministic method that provides two values, one is the minimum and other is maximum based on the above stated assumptions. Gabriel et al (2004) developed a model based on earned value concept capable of providing a range of possibilities using simulation.

2.7 Desired Characteristics of an Optimizing and Controlling System

To optimize earthmoving operations, the system should:

1. account for site conditions, topography of travel roads (grade and rolling resistance), soil type, indirect cost, and available resources to contractors;
2. be able to dynamically reconfigure crew formations in near real time;
3. rely on information that is easy to obtain;
4. consider multiple borrow pits and landfill sites; and
5. be easy to use.

For tracking and controlling earthmoving operations, the system should:

6. rely on data that is easy to collect;
7. track equipment on construction sites in near real time;
8. automate control performance;
9. integrate cost and schedule functions;
10. be able to coordinate all the project's teamwork;

11. be accurate in forecasting project cost and time;
12. be able to identify possible causes for unacceptable performance, if any; and
13. act in time to provide an early warning of cost overrun and/or scheduling delays.

2.8 Summary

A review of the literature on various methods of productivity estimation and models for optimizing earthmoving operations is given in detail. This chapter highlights the advantages and disadvantages of such methods and tools. This chapter also discusses the use of spatial technologies, including the Geographic Information System (GIS) and the Global Positioning System (GPS), and briefly describes their potential use in the construction industry with a focus on earthmoving operations. Recently developed project tracking and control models are also briefly described. The literature review helps identify some limitations in the current optimizing, tracking and control of earthmoving operations. The chapter concludes by highlighting the desired characteristics of a control system.

Chapter 3: Proposed Model

3.1 Introduction

This chapter introduces a model designed for optimizing, tracking, and controlling earthmoving operations. The model is designed to support, enhance, and improve the current practice in earthwork operations. The developed model utilizes genetic algorithm (GA), linear programming (LP), and spatial technologies such as Global Positioning System (GPS) and Geographic Information System (GIS). GA is used for optimization in conjunction with a set of rules, developed in this study, to accelerate the optimization process and to avoid generating and evaluating hypothetical and unrealistic crew formations. To determine quantities of moved earth from different borrow pits and place these quantities at different landfill sites to meet optimization objective set by the user, LP is combined with GA.

The spatial technologies are used for data collection, graphical representation, and analyzing of earthmoving activities. These technologies are selected to assemble, store, manipulate, and display geographically referenced information. The developed model adopts the earned value concept developed by U.S Department of Defense (1967) and the technique of project ratios introduced by Eldin and Hughes (1992). The model also introduces modifications that allow for more accurate forecasting of project time and cost at any future set date (Alshibani and Moselhi 2007). The model is implemented in prototype software as a proof of concept. It is coded in visual C++ V.6, employing object-oriented

programming, utilizes Microsoft Foundation Classes (MFC), and operates under Microsoft Windows. Figure 3-1 depicts the developed model layout.

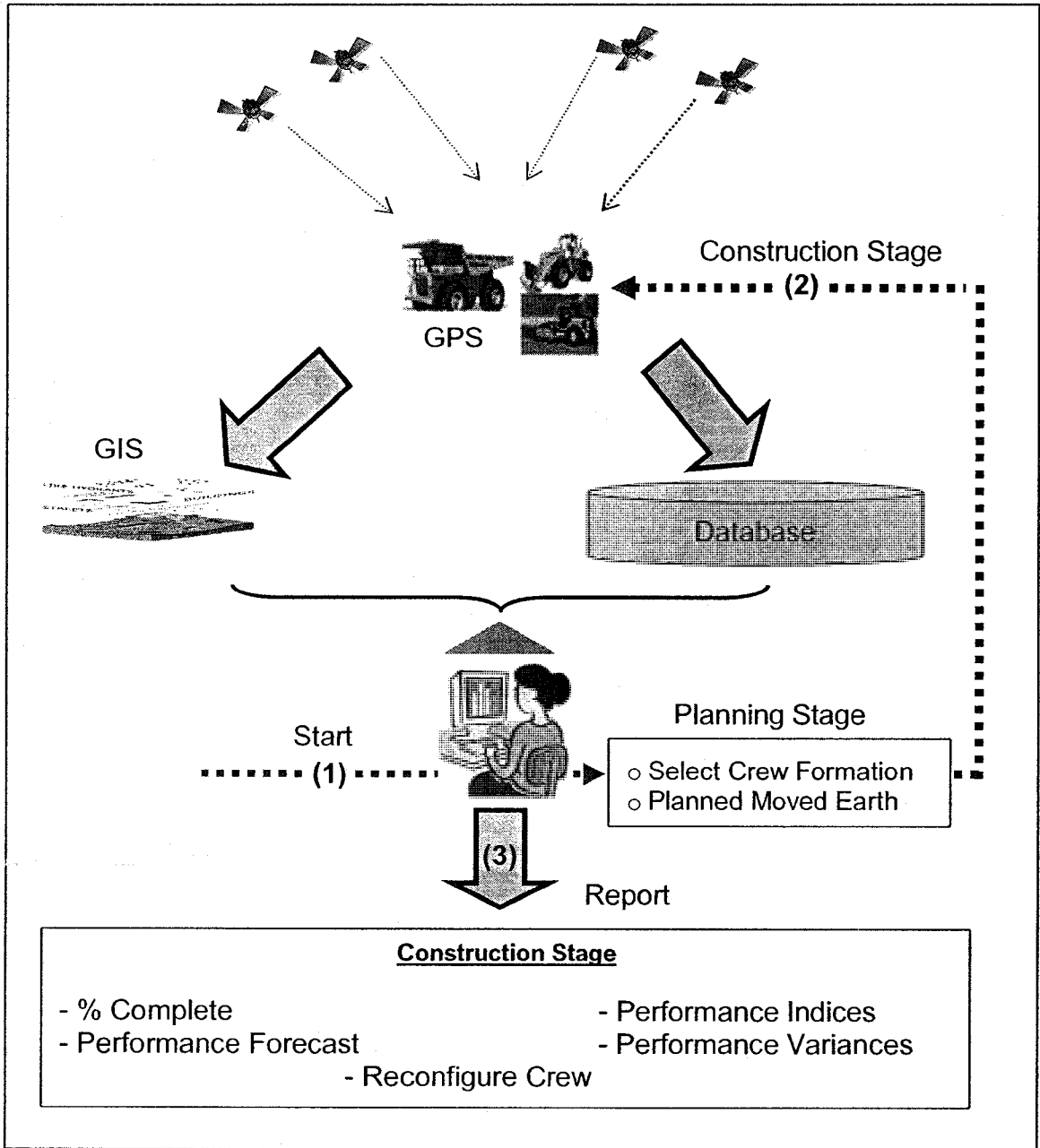


Figure 3-1: Model layout

3.2 Model Requirements

The developed model requirements are based on the literature review presented in Chapter 2 along with the desired characteristics of the data collection and control system. Firstly, optimizing earthmoving operations aims to minimize the total cost of the project and to maximize the contractor's profit. Project optimization involves gathering information about the equipment, project, soil, and construction site. Secondly, project tracking and control involves collecting large amounts of data from the construction site; processing and analyzing the collected data; measuring the onsite performance; comparing the actual performance with that planned to determine any variances; and forecasting project time and cost. To achieve the model requirements, five phases are required:

Phase 1 consists of:

- Designing the model's database to host required information for optimizing and tracking earthmoving operations

Phase 2 consists of designing and developing the optimization module to rectify some identified limitations in current practice. It includes:

- Studying different optimization tools that are available and select a tool that is capable of solving such optimization problems with a reasonable degree of success
- Developing a set of rules to speed up the optimization process

- Linking GIS map and the developed optimization tool to estimate speed and travel time accurately and ultimately to select the best crew formation;
- Automating the optimization process in a computer model

Phase 3 includes designing and developing the tracking and controlling module.

It includes:

- Developing a method for onsite data collection that satisfies the characteristics of an automated data collection system described by Kannan (1999)
- Developing a method of estimating onsite productivity based on GPS data
- Designing and developing a forecasting method that is capable of providing accurate results and relies on GPS data
- Automating the tracking module in a computer model

Phase 4 consists of:

- Implementing the developed methodology in user-friendly software as a proof of concept

Phase 5 consists of:

- Validating the developed model in optimizing and tracking earthmoving operations by testing example projects drawn from the literature and by comparing the model's results with those of other researchers to illustrate its capabilities and essential features

In this chapter, the database module is described in detail, while optimization and control modules are discussed in detail in Chapter 4 and Chapter 5, respectively.

3.3 Model Configuration and Data Flow

As depicted in Figure 3-2, the model has been designed to facilitate data flow among its modules. The model, in planning stage, commences by accepting data from the users, extracting data from the model's database, and a GIS map. The data accepted by the user includes project data, daily indirect cost, actual starting date, etc. The data extracts from the model's database includes data about equipment (e.g., equipment model, hourly cost, etc), soil (shrinkage / swell factor), and job and management conditions. The data retrieved from the GIS map includes information about travel roads to establish a road profile. The GIS information is used to calculate segment length and its grade resistance. The output of this calculation is required for the optimization process as presented in Chapter 4. In planning phase, the model selects the optimum crew formation that satisfies the objective of optimization set by the user. This objective can be defined as minimizing construction time, minimizing construction direct cost, or minimizing construction total cost.

Having selected formation of the crew to carryout the work, project baseline is generated. The model afterward triggers to track earthmoving operations. The tracking process includes the following four main steps:

- 1- Collecting onsite data using GPS
- 2- Estimating onsite productivity
- 3- Assessing actual performance
- 4- Forecasting project time and cost

During construction, the model commences by accepting data from the user and from GPS receivers. The data entered by the user includes actual starting date, tracking technique used, etc. The model uses data collected by GPS receivers for tracking and control. This method can overcome some identified limitations of the data collection methods used in current practice. The GPS data includes data about positions of moving equipment (X, Y, Z, time, date, and speed). Upon the completion of collecting onsite data, the model maps this information onto a GIS map for graphical representation. The model ultimately analyses this data to determine the hauling unit cycle time to estimate onsite productivity, to assess project performance, and to forecast project time and cost. Using GPS data to estimate onsite productivity and to forecast time has many features including:

1. It automates onsite data collection without human involvement.
2. It is a cost-effective method.
3. It tracks equipment in near-real time.
4. It facilitates an information exchange between project team members, which is the main setback of the current practice in tracking and controlling earthmoving operations (Alshibani and Moselhi 2007).

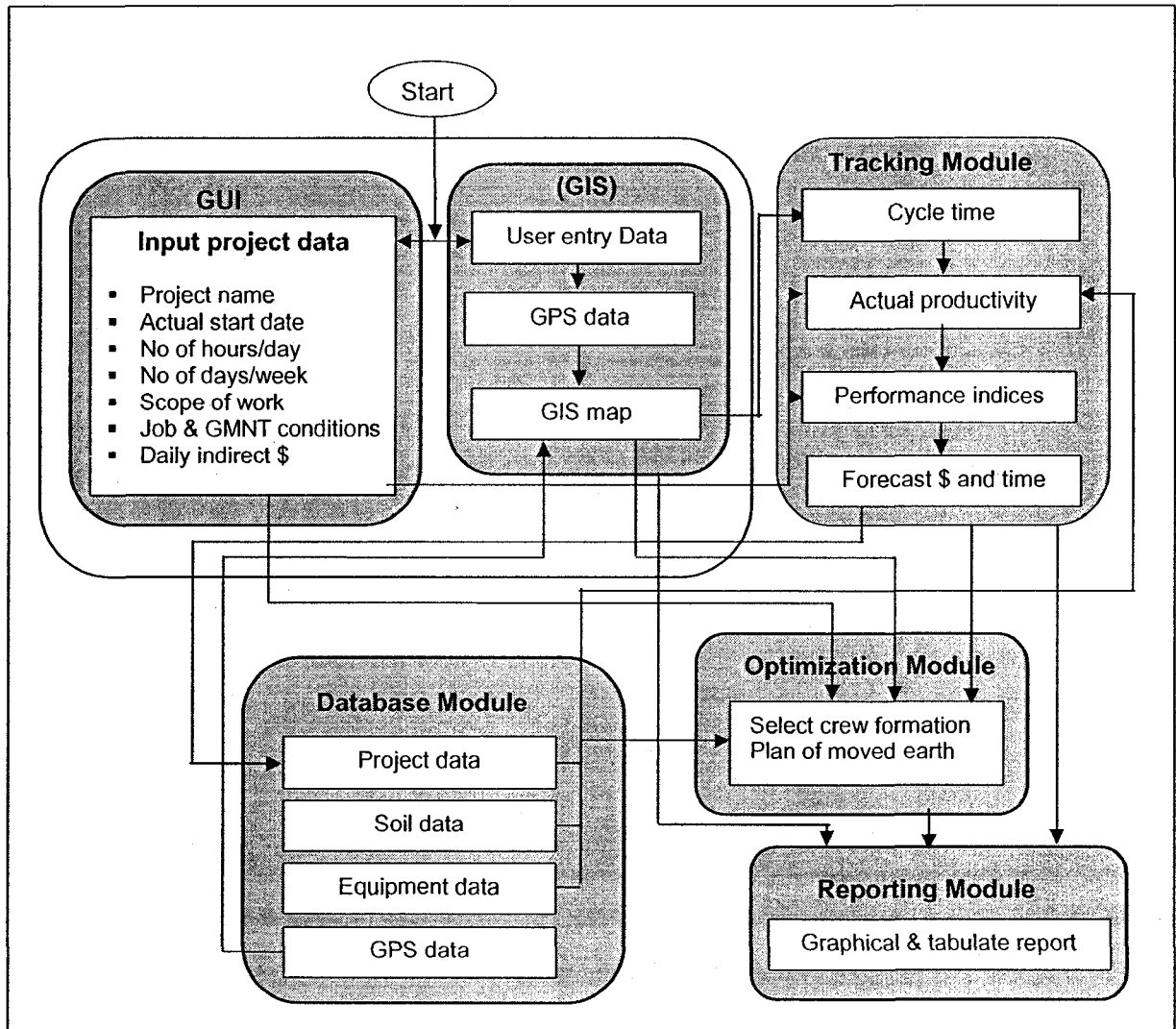


Figure 3-2: Data flow

3.4 Model Main Components and Architecture

The proposed model is designed as stand-alone prototype software to assist engineers and contractors in optimizing, tracking, and controlling earthmoving operations. The model incorporates four main components designed with a modular format. These modules are:

1. Database Module

2. Optimization Module
3. Tracking and Control Module, which includes the following algorithms:
 - A. Onsite productivity measuring algorithm
 - B. Pathfinder algorithm
 - C. Performance indices algorithm
 - D. Performance variances algorithm
 - E. Performance forecasting algorithm
4. Reporting module

The database module has been designed and implemented to host the data necessary for calculations and for storing data collected by GPS receivers. The module is at the core of the developed model. This design facilitates a data exchange and interaction among the main components of the model. As shown in Figure 3-3, this design allows a flexible expansion of the proposed model without affecting the model's main components. For example, the model can expand to include a scheduling module.

The optimization and tracking modules were designed so that they can operate independently or interactively. Based on the user's input, the model guides her/him through the optimization and tracking processes. The model is activated by accepting data from the user and the project's database. For optimizing earthmoving operations, the model initially accepts the data entered by the user who defines the project under consideration. This data includes job and management conditions, scope of work, indirect costs, etc. As can be seen from Figure 3-3, the model extracts information about equipment and soil types from

the model's database. Having selected the optimum crew configuration, the model's database is updated, project cost and time are also saved, and project baseline is generated.

During construction, the model is triggered by downloading GPS data into the GIS map. To report project progress, the model first estimates onsite productivity and compares it with that as planned. In addition to GPS data, the model retrieves needed information from the user and the model's database. Upon completing the estimation of onsite performance, the model afterward forecasts project cost and time (Alshibani and Moselhi 2007). The forecasting output is saved in the project's database to determine the cost and time adaptive factors. A detailed description of these calculations is described in Chapter 5. The dotted lines, in Figure 3-3, represent the data flow of the computation processes within the model.

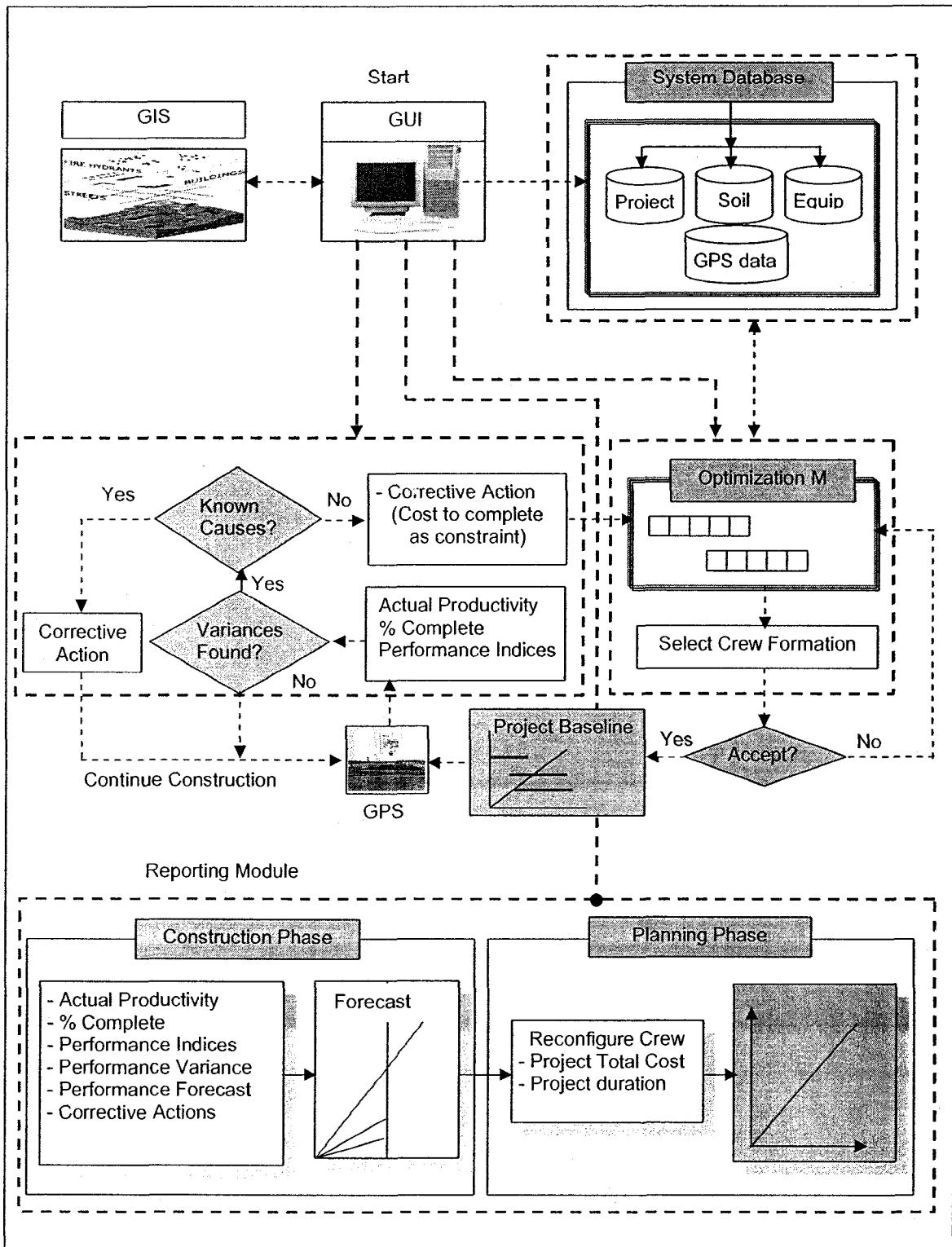


Figure 3-3: Main components of the developed model

3.5 Database Module

In heavy engineering construction projects, earthmoving operations are equipment intensive (Christian and Xie 1996), characterized by large fleets. Optimum use of, as well as close monitoring of, such equipment requires storing and retrieving a large amount of data. Therefore, a database module has been designed to support the management functions of the proposed model and to reduce the users' effort in extracting information from paper-based sources. The database management system assists in storing and retrieving data in an interactive manner. There are different types of databases, characterized by their data structure and processing mechanisms (Marzouk 2002). They include: (1) relational database; (2) object-oriented database; (3) deductive database; and (4) network database. The relational database is used in the proposed database module to organize the data as tables. The relationship database links entities (tables) by including one of the entity attributes in the other entities.

The database module has been developed using Microsoft Access Database Management System. A relational database management system has been used in view of its combination of power, simplicity, and ease of use. This design allows all modules to be integrated easily (see Figure 3.1). The module is based on that developed by Hassanien (2002). The module is composed of three main separate relational databases. They are: (1) equipment; (2) project information; and (3) soil data.

Equipment data includes the available equipment and their related information, such as the equipment models, capacity, hourly fuel consumption, ownership, and operating costs, etc. These data were mostly obtained from the equipment manufacturer. It is worth noting that the choice of the equipment types is based on those that are most often employed in this class of projects (Hassanien 2002).

Project's database includes: (1) installed quantities and actual cost; and (2) the data collected by the GPS receivers (positioning, date, time, and velocity). Soil data includes properties of different types of soil such as shrinkage factors and swell factors. These data items are necessary to support the computations of the proposed model in planning and during the construction phases. The developed entity relation diagram of the resources database is presented in Figure 3-4. The following six equipment types were identified as mostly utilized in this class of projects: (1) loaders; (2) backhoes; (3) dozers; (4) trucks; (5) compactors / motor graders; and (6) water tanker. Table 3.1 represents the information stored in the resources database, and Table 3.2 represents the data stored in the project's database. The loader can be fitted with several bucket types; hence, an entity entitled "Loader Bucket" was developed to capture the attributes of buckets, such as the type, width, capacity, weight, and height. The Loader can have one of several bucket attachments, and therefore a one-to-many relation exists between "loader" and "loader bucket" entities. Similarly, backhoes and dozers have one-to-many relations with buckets and blades, respectively. The entity "Equipment" showed in Figure 3-4 stores the attributes common to equipment types, such as the manufacturer, model, equipment ID, and hourly cost.

Table 3. 1: Resources database (Hassanien 2002)

Resource	Data Stored
Equipment	<ul style="list-style-type: none"> ○ Manufacture and model ○ Unique identifier (châssis number, licence plate) ○ Purchase date ○ Travel speed (on and off highway) ○ Daily cost ○ Total hours worked ○ Etc

Table 3. 2: Data stored in project database

Project	Data Stored
Project	<ul style="list-style-type: none"> ○ Project ID ○ Project name ○ Type ○ Location ○ Status ○ Plan Total Cost ○ Plan Duration ○ Plan Start Date ○ Actual Start Date ○ Contract Type ○ Project Owner
Progress	<ul style="list-style-type: none"> ○ Actual % Complete ○ Planned % Complete
Company	<ul style="list-style-type: none"> ○ Company name ○ Address ○ Phone Number ○ Fax Number ○ Email address

Since a contractor can own more than one piece of equipment of the same model, "Equipment" is connected by one-to-many relations to entities representing each of the above stated equipment types. It should be noted that other information could be saved in the proposed database module as separated

tables. For example, when the user selects to draw different travel roads in GIS map the spatial data for the drawn road is saved for later use. During the optimization process, the pathfinder algorithm retrieves this data to compute travel and return speed and time. In addition, the tabular performance charts of different trucks models are saved in the model's database. These tables can continuously updated by the optimization and tracking modules. Furthermore, forecast table is added to store the values of the forecasted cost and time. These values are then used to compare the forecasted cost with the actual cost to obtain the adjust values. Figure 3-5 depicts the developed model's database

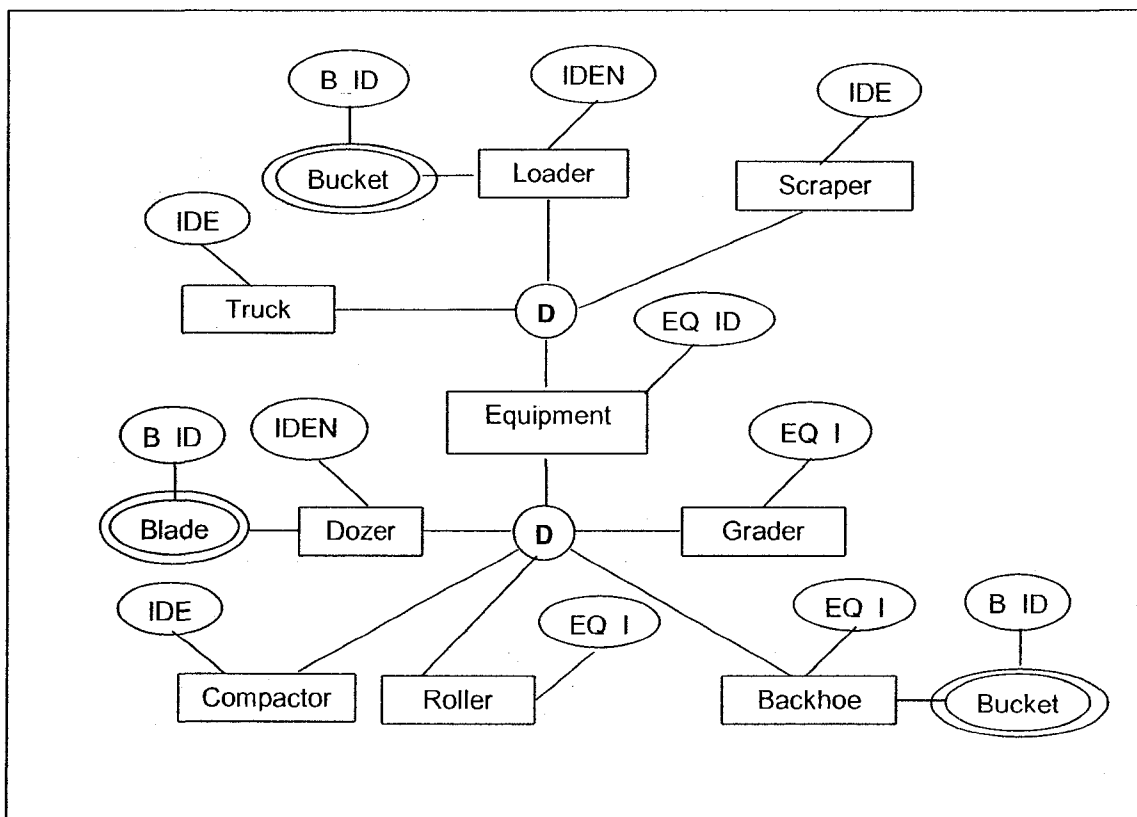


Figure 3-4: Developed entity relation diagram (Hassanien 2002)

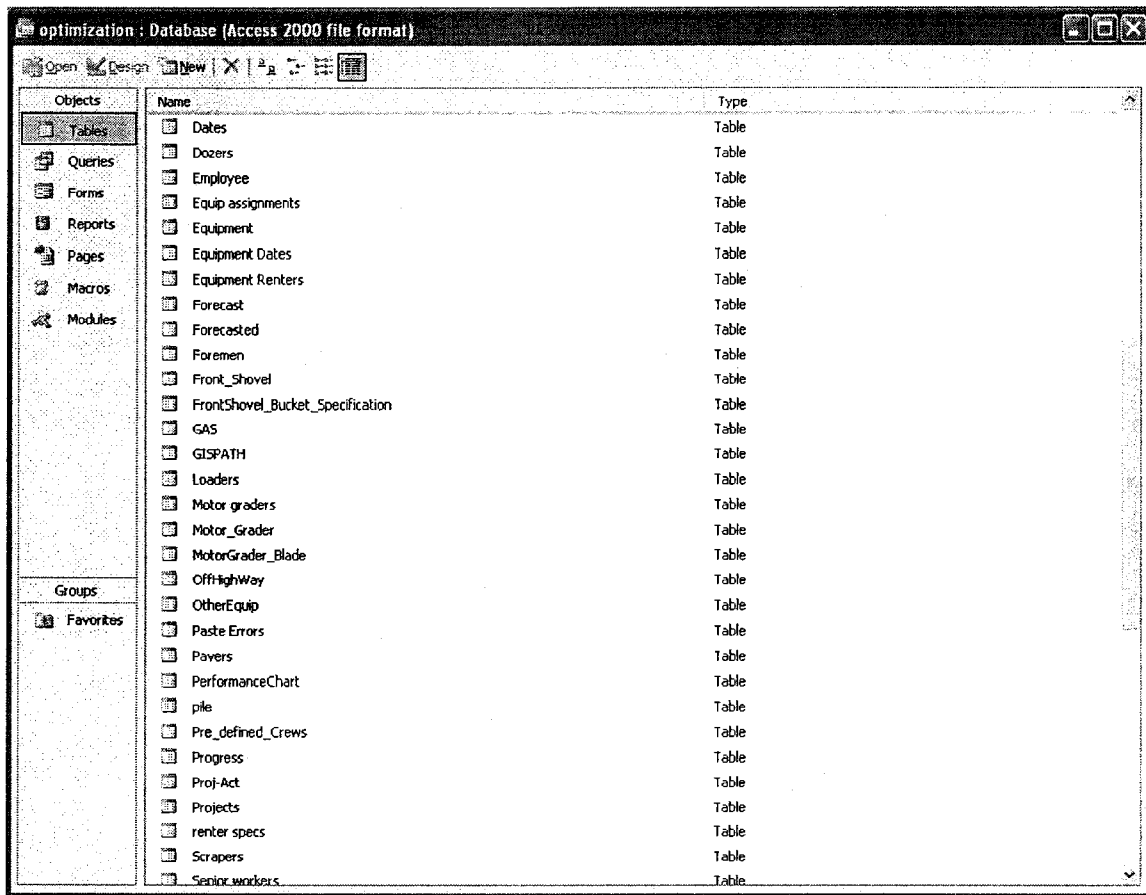


Figure 3-5: Model's database

3.6 Optimization Module

Optimizing earthmoving operations is a crucial task for the project management team. It can result in substantial savings in both the time and the cost of earthmoving operations (Farid 1994, Alkass et al 2003). The optimization processes involves many variables, constraints, and objectives. The variables include quantities of earth required for landfill sites; capacities of available borrow pits, and resources available to contractors. The constraints include the number of available equipment for each type (loaders, trucks, etc), capacities of borrow pit sites, available travel roads, allowed speed, and their surface conditions,

project time and budget, and maximum speed of hauling units. The objectives include the following: (1) selecting the best crew formation to carry out the work at hand; and (2) determining the quantities of earth to be moved from different borrow pits and placed at different landfill sites to minimize construction time, direct cost, or project total cost. These objectives have to be considered collectively. In other word, the quantities of earth to be moved from different borrow pits and placed at different landfill sites are determined while the crew formation is being selected.

In order to develop an efficient optimization model that is capable of combining the two objectives, different optimization techniques have been reviewed such as simulation, genetic algorithms, linear programming, etc. As stated in Chapter 2, several models have developed to optimize earthmoving operations; however, no model can predict the output of such operations with a satisfactory degree of confidence in all situations (Marzouk and Moselhi 2000).

Although the genetic algorithms (GA) are global search methods that have the property of maintaining a population of potential solutions using a selection process based on the fitness of each individual crew, the literature reveals that using standard genetic algorithm to optimize the selection process can be very complex and time consuming. It requires a heavy computational burden and it requires long time computation (Malachi and Singer 2000, Chen 2001). On the other hand, linear programming has been used extensively in optimizing earthmoving operations thanks to its simplicity. For these reasons, the developed optimization module has combined the genetic algorithm with the

linear programming to benefit from their advantages and eliminate their disadvantages. To speedup the computation of genetic algorithm, a waiting time rule is developed as described in Chapter 4.

Combining genetic algorithms and linear programming is relatively new in construction as there has been no such use reported in the literature. But this combination has been used to solve optimization problems in other area of engineering such as solving Mixed Integer Programming Problems (MIPP) (Luo et al 2001), integrating production planning in cellular manufacturing systems (Chen 2001), power/Voltage control (Malachi and Singer 2000), and Water Supply Reservoir Operation (Ries et al 2006). Luo et al (2001) concluded that integration GAs and LP has many advantages including major reduction in computation time.

Combination of GA and linear programming has been utilized in the development of the optimization module. The combination was achieved at fitness function of GA. The optimization process is carried out in two phases. The first phase was designed to select the quantities of earth to be moved from different borrow pits and placed at different landfill sites. The second phase was designed to evaluate the generated crews and select the best crew to carryout the work at hand to minimize construction time, construction direct cost, or construction total cost. As presented in Figure 3-6, the genetic algorithm first generates an initial population (crew scenarios). After that, linear programming is called to determine the quantities of earth to be moved from different borrow pits and placed at different landfill sites for the generated crew and based on the optimization goal.

Afterwards, the genetic algorithm evaluates and then saves the fitness of the evaluated crew. The GA then conducts the usual genetic operations of selection, crossover, and mutation, and generates a new crew formation. The new crew is then sent to LP for evaluation and so on. Finally, the module selects the best solution found (best crew formation) to carry out the work that meets the objective set by the user.

The developed optimization module incorporates four main components. They are genetic algorithms, linear programming, geographic information systems (GIS) and the system's database module. Incorporating GIS in the developed module facilitates an accurate estimation of speed and travel and return time of hauling unit required for optimization as it is described in Chapter 4.

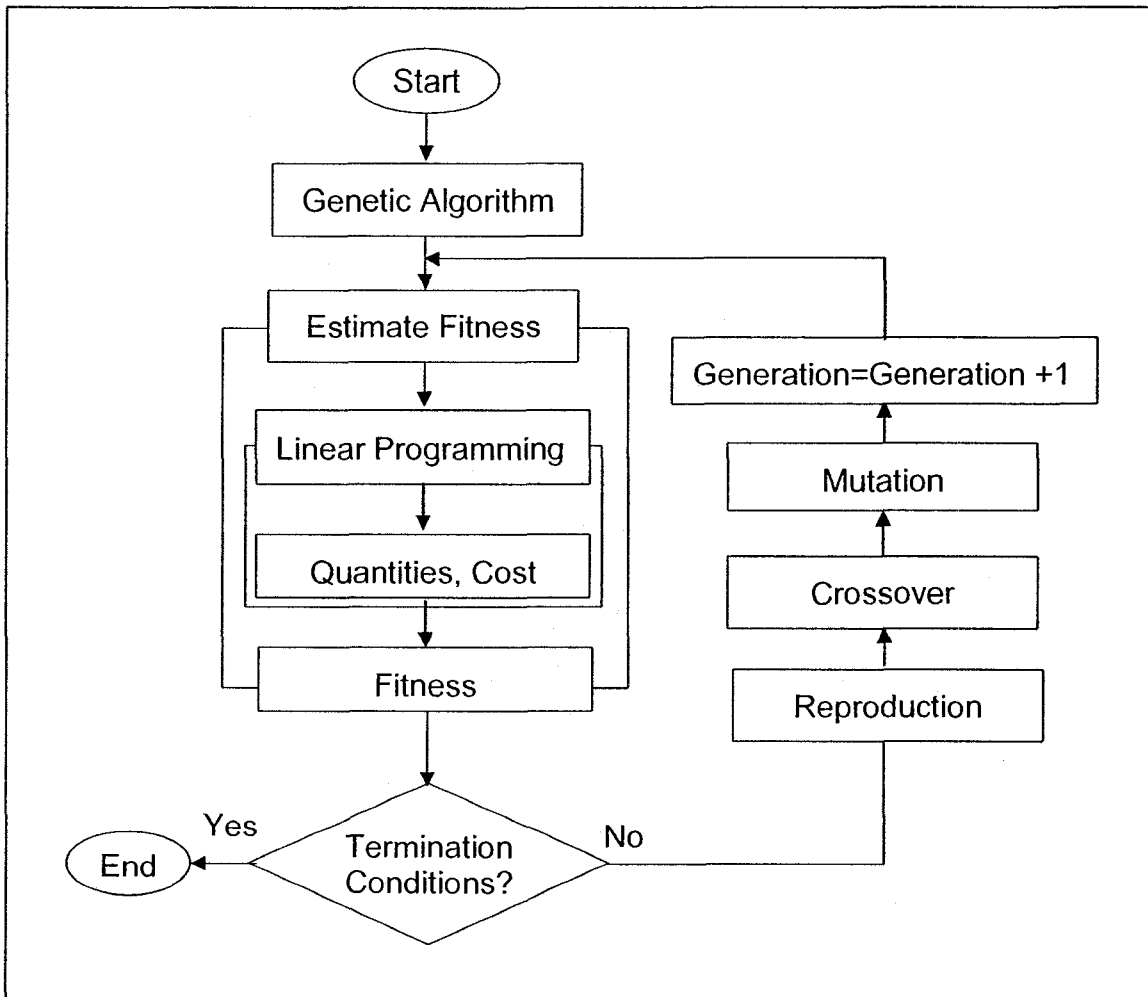


Figure 3-6: Combined GA with LP (GA-LP)

The developed module has a number of interesting features by comparison with current optimization models including the following characteristics:

1. The unit cost used for optimizing earthmoving operations is based on the crew formation selected rather than the experience of the planner.
2. It optimizes the use of available resources not only in the planning stage but also during construction. This allows for near-real time tracking for crew configuration and it balances the use of equipment throughout the life of the project.

3. It extracts the travel road topography directly from the GIS map.
4. It accounts for acceleration.
5. It accounts for the different travel roads that connect borrow pits and landfill sites and selects the road that offers the shortest travel time.
6. It gives the user a flexibility to define several travel roads using the developed drawing tool.
7. it is easy to use and does not require advanced computer skills
8. it considers multi borrow pit and landfill sites

3.7 Tracking and Control Module

Project tracking and control encompass collecting data from the construction site, monitoring project progress, comparing actual performance to that planned, and determining if any variation exists (Moselhi, 1993). A detailed comparison between planned and actual performances enables the identification of possible causes behind an unacceptable performance so that corrective action can be taken just in time.

The literature indicates that tracking and control of construction projects depend primarily on the nature, accuracy, frequency, and time required for collecting onsite data about construction operations (Moselhi and El-Omari 2006). Additionally, analyzing actual performance and forecasting project time and cost at any future set date are also basic functions of project tracking and control (Hassanien 2002).

As described in Chapter 2, manual methods of data collection are time consuming and not accurate. Automated data collection methods can improve the speed and accuracy of data acquisition in a cost effective manner. Earthmoving operations are equipment intensive characterized by large fleets; therefore, tracking this equipment is an essential function of tracking and controlling earthmoving operations. Despite improvement made in integrating cost and schedule controls, control systems still suffer from an inability to: (1) automate onsite data collection in a cost-effective way; (2) calculate onsite productivity based on data easy to collect; (3) forecast project time and cost accurately; and (4) report project progress with a short time lag. These inadequacies complicate the task of project managers to respond to any unacceptable performance.

This section briefly describes the tracking and controlling module developed in this study to rectify limitations stated above. The module proposes an alternative methodology for collecting onsite data, estimating onsite productivity, and forecasting project time and cost at set future date. The module utilizes spatial technologies including GIS, GPS, and other algorithms developed in the present study. GPS is used to automate onsite data collection in nearly real time, whereas GIS is used to automate data acquisition and analysis. The developed algorithms, which have been integrated into the developed module, are dedicated to: (1) monitoring earthmoving productivity; (2) calculating project performance indices; (3) forecasting project time and cost; and (4) calculating performance variances. The module has many interesting features including the

following: (1) it automates onsite data collection; (2) it estimates onsite productivity using data collected by GPS receivers as a new method, instead of using data collected by human observers on site; (3) it forecasts project time and cost using the earned value concept and/or the project ratios technique (Alshibani and Moselhi 2007); and (4) it detects possible cause(s) behind unacceptable performance. The module takes six steps to carry out the tracking and control process. They are:

Step 1

Collecting data from the construction site using GPS receivers

Step 2

Mapping the collected GPS data that represents moving equipment by transforming their respective GPS positioning data (longitude, latitude, and altitude) into the Geographic Information System (GIS) to develop a graphical representation

Step 3

Analyzing the collected GPS data to determine the number of cycles (trips) that tracked equipment makes within a particular period and to estimate actual productivity

Step 4

Measuring project performance at the report date and forecasting its status at any future set date

Step 5

Detecting possible causes behind unacceptable performance

Step 6

Generating progress reports.

Figure 3-7 depicts an overview of the proposed tracking and control methodology.

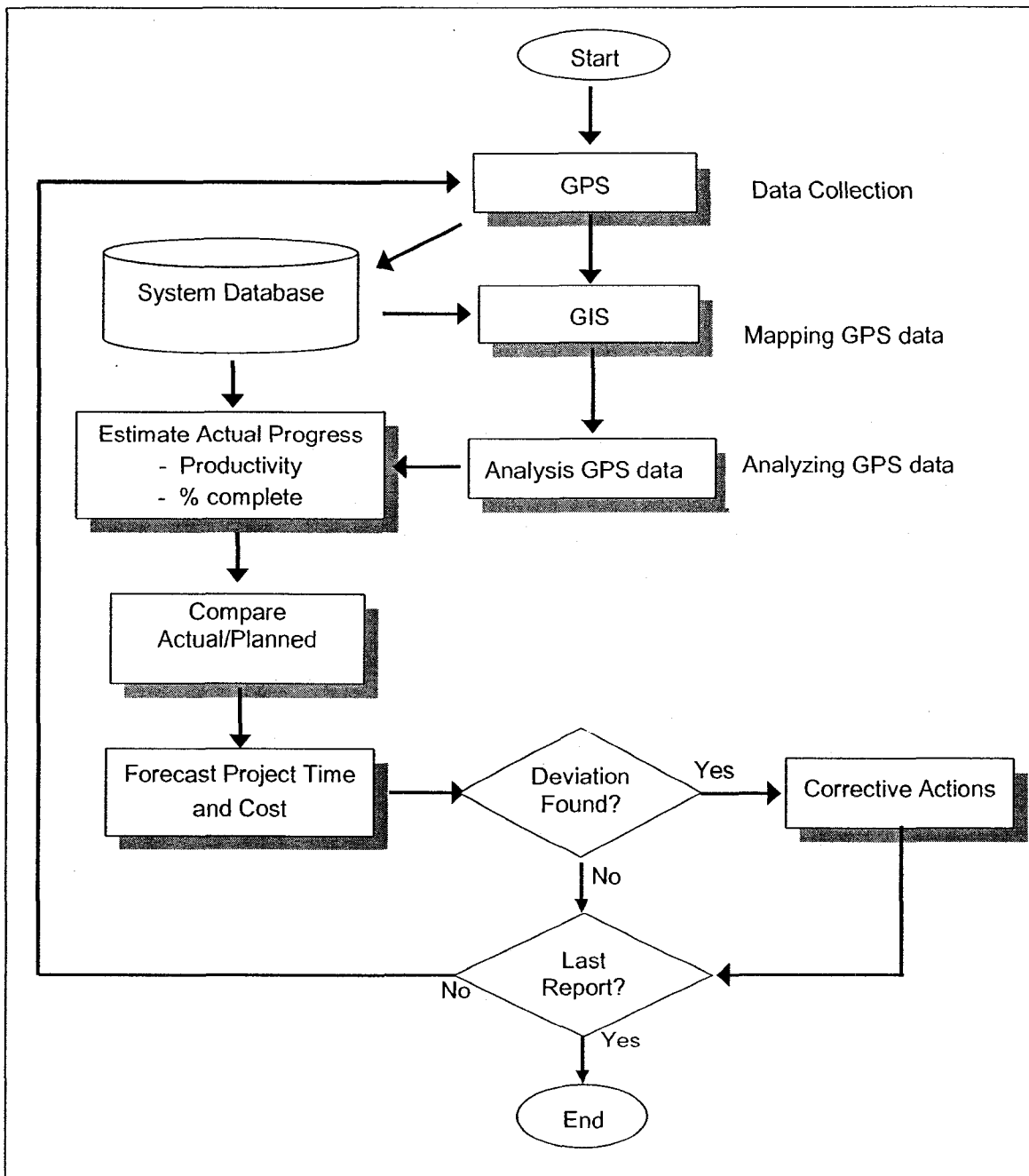


Figure 3-7: Tracking and control process

The proposed tracking and controlling methodology is implemented in a computer model. It consists of implementing a graphical user interface using visual C++ v.6 and Map-Object library introduced by ESRI. It is capable of automatically reading a GIS map's main parameters and of writing them into a model's central database as illustrated in Figure 3-8. The GUI was designed to allow the user to do the following:

1. Zoom in and out at any selected part of GIS map
2. Extend any selected part of a GIS map in any direction
3. Read and write from and to a GIS map
4. Add and delete a layer in a GIS map
5. Load GPS data to a GIS map

In order to allow the user to add layers to a GIS map, a drawing tool has been developed. Drawing the boundaries of loading and dumping areas is an example of drawing a layer to a GIS map as discussed in Chapter 5. The add layer function automatically saves the added layer into the model's database in dbf format. To activate the tracking and control module, the user needs to load GPS data using the "load GPS Data" function in the toolbar. In order to track certain equipment onsite, the user selects the "track" push button. This allows the user to locate any equipment on the construction site for further analysis. For example, the user can track a hauler in a certain period to analyze its productivity.

It is worth noting that the module retrieves data required for computation from the central database, the user entry data, and the GIS map. The data retrieved from the central database includes project information, soil data, and equipment data.

The project data contains as-planned and actual data such as productivity, cost, and quantities. The equipment data includes equipment capacity, hourly cost, speed, etc. The soil data includes the properties of soil such as shrinkage and swell factor. The user entry data includes report date, tracking technique used, etc. Chapter 5 describes in detail the proposed tracking and control module.

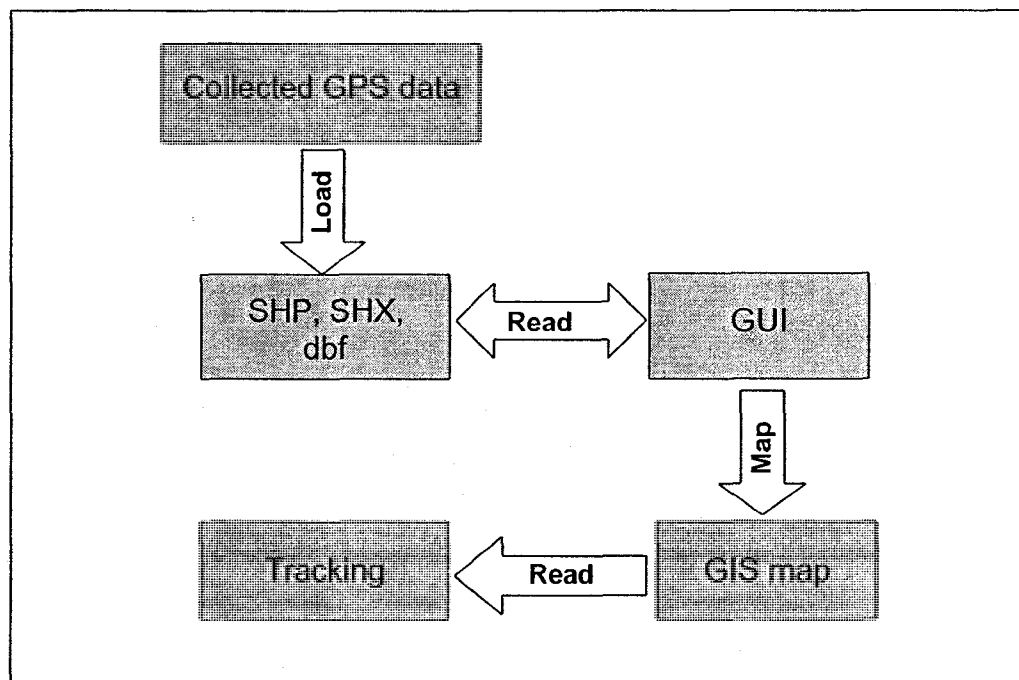


Figure 3-8: Loading and reading GPS data

3.8 Reporting Module

The reporting module generates two forms of reports, tabular and graphical. In the planning phase, it provides the user with a tabular report depicting the selected crew to carry out the work at hand. It includes the number and the model of selected equipment, the project unit cost and the project duration. It also provides statistical information for the initial and final population of the genetic algorithms employed in optimizing equipment selection. The quantity of

earth to be moved from different borrow pits and placed at different landfill sites is also presented in tabular format. The module also provides graphical reports. In the planning phase, the module depicts project cost breakdown structure, while during construction the module provides the user with graphical reports showing the cost and time forecast. It also provides a tabular report depicting the project performance. These reports were designed to suit the needs of project participants.

3.8.1 Tabular Reports

A tabular format has been designed as properties pages in which five pages are presented. Each page presents a certain performance such as planned performance, this period performance, actual to date performance, performance indices, and performance forecasting. This design offers project management team a flexibility to compare project actual performance to that planned. The table presents planned daily cost, equipment selected, planned quantities, along with cumulative cost to date at the equipment and crew level. Figure 3-9 depicts example of tabular and graphical reports as generated by the developed module.

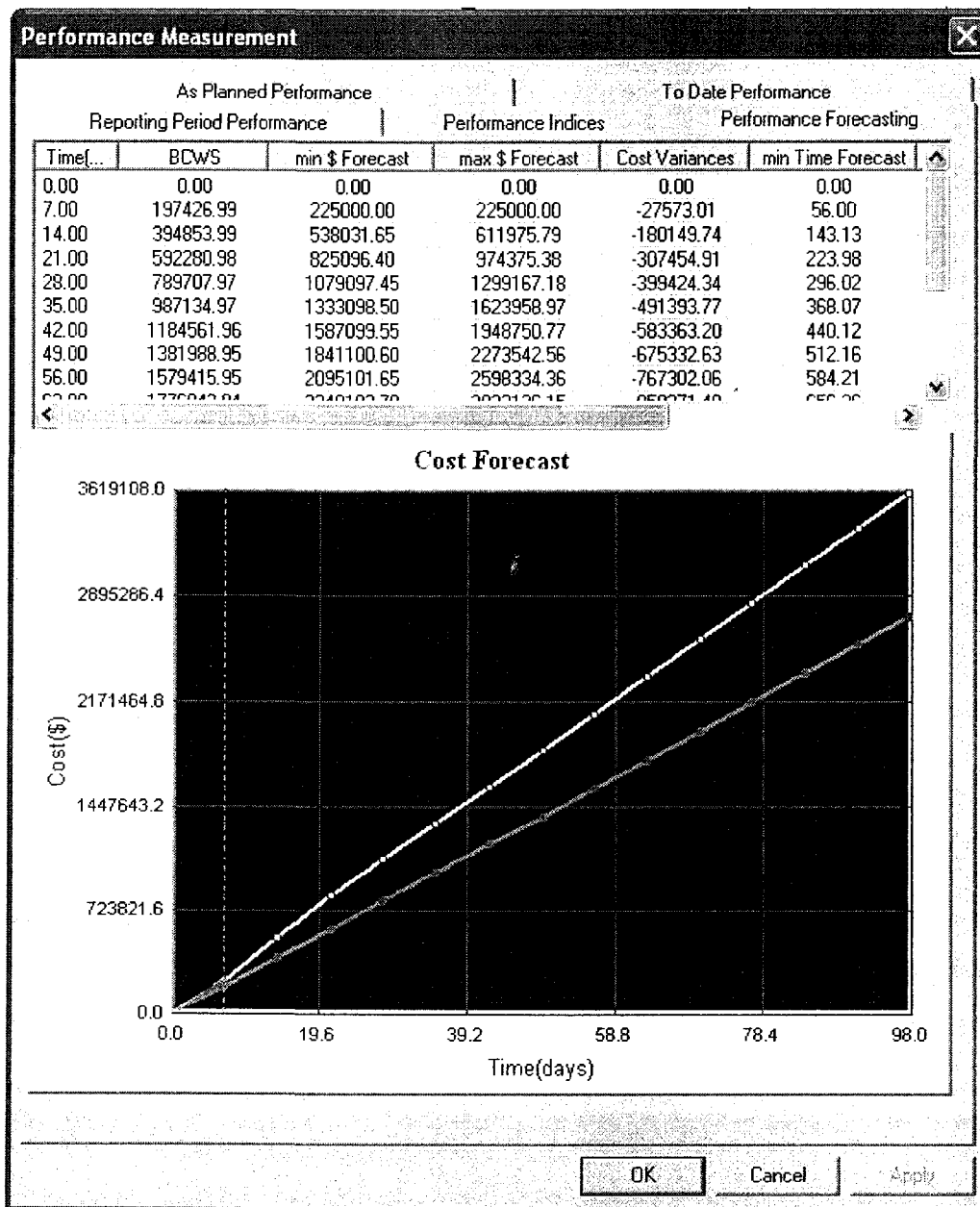


Figure 3-9: Tabular and graphical reports at construction phase

3.8.2 Graphical Reports

The module generates several charts such as project cost breakdown, cost and time forecast, and project baseline (S-curve), depicting the start and completion dates and the relation between project cost and time. In addition, the reporting

module provides a graphical representation of the hauling unit path in GIS map, depicting the positioning data of different travel roads (Figure 3-10).

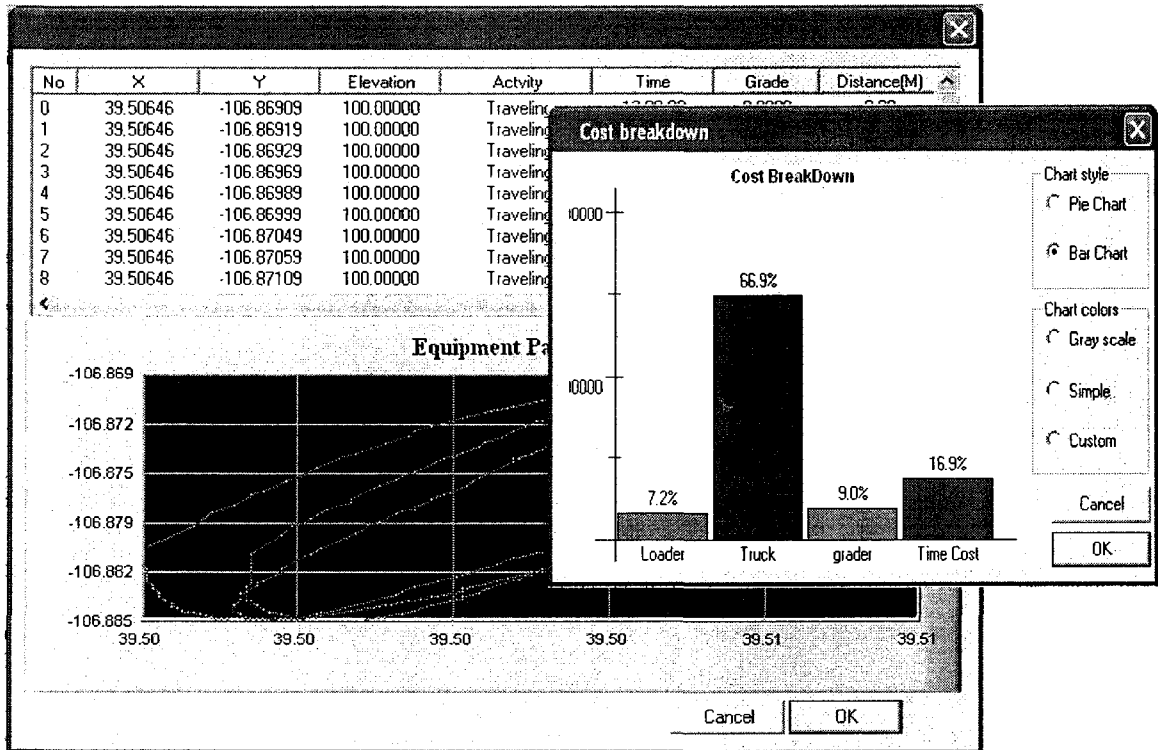


Figure 3-10: Tabular and graphical reports in planning phase

3.9 Summary

In this chapter, the main modules and essential features of the developed model were described. The database module of the proposed model was discussed. The main elements of the database, optimization, and tracking and control modules were also presented. The model main components, its architecture, and data flow are also described. The various reporting formats generated by the reporting module were also presented.

Chapter 4: Optimization Module

4.1 Introduction

Optimizing earthmoving operations poses a major challenge to engineers and contractors. This challenge is demonstrated by two main tasks as stated by Marzouk (2002). The first is to satisfy all the constraints that are imposed by specific site and job conditions, project budget and time, and equipment availability. The second task is to select the best crew formations that can satisfy all the constraints. As cited in Chapter 2, to assist engineers and contractors in carrying out these challenging tasks, various models have been developed using different techniques. Marzouk (2002) stated that these models do not adequately: (1) consider the interaction among the individual pieces of equipment in a fleet, as in the case of Fleet Production and Cost Analysis (FPC) software (Caterpillar Inc. 1998); (2) evaluate, concurrently, different fleet scenarios and provide reliable estimates of haulers' travel time, as in the case of MicroCYCLONE (Halpin and Riggs 1992). In addition these models do not: (3) dynamically reconfigure crew formations as site operations progress; and (4) consider multi-borrow pits and landfill sites, as in the case of Marzouk (2002). The use of simulation in optimizing earthmoving operations is still limited in construction industry as stated in Chapter 2.

This chapter presents a newly developed methodology for optimizing earthmoving operations to address the above-stated limitations in current optimization models (Moselhi and Alshibani, 2007-a; Moselhi and Alshibani,

2007-c). The developed methodology utilizes genetic algorithms (GA), linear programming, and GIS to search for near-optimum crew formation and to select quantities of earth to be moved from different borrow pits and placed at different landfill sites to minimize either project time, project direct cost, or project total cost.

On one hand, a genetic algorithm has powerful computation utilities that speed up calculations. This is enhanced by employing the waiting time rule developed in this study (Section 4.7). GA has been used to generate different solutions (crew formations) and to estimate their fitness. On the other hand, linear programming runs are conducted for solutions (crews' configuration) that are generated by the genetic algorithm. GIS is used to feed the optimization module with the characteristics of the travel roads using the developed Pathfinder algorithm. The following sections describe in detail the developed module components, its computation process, and formulation.

4.2 Description of the developed Optimization Module

The module was developed to achieve the following objectives: (1) optimum use of available resources; (2) balanced use of resources throughout the project duration and/or its development stage; (3) selection of suitable equipment for the work at hand; (4) optimizing the earthmoving plan to minimize project direct cost, project total cost or project time; and (5) completion of projects with the least cost and within the given targeted project duration. The module is also capable of

generating crew formations to meet, as close as possible, specified time and/or cost constraints.

Unlike current optimization models, the developed module optimizes the use of resources available to contractors not only in the planning stage but also during construction, as form of corrective action, if there is any deviation from as planned. The module addresses two areas of concern in optimizing earthmoving operations (Son et al 2005): (1) quantities of earth to be moved and (2) distance of traveled road. It also accounts for: (1) resources available to contractors; (2) availability of different borrow pits and landfill sites, their respective capacities, and setup costs; (3) indirect project cost; (4) topography of traveled roads; (5) project budget and/or time; and (6) soil swell/shrinkage factors. The module is designed to incorporate four sub-modules: (1) database, (2) genetic algorithm, (3) linear programming, and (4) a GIS sub-module. Figure 4-1 depicts the main components of the module and the data flow among them.

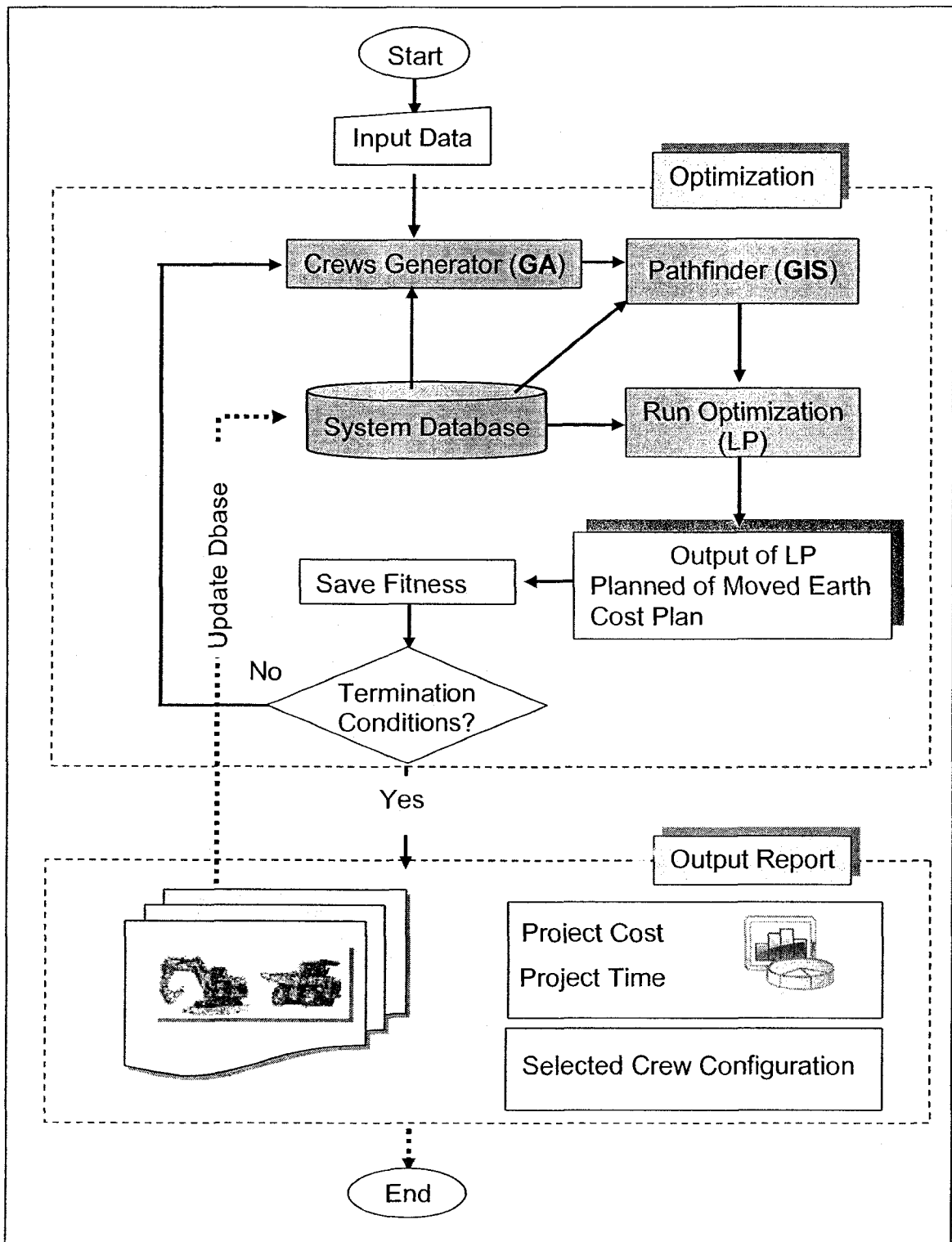


Figure 4-1: Main component of the optimization module

The module commences by accepting data from two sources. The first source is data entered by the user. This data includes project information such as scope of the work, indirect cost, the number of working hours per day, number of working days per month, and the user requirements for optimization, etc. The second source is data retrieved from the model's database. This includes equipment data and soil type data. The equipment data includes equipment hourly cost, its capacity, its maximum speed, etc. The soil data includes the shrinkage and swelling factors. Upon completion of the data entry, the optimization processes is carried out through six main phase, which are;

1. Generating different crew formations (initial solutions) using the genetic algorithm.
2. Estimating travel and return time of a hauling unit using the developed Pathfinder algorithm (Section 4.3)
3. Estimating crew productivity (Section 4.4)
4. Selecting quantities of earth to be moved from different borrow pits and placed at different landfill sites, based on the crew generated in phase 1, to meet the user's requirement for optimization using the developed linear programming sub-module.
5. Estimating crew fitness by the genetic algorithm (Section 4.9.1)
6. Selecting a near-optimum crew formation that satisfies the project constraints.

Phase 1: Generating Crew Formation

Generating crew formation (the initial population) is the first phase of optimizing earthmoving operations. The genetic algorithm sub-module generates crew formation based on user selection. Two pre-defined crew formations are available. The first consists of loaders, trucks, and other support equipment. The second crew consists of scrapers, pushers, and other support equipment. The module accounts for equipment availability to a contractor and its suitability to carry out the work at hand when generating crew formations.

In order to estimate the productivity of the generated crew (phase 1), the module estimates the travel and return time of a hauling unit in the generated crew using the developed Pathfinder Algorithm (Section 4.3). Estimating travel and return time accurately requires accounting for grade, rolling resistance, and acceleration. The grade resistance is determined based on data entered by the user if travel roads are defined by the user. However, if the user selects the use of a GIS map to define travel roads, the developed Pathfinder algorithm calculates grade resistance using spatial data (x , y , and z). The rolling resistance, on the other hand, is determined based on the user's entry data (tire penetration). Having determined the total resistance, the maximum speed can then be extracted from a tabular rim-pull chart that is available in the model's database, where charts for different trucks models are stored. To account for acceleration, the module, based on the grade resistance and the equipment motion, determines the speed factor as shown in Table 4.1. The travel and return speed are calculated by multiplying the maximum speed retrieved from the

performance chart by the speed factor obtained from Table 4.1. Knowing the length of the road segment and travel and return speed, travel and return time can be calculated. A detailed description of these calculations is presented in Section 4.3.

With the hauling time (travel and return time) of a hauling unit estimated in phase 2, the module then estimates the productivity of the crew generated in phase 1. The module calculates the productivity of loader(s) and truck(s) on the crew and the minimum productivity is selected. The data required for estimating productivity, such as equipment capacity, soil type, and job and management conditions are extracted from the system's database and from the user entry data. It is essential to note that the match between hauling and loading units is accounted for in estimating productivity by applying the waiting time rule developed in this study, as described in Section 4.7.

After estimating the crew productivity, the time required to finish the work at hand is determined, knowing the scope of the work. The unit cost of moving earth can then be calculated. The linear programming sub-module then is fired to determine the quantities of earth to be moved from different borrow pits and placed at different landfill sites so as minimize project cost or time. The module formulation is described in Section 4.9.

In order to evaluate the generated crew, its fitness must be estimated. Upon completing determination of the time required to complete the work and determination of the earth to be moved, the crew direct cost obtained from LP in

phase 4 is saved in the fitness function of GA, if the objective is to minimize project direct cost. The indirect cost is added as described in Section 4.9.1.3, if the objective is to minimize total cost.

Phase 6: Selecting Best Crew Formation

Selecting the near optimum crew formation is the last phase conducted in the developed module and it is provided from GA.

4.3 Pathfinder Algorithm

In optimizing earthmoving operations, construction site conditions, travel roads' topography, and surface conditions are key elements. They have great impact on hauling speed and therefore on crew productivity and construction cost and time. In the current practice of optimizing earthmoving operations (transportation problem), the unit cost is estimated based on engineers' experience. This estimation can lead to a wrong result since the unit cost should be determined based on the time required to transport a unit quantity of earth from borrow pit to landfill.

In addition, selection of the optimal travel roads increases crew productivity and consequently minimizes construction total cost. The optimal travel road is defined as the road that offers the shortest travel and return time. Estimating the travel and return time of hauling units is a vital for production estimate in planning and during construction (Marzouk and Moselhi 2004). In the planning phase, travel and return time is initially estimated as part of project planning and cost estimates needed for bid preparation (Kannan 1999). During construction,

estimation of travel time is required to estimate onsite productivity, report project progress, and forecast project time and cost at completion.

Formerly, the travel and return time of a hauling unit is determined based on the use of manual methods, which involves the use of equipment performance charts. Using this method requires engineers to collect the equipment and project information needed for calculating travel and return time. This information includes equipment mechanical specifications, maximum allowable speed, soil type, and road surface conditions. Equipment manufacturers provide information about equipment in handbooks that include rim-pull curves and operating weight. The user then must use this information, along with travel roads information, to calculate truck speed, which is then used to calculate travel and return time under loaded and unloaded conditions. The manual methods are time consuming, especially for large projects with many travel roads containing many segments with different grade resistance. In addition, manual methods are not accurate because they do not account for acceleration, but rather they are based on theoretical maximum direct speed values. These charts, however, cannot be directly used for road profiles with road segments that have different total resistance (Marzouk and Moselhi 2004).

Recognizing the limitations of manual methods, equipment manufacturers developed computer programs to analyze the performance of construction equipment (Kannan 1999). These programs have been developed to perform essentially the same calculations as manual methods, but at a more detailed level. Equipment mechanical specifications and project conditions are input data

for these computer programs, which have equipment databases to assist the user. In addition to manufacturers' software, others have developed computational model using different techniques such as fuzzy clustering (Marzouk and Moselhi 2004).

The "Pathfinder" algorithm has been developed in order to estimate travel time and select near optimum path that connects different borrow pits and landfill sites. The algorithm uses GIS mapping data, tabular versions of the performance charts, and average speed factors as an alternative approach to estimate travel and return time. The algorithm accounts for factors that influence the travel and return time of hauling unit such as: (1) maximum allowable speed; (2) length of road segment; (3) total resistance (grade + rolling resistance); (4) travel acceleration; and (5) a hauler's model.

The algorithm developed here has been designed to integrate with the optimization module to select the near-optimum crew formation. The algorithm mainly feeds the optimization module with the travel and return time required to estimate crew productivity as described in Section 4.4. The "Pathfinder" algorithm has many interesting features including: (1) it can easily be used in large and complex projects; (2) it allows the user to draw various travel roads directly into the GIS map using the developed drawing tools; (3) it allows for testing and analyzing many travel roads; and (4) it offers graphical visualization of travel roads.

As depicted in Figure 4-2, the developed algorithm estimates travel time and return time, and selects the near-optimum path by taking the following steps:

1. The pathfinder algorithm starts by prompting the user to define the available paths (travel roads) that connect borrow pits and landfill sites interactively; using drawing tools (see Figure 4-3).
2. The algorithm next retrieves the position data (longitude, latitude, and altitude) of travel roads from the GIS map.
3. The algorithm then finds the relation between longitude and latitude with altitude (profile of road) to determine gradient resistance for each segment in the road under consideration.
4. The algorithm subsequently retrieves the mechanical specifications of the hauling unit (i.e. equipment weight, maximum speed) and soil type from the system's database to calculate the rolling resistance for that unit using the following Equation:

$$RR = (40 + (30 \times TP)) \times GVW \quad (4.1)$$

where,

RR : Rolling resistance in pounds.

TP : Tire penetration in inches; depends on soil type entered by the user and is measured in inches.

GVW: Gross vehicle weight in tons retrieved from the system's database. Note that the rolling resistance can be directly entered by the user

5. Having calculated the total resistance (rolling resistance + gradient resistance); the algorithm then obtains the maximum speed in each road segment from the tabular performance charts. It should be noted that the weight of an empty truck is used in determining the maximum return speed and the truck gross weight is used in determining the maximum travel speed.
6. To account for acceleration and deceleration, maximum truck speed, obtained from the tabular performance chart, is multiplied by the appropriate average speed factor shown in Table 4.1. The average speed factor depends on the segment length and grade, and whether the hauling unit is in motion or it moves from a stop.
7. The algorithm compares the calculated speed with allowable speed. If the allowable speed is greater than the calculated, the calculated speed is used; otherwise, the allowable speed is used to determine travel time.
8. The travel and return times are determined knowing the segment length and the truck speed.
9. Steps 2 to 8 are repeated until all the available roads are analyzed.
10. Based on the travel and return time, the optimum road is selected.

Table 4.1: Average speed factor (Source: adapted from Bishop, 1968, Table 9.2-2:574)

Length of haul road section (ft)	Unit start from stop			Unit in motion when entering section		
	Grade			Grade		
	+	0	-	+	0	-
0-350	0.25	0.38	0.50	0.50	1.25	2.00
351-750	0.35	0.48	0.60	0.60	0.68	0.75
751-1500	0.50	0.58	0.65	0.70	0.75	0.80
1501-2500	0.60	0.65	0.70	0.75	0.78	0.80
2501-3500	0.65	0.60	0.75	0.80	0.82	0.85
3501+	0.70	0.60	0.85	0.80	0.88	0.95

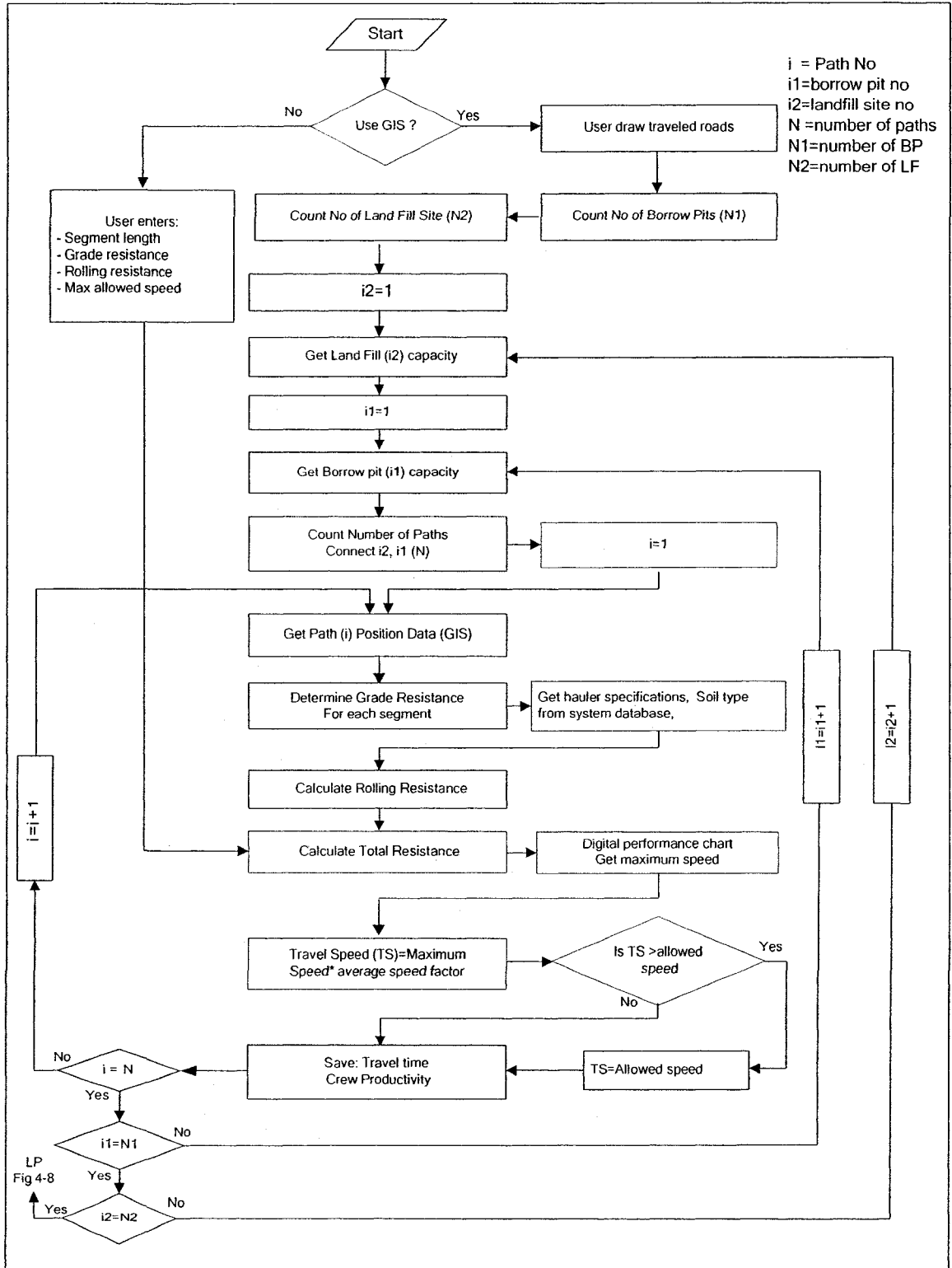


Figure 4-2: Estimating travel time using the Pathfinder Algorithm

To illustrate the benefits of using the Pathfinder algorithm in enhancing the developed optimization module for selecting the near-optimum travel road(s) and the near-optimum crew formation, a hypothetical example project was tested. The project involves moving 100,000 m³ (bank volume) of dry clay from a borrow pit located at different distances from the project site. The characteristics of the equipment available to the contractor are summarized in Table 4.2.

Table 4.2: Characteristics of available equipment

Loaders	
Model	CAT 994
Available Number	11
Bucket Capacity (m ³)	18.3
Hourly Owning & Operating Cost (\$/hr)	185
Haulers (Off- highway truck)	
Model	CAT 777D
Available Number	45
Hourly Owning & Operating Cost (\$/hr)	85
Capacity (m ³)	30

In this project, the site engineer was not sure about selecting the travel road that offers the shortest travel and return time. A site visit suggests that there are three roads which can be used to haul the excavated material. These roads have different distance and grade resistance. They have an average rolling resistance of 5%. In order to use the developed algorithm in selecting the near-optimum travel road, the user has to use the developed drawing tools to define the available roads, as described in Figure 4-3. To decrease the amount of data stored and analyzed, the user selects 'point object' to draw the roads. Five different types of information have been stored for each traveled road as

database files. These are path name, rolling resistance, X, Y, and Z coordinates.

A sample of the coordinate data of these roads is presented in Table 4.3.

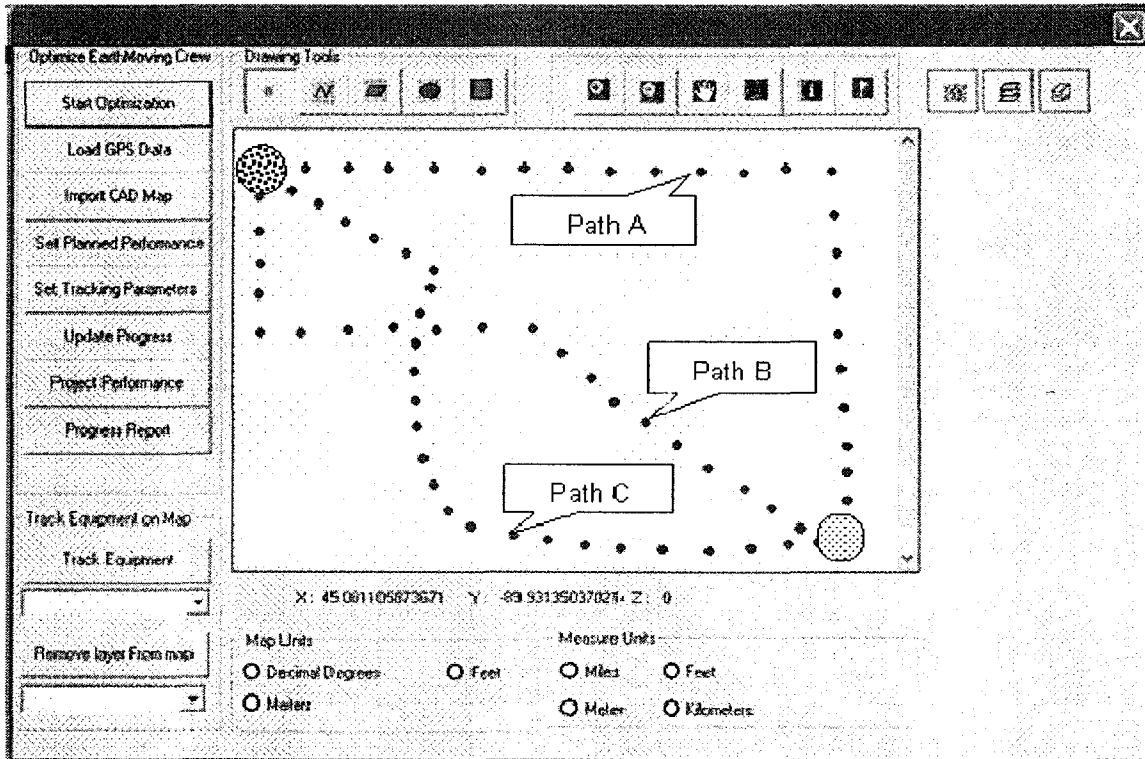


Figure 4-3: Dialog windows of the developed algorithm

Table 4.3: Sample of coordinate's data of traveled roads

Path Name	X	Y	Z	Path Name	X	Y	Z
Path-A	45.04935	-89.9016	100	Path-B	45.07452	-89.9173	165
Path-A	45.05296	-89.9018	100	Path-B	45.07622	-89.919	170
Path-A	45.05626	-89.9018	100	Path-B	45.07856	-89.9206	175
Path-A	45.05923	-89.9018	100	Path-B	45.08089	-89.9222	165
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
Path-B	45.04925	-89.9017	100	Path-C	45.06263	-89.9252	145
Path-B	45.04946	-89.904	100	Path-C	45.0638	-89.9272	145
Path-B	45.04946	-89.9065	100	Path-C	45.0655	-89.9284	150
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-

Having drawn the travel roads on a GIS map is completed, the algorithm starts performing the steps described in Section 4.3 to determine travel and return time for each defined road. The algorithm first uses the coordinate data to determine the length of each segment “d” using Haversine’s Equation as described in Section 5.4.2. Next, the algorithm calculates the grade resistance for each road segment. The algorithm then uses a tabular equipment performance chart and the average speed factor to determine the speed, and then it determines travel and return speed and time. The total travel and return time are then estimated. The road with the shortest hauling time is considered the optimal choice. Table 4.4 represents a sample of travel and return speeds and times as determined by the developed algorithm. As shown in the screen printout (Figure 4-4), the algorithm has selected traveled road “Path-B” as the near-optimum road. Although path-B has different grade resistance along its segments (+3% to -9%), this path was selected since it offers the shortest travel and return time (30 minutes) to complete the entire trip. The length of this path is 6.19 km in one-way trips. Figures 4-5 and 4-6 represent the road profile and the calculated travel and return speed provided by the developed algorithm for Path-B and Path-C, respectively.

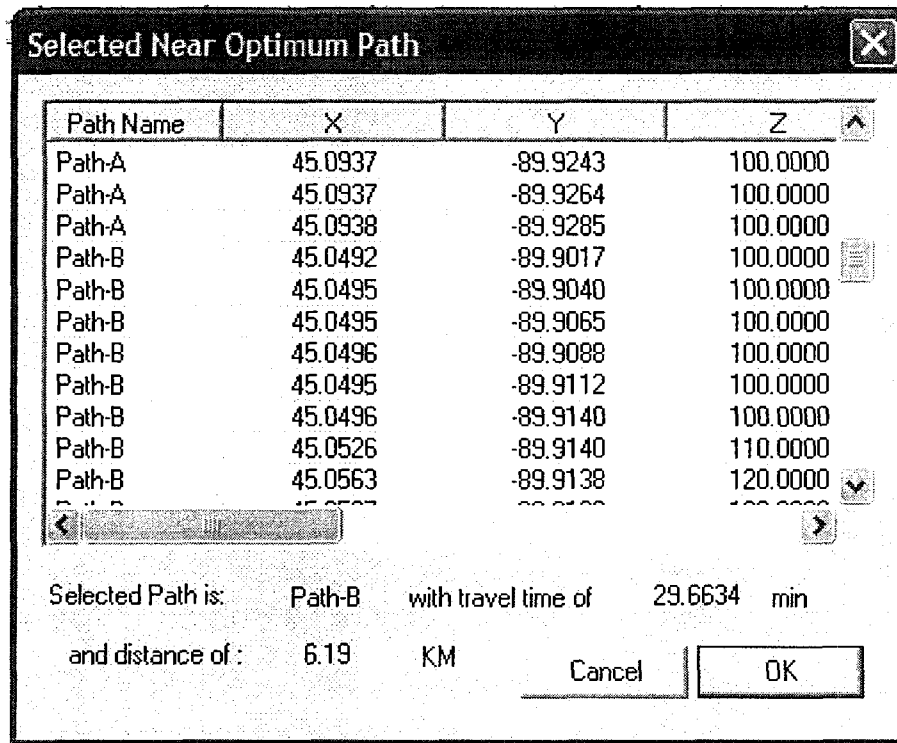
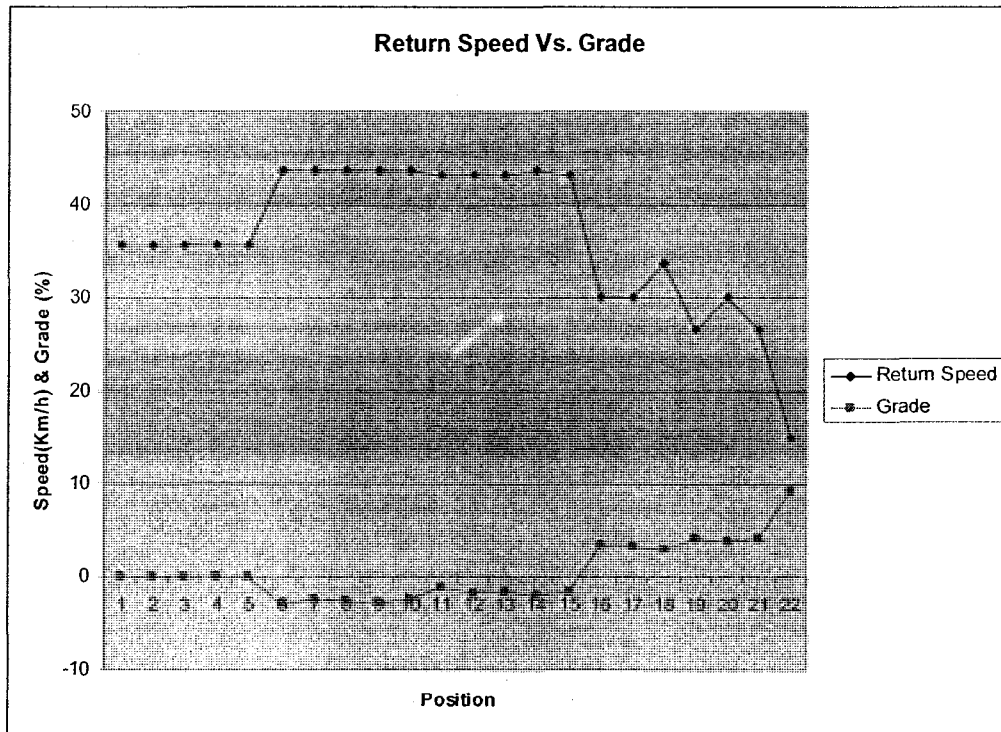
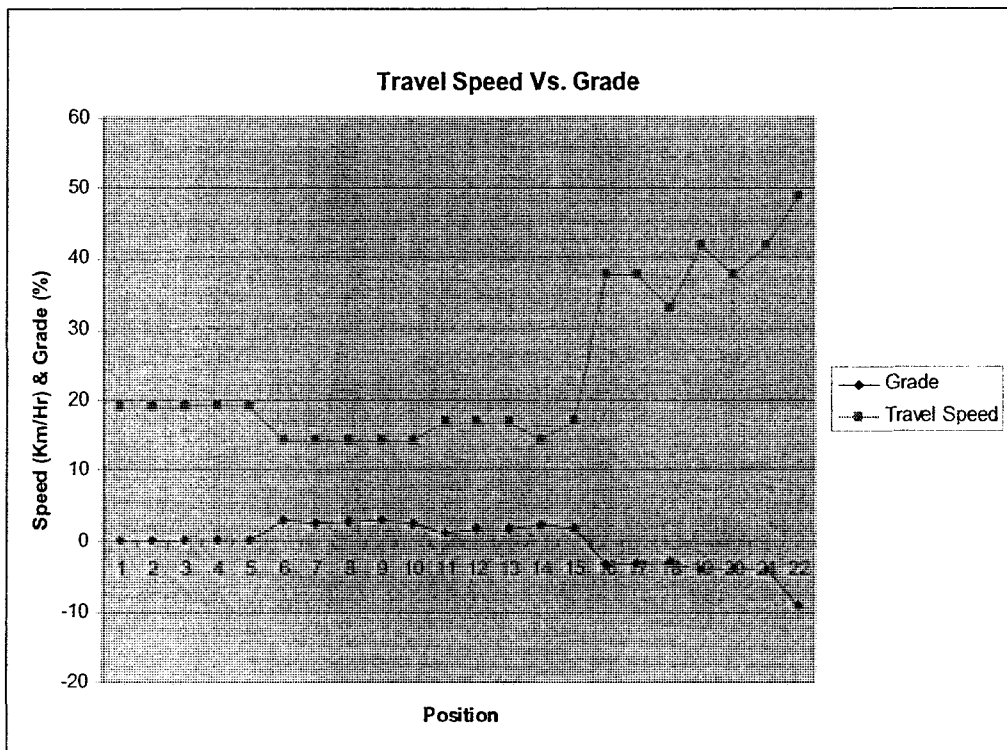


Figure 4-4: Output of Pathfinder Algorithm

Table 4.4: Sample of travel and return time determined by the developed algorithm

Path Name	D (M)	Grade (%)	T. Speed(Km/hr)	T. Time(Min)	R. Speed(Km/hr)	R. Time(Min)
Path-A	0	0.00	0.00	0.00	0.00	0.00
Path-A	401.827	0.00	21.00	1.15	39.225	0.61
Path-A	366.0557	0.00	21.00	1.05	39.225	0.56
-	-	-	-	-	-	-
-	-	-	-	-	-	-
-	-	-	-	-	-	-
Path-B	0	0.00	0.00	0.00	0.00	0.00
Path-B	176.7771	0.00	19.04	0.56	35.564	0.30
Path-B	200.2196	0.00	19.04	0.63	35.564	0.34
Path-B	183.9139	0.00	19.04	0.58	35.564	0.31
Path-B	183.9139	0.00	19.04	0.58	35.564	0.31
-	-	-	-	-	-	-
-	-	-	-	-	-	-
-	-	-	-	-	-	-
-	-	-	-	-	-	-
Path-C	267.4135	0.00	21.00	0.76	39.225	0.41
Path-C	272.8437	0.00	21.00	0.78	39.225	0.42
Path-C	245.6698	0.00	21.00	0.70	39.225	0.38
-	-	-	-	-	-	-
-	-	-	-	-	-	-
-	-	-	-	-	-	-



Travel road "Path-B"

Figure 4-5: Grade vs. speed (Path-B)

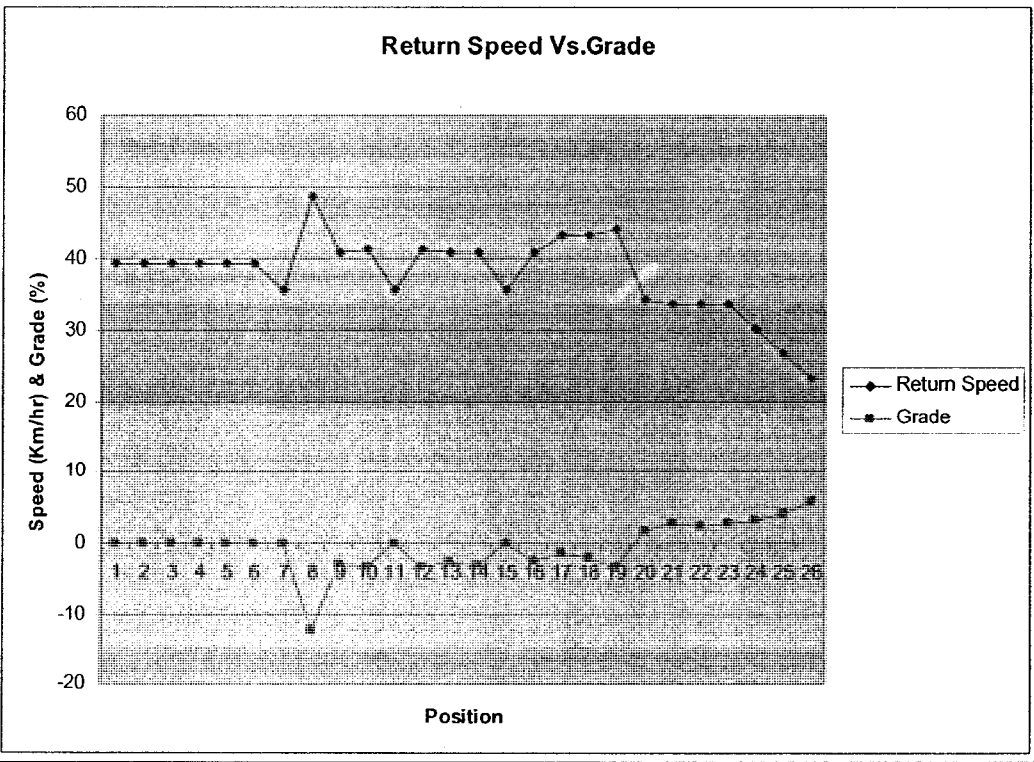
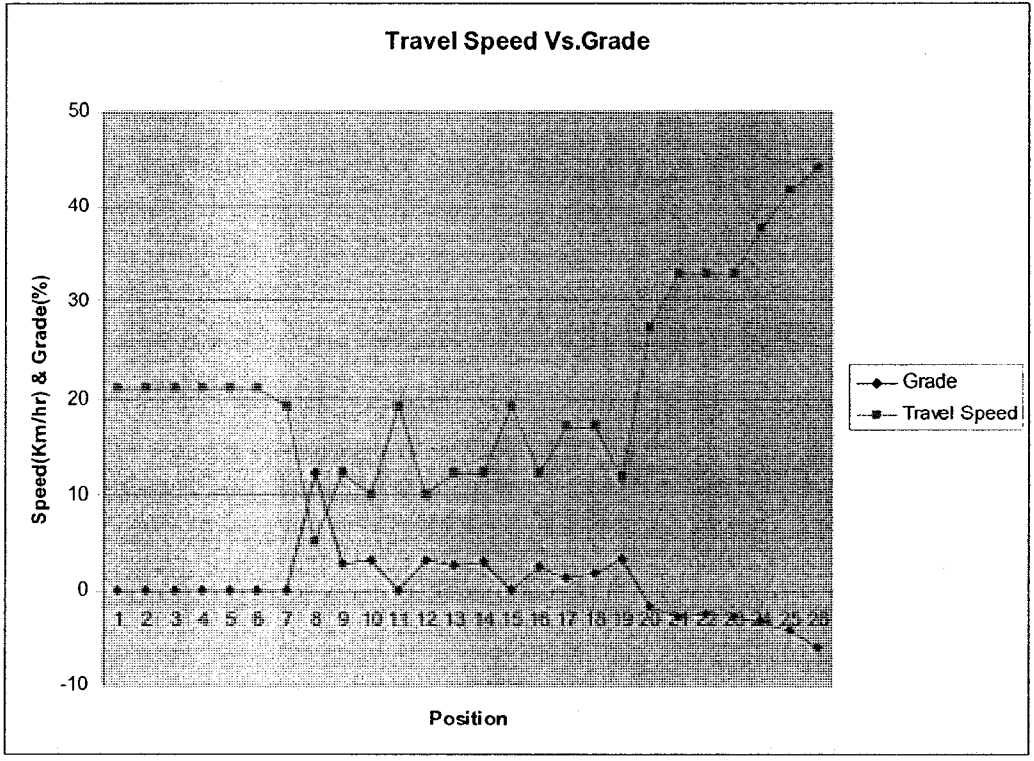


Figure 4-6: Grade vs. speed (Path-C)

4.4 Estimation of Crew Productivity

Estimating crew productivity is an important task in optimizing earthmoving operations in the planning stage. It requires accounting for factors that have a great impact on equipment productivity. These factors include weather conditions, road conditions, job and management conditions, operator skills, etc. The uncertainty associated with these factors makes productivity estimation a difficult task. Formerly, project managers relied on their expertise and historical data from similar projects when they estimated productivity. However, since every project is unique, assigning the same conditions to all projects may not be accurate in many cases. Estimating productivity has been the subject of much research in academia and industry. As described in Chapter 2, many models have been developed to estimate productivity using different techniques including traditional methods and artificial intelligent methods.

In order to estimate crew productivity in a simple and effective fashion, a deterministic method has been developed. This method utilizes the Pathfinder algorithm to estimate travel and return time as discussed earlier. As described in Section 4.3, having generated a crew's (scenario) by GA, crew productivity is estimated by taking the following steps:

1. The module first estimates the productivity of loading units in the generated crew (chromosome). The number of loaders in the crew is retrieved from the gene representing loading units. The data required for estimation is retrieved directly from the model's database and from information entered by the user. The data retrieved from the model's

database includes bucket capacity, soil data, etc. The data entered by the user includes management and job conditions.

2. Next, the module estimates the productivity of hauling units in the generated crew. The travel and return times needed for the calculation are determined as described in Section 4.3, using the Pathfinder algorithm, whereas dumping time is retrieved from the model's database. The number of trucks in the generated crew is retrieved from the gene representing hauling units. The data required for the estimation is retrieved directly from the model's database. This data includes truck capacity and soil data. If the generated crew consists of support equipment, their productivity is also estimated.
3. Upon estimating the productivity of the loading, hauling, and support units, if any, the module then determines the idle time resulting from any mismatch among them using waiting rule (Section 4.7).
4. The module compares the hauling, loading, and support units' productivity and takes the smallest productivity to control the crew's productivity.

After calculating the crew productivity, the module determines the time required to complete the work, knowing the scope of the work. Having calculated the time required, the project cost can then be determined. These steps are repeated until the termination conditions are met. Figure 4-7 depicts a flow chart for estimating productivity in the developed module.

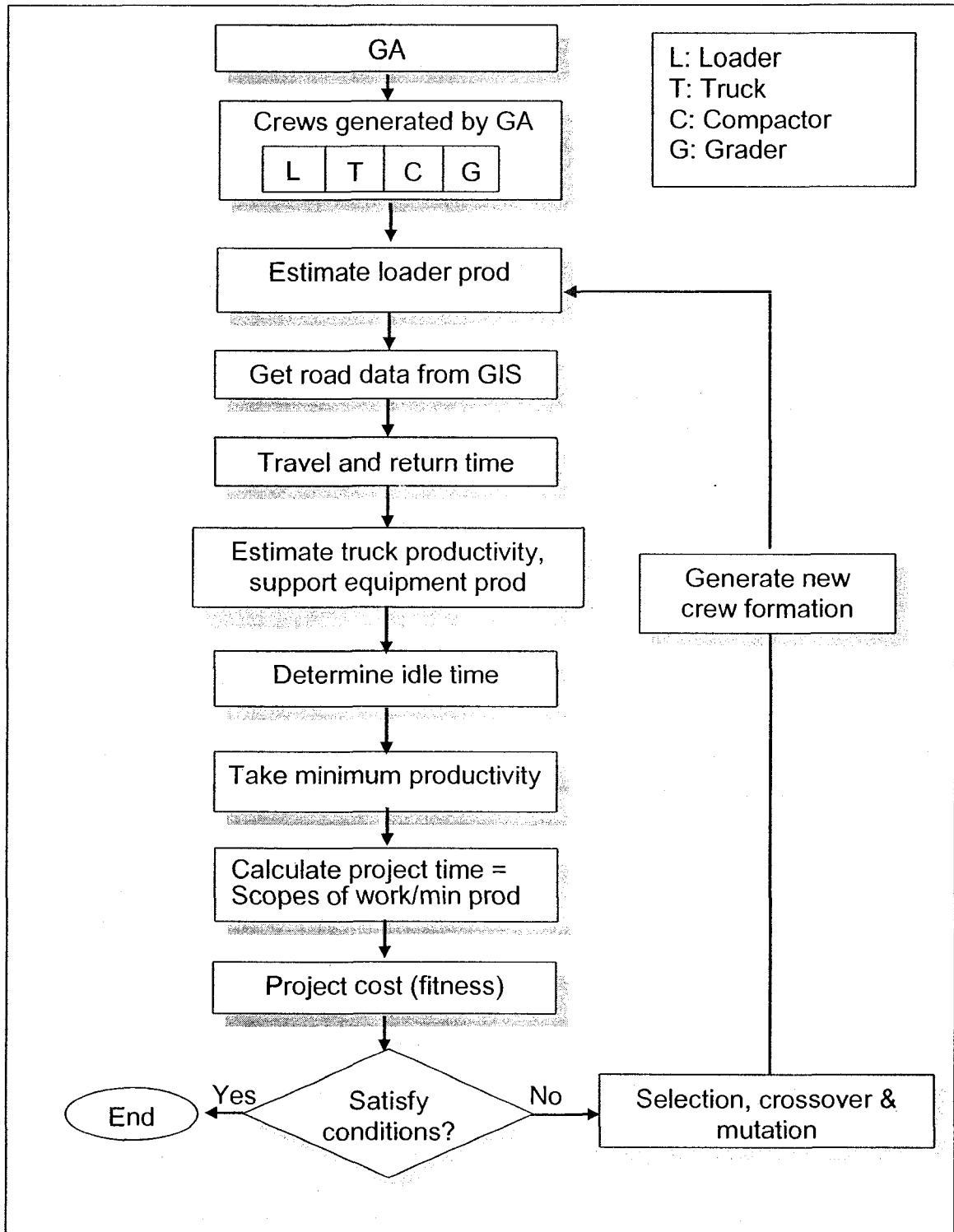


Figure 4-7: Productivity estimation

4.5 Genetic Algorithm

The developed optimization module has combined a genetic algorithm and linear programming to optimize earthmoving operations. Genetic algorithms resemble the biological evolution principle of survival of the fittest (Holland 1992, Coley 1999). They are adaptive heuristic search algorithms that can be used to solve optimization problems. They have been used in many areas of construction, such as bidding strategy (Moselhi and Hegazy 1994), time/cost trade-off (Hegazy 1999), project control (Hegazy and Petzold 2003), and optimizing earthmoving operations (Marzouk 2002).

4.5.1 Crew Representation

The genetic algorithm represents crew formations as chromosomes. The number of genes in the chromosome depends on the selection of a predefined crew formation. Two predefined crew formations are available. The first consists of loading units, hauling units, and other support equipment if required. The second predefined crew consists of scrapers, dozers, and other support equipment if required. If the user selects the first predefined crew formation, the chromosome consists of four genes. The first gene represents the number of loading units, the second represents the number of hauling units, and the third and fourth genes represent the number of secondary units, if any. If the user selects the second predefined crew formation, the chromosome in this case may consist of four genes. The first gene represents the number of scrapers, the second represents the number of dozers, and the third and fourth genes represent the number of secondary units, if any. The gene is dedicated to representing the number of

each type of equipment used in that crew scenario and it contains integer number data. The amount of equipment in each scenario represents the constraints of the resources available to the contractor in terms of equipment. The whole set of chromosomes considered here are referred to as a population. Figure 4-8 depicts the composition of the developed chromosomes for the predefined crew formations.

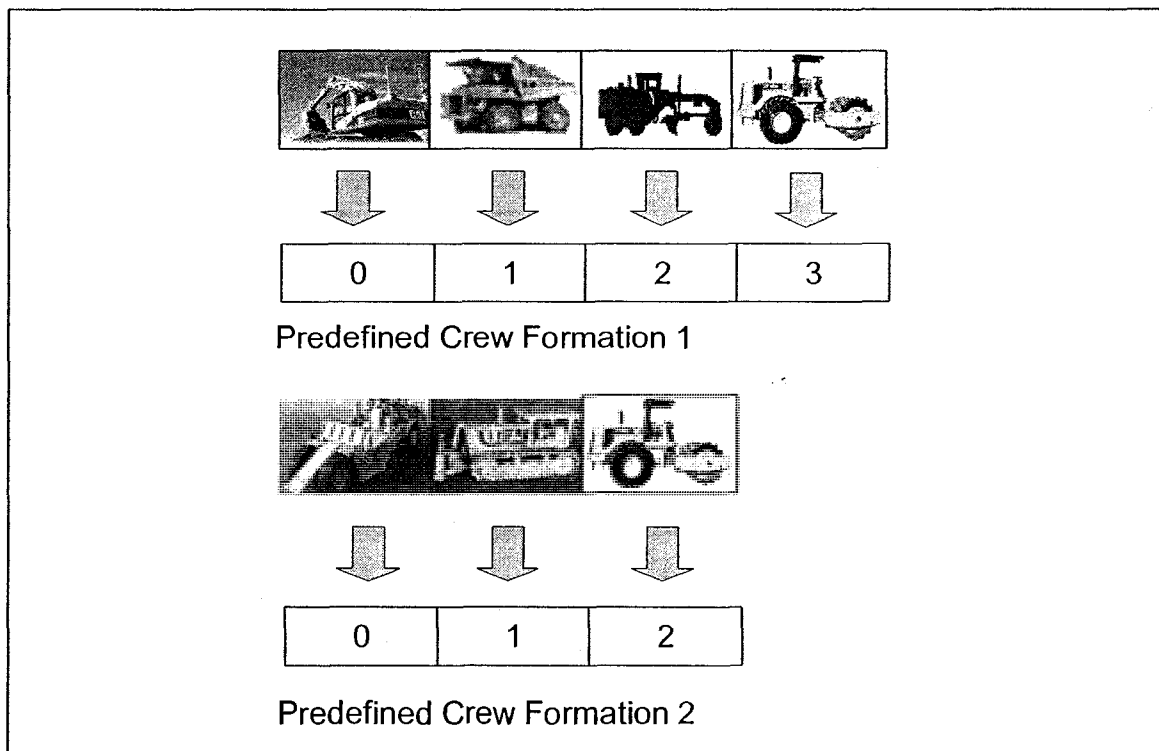


Figure 4-8: Developed chromosome

4.5.2 Genetic Operators

Populations and chromosomes (crew formations scenarios) are first generated and then tested for their respective fitness. The populations are generated by the use of a set of genetic operators such as selection, crossover, and mutation

(Holland, 1992). The selection process is carried out to choose a chromosome from the current generation's population for inclusion in the next generation's population. Before making it into the next generation's population, selected chromosomes may undergo crossover and/or mutation, in which the offspring chromosome(s) are actually the ones that make it into the next generation's population. The following is the selection function used in the developed optimization module. It randomly picks one of the chromosomes within the top 25% of the population.

```
Chromosome & mySelectionFunction(Population &population)
{
    // Sort chromosomes from best to worst
    population.sort();
    int lastIndex = (int) (0.25f * (population.getNumberOfChromosomes() - 1));
    return population.chromosomes(ga.randomInt(0, lastIndex));
}
```

Crossover is a basic operation in a genetic algorithm. It provides a means of exploring a new alternative in the solution space. In the developed module, the selected chromosomes can undergo crossover and/or mutation to produce a new chromosome (offspring). The crossover merges (mates) two chromosomes (parents) to produce a new chromosome (offspring) that may be better than both of the parents. Crossover occurs during evolution according to a user-definable crossover probability. This probability should usually be set high (0.9 is a good first choice). After selecting a pair of chromosomes (parents), the arithmetic

crossover operation is performed. It linearly combines two parent chromosomes' vectors to produce two new offspring according to the following Equations:

$$\text{Offspring 1} = X * \text{Parent 1} + (1 - X) * \text{Parent 2} \quad (4.2)$$

$$\text{Offspring 2} = (1 - X) * \text{Parent 1} + X * \text{Parent 2} \quad (4.3)$$

where,

X: a random weighting factor (chosen before each crossover operation).

Given that the chromosomes contain integer genes, these genes are rounded after the linear combination operation. Figure 4-9 presents the combination of two parents (each consisting of four integer genes), which have been selected for crossover.

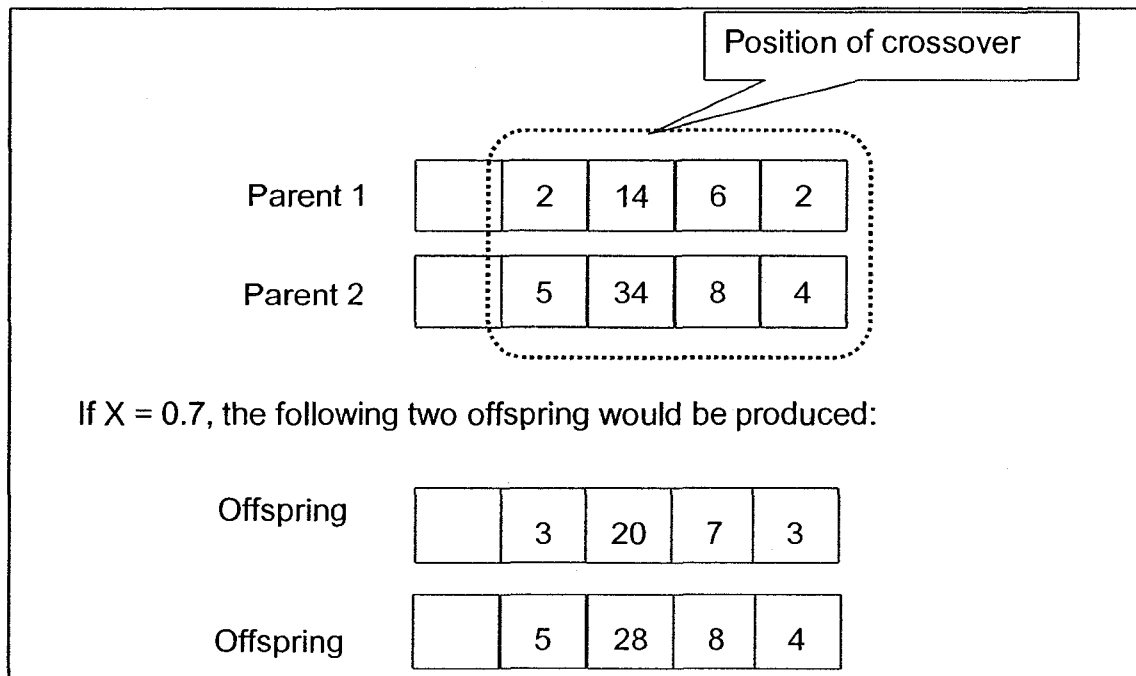


Figure 4-9: Arithmetic crossover process

The mutation process is carried out in an effort to avoid local minima after the creation of a new population. The mutation function adds Gaussian distributed random value to the gene located at a gene number. The new gene value is clipped if it does not fall between the user-specified boundaries (number of equipment available). It should be noted that the Gaussian distributed random value is rounded before being added. This can result in completely new gene values being added to the gene pool. With these new gene values, the genetic algorithm may be able to arrive at a better solution than was previously possible. Mutation occurs during evolution according to a user-definable mutation probability. This probability should usually be set low (0.01 is a good first choice). If it is set too high, the search will turn into a primitive random search. It should be noted that the mutation process applied to all the genes in the chromosomes representing the number of each type of equipment. Figure 4-10 depicts the Gaussian mutation process. The following is the mutation function used in the developed module.

```
void myMutationFunction(Chromosome &chromosome, int geneNumber)
{
    chromosome.genes(geneNumber).setValue(chromosome.genes(geneNumber).getValue()+
    roundFloat(ga.randomUnitGaussian()));
    // Clip if necessary
    If(chromosome.genes(geneNumber).getValue()>
    ga.geneDefinitions(geneNumber).upperBound)
    chromosome.genes(geneNumber).setValue(ga.geneDefinitions(geneNumber).upperBound);
```

```

if(chromosome.genes(geneNumber).getValue(<
ga.geneDefinitions(geneNumber).lowerBound)
chromosome.genes(geneNumber).setValue(ga.geneDefinitions(geneNumber).lowerBound
}

```

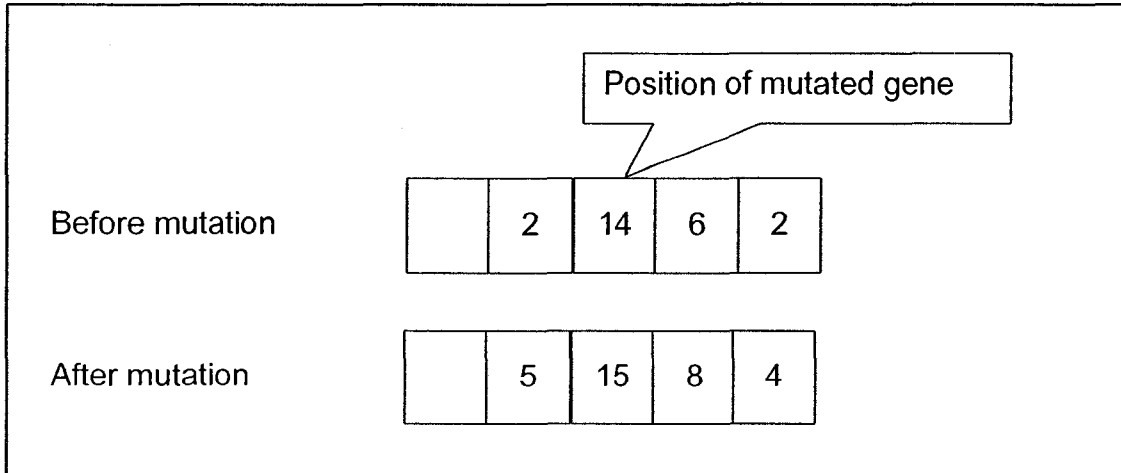


Figure 4-10: Gaussian mutation process

4.6 Computation Process

As shown in Figure 4-11, the optimization module optimizes crew formation and selects the quantities of earth to be moved from different borrow pits and placed them at different landfill sites, with the goal of minimizing project time, project direct cost or project total cost by performing the following steps:

1. The module starts by accepting data entered interactively by the user through a set of interface dialog windows. This data includes the scope of the work, daily and monthly working hours, daily indirect costs, soil type, capacity and setup cost of available borrows pits and landfill sites, and their respective distance to the contractor storage area.

2. Following completion of the data entry, the user selects a crew configuration from two predefined crews offered by the module.
3. After completing user data entry and selection, the module generates the initial population, based on the user's selection of a predefined crew formation, using the genetic algorithm sub-module.
4. The module then begins estimating the productivity of the generated crew. If the user selects to use GIS to define travel roads, the module estimates the travel and return times required to calculate crew productivity using the Pathfinder algorithm, taking into consideration the available travel roads that connect borrow pits and landfill sites. In this case, the travel and return times of the roads are determined as described in Section 4.3. The algorithm then selects the road that offers the shortest travel and return times. It should be noted that the travel time is calculated based on the topography of travel roads, thus introducing an improvement to the current module in estimating hauling units' cost. The data required for these calculations is directly retrieved from the central database (e.g., equipment hourly cost, capacity, and speed, soil type, etc) and GIS position data (X, Y, Z coordinate). If the user selects not to use the GIS, then the user is required to enter all the travel road data via dialog windows. The entered data includes number and length of segments, gradient resistance, rolling resistance, and maximum speed allowable.

5. Having estimated the travel and return times, crew productivity is determined and the time required to carry out the work at hand is calculated knowing the scope of work as described in Section 4.4.
6. Subsequent to calculating the duration of the project, the unit cost of excavation, haul, and compaction is determined for the crew under consideration as described in Section 4.8.
7. After calculating the project duration and unit cost, the linear program sub-module is activated. It determines the quantities of earth to be moved from different borrow pits and placed them at different landfill sites so as meet the optimization objective set by the user and satisfy project constraints. These constraints include the capacities of borrow pits, the earth required at landfills sites, the equipment available to the contractor, and budget and/or time if applicable. Project constraints are described in Section 4.10.
8. The output of the objective function of the linear programming sub-module is then fed to fitness function of the genetic algorithm to evaluate fitness. After evaluating the fitness of all of the chromosomes in the first population, the chromosome (crew) with the best fitness is saved.
9. While the module searches for a solution, the three main genetic operations are conducted.
10. After performing genetic operations, a new crew is generated. The new crew formation is then evaluated (steps 4 to 9). This process is

repeated in the search for a near-optimum crew formation until one of the following user specified termination conditions are reached:

- Number of Generations
- Evolution Time (processing time)
- Fitness Threshold value

11. Having identified the best available crew formation, the module then updates the resource database and the project baseline is generated.

Figure 4-12 depicts the fitness evaluation of the generated crew. It also represents the integration of the linear programming sub-module with that of the genetic algorithm.

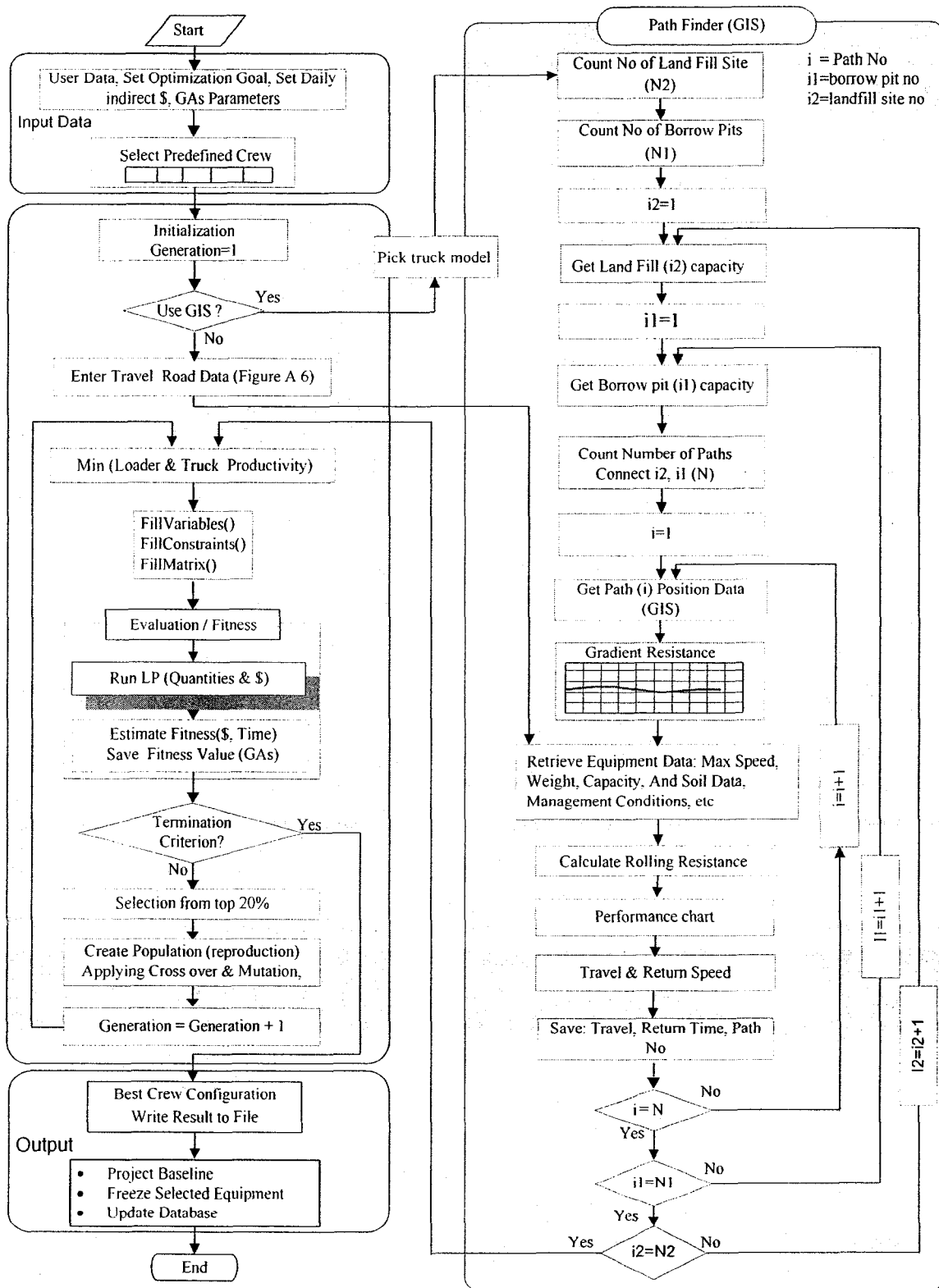


Figure 4-11: Computational process of developed module

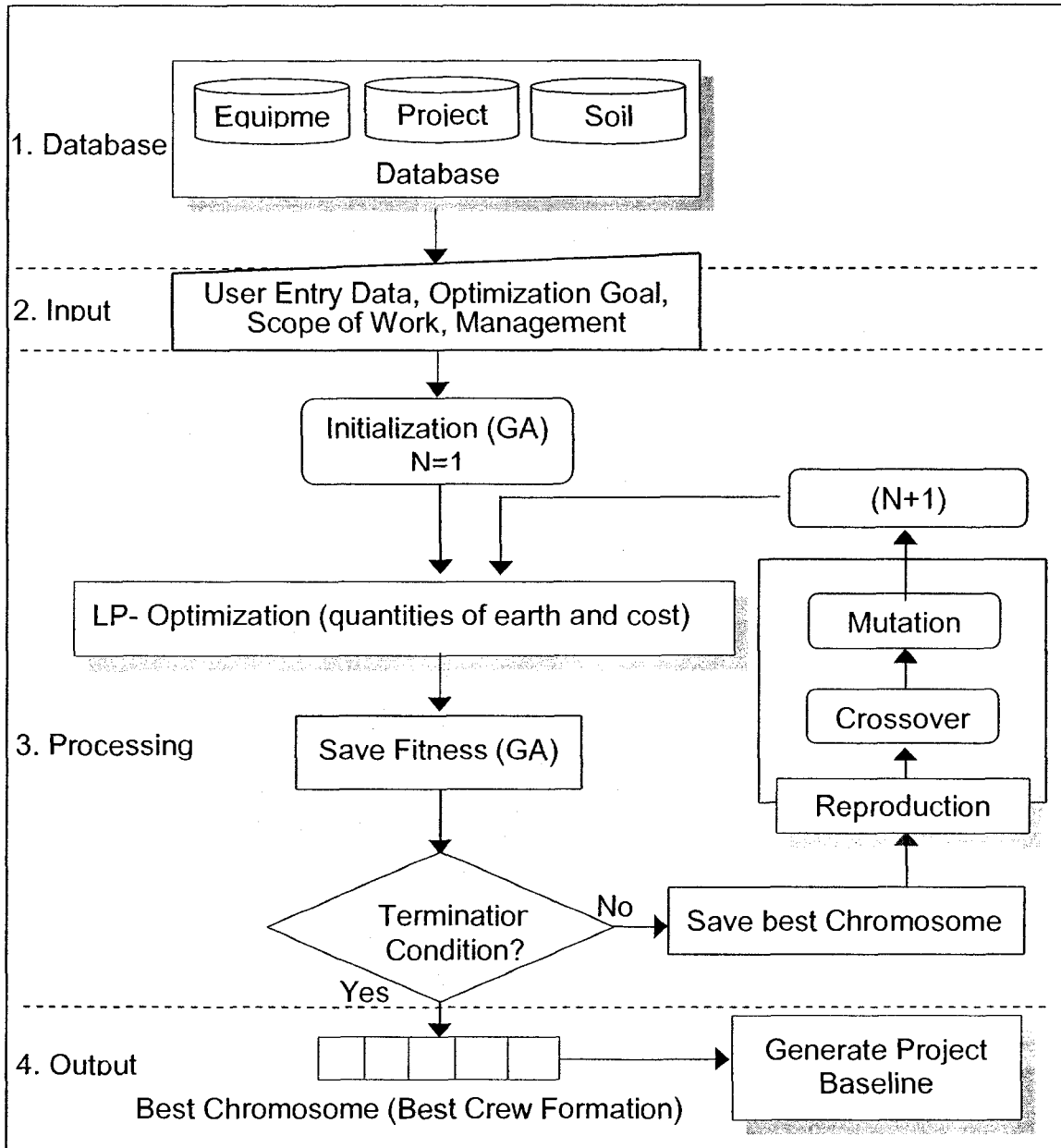


Figure 4-12: Flow chart for fitness estimation

4.7 Satisfying a Specified Budgetary and/or Time Constraint

In order to increase the practicality of the developed optimization module, a provision is made to enable selecting crew formation to meet specified budget and/or time constraints. This task can be encountered in the initial planning stage and during construction of the project. During the construction stage, this is

carried out in an effort to support the generation of likely corrective action(s) when there has been unacceptable deviation in the actual performance from what was planned.

Configuring crew formation to satisfy a specified deadline and/or budget is an iterative process. The formulation described above is repeatedly applied to the work at hand. In this case, the module sets the objective function in the genetic algorithm into the deadline or budget, based on the optimization goal set by the user. On one hand, in the planning phase, if the objective is to minimize construction cost, the objective function is set to the budget value. If the optimization goal is to minimize construction time, the objective function is set to the project deadline. On the other hand, during construction, this optimization is carried out in an effort to support the generation of likely corrective action(s) when there is unacceptable deviation in actual performance from that planned. In this case, the hauling time is calculated based on data collected by GPS receiver units as described in Chapter 5. The module considers the remaining cost to completion as constraint. It sets the fitness function of the GA to the value of the remaining cost to completion so that the module selects a crew formation that will meet this project constraint.

Since precise constraints cannot be always satisfied with this form of optimization problem, the module can configure crews to meet the constraints within a specified cost or time range. If no appropriate crew formation is found, based on the available resources, the module reports this finding so that other options can be considered, such as renting additional equipment. The termination type in this

case is "Fitness Threshold". Figure 4-13 represents the main steps carried out to optimize crew formation during construction.

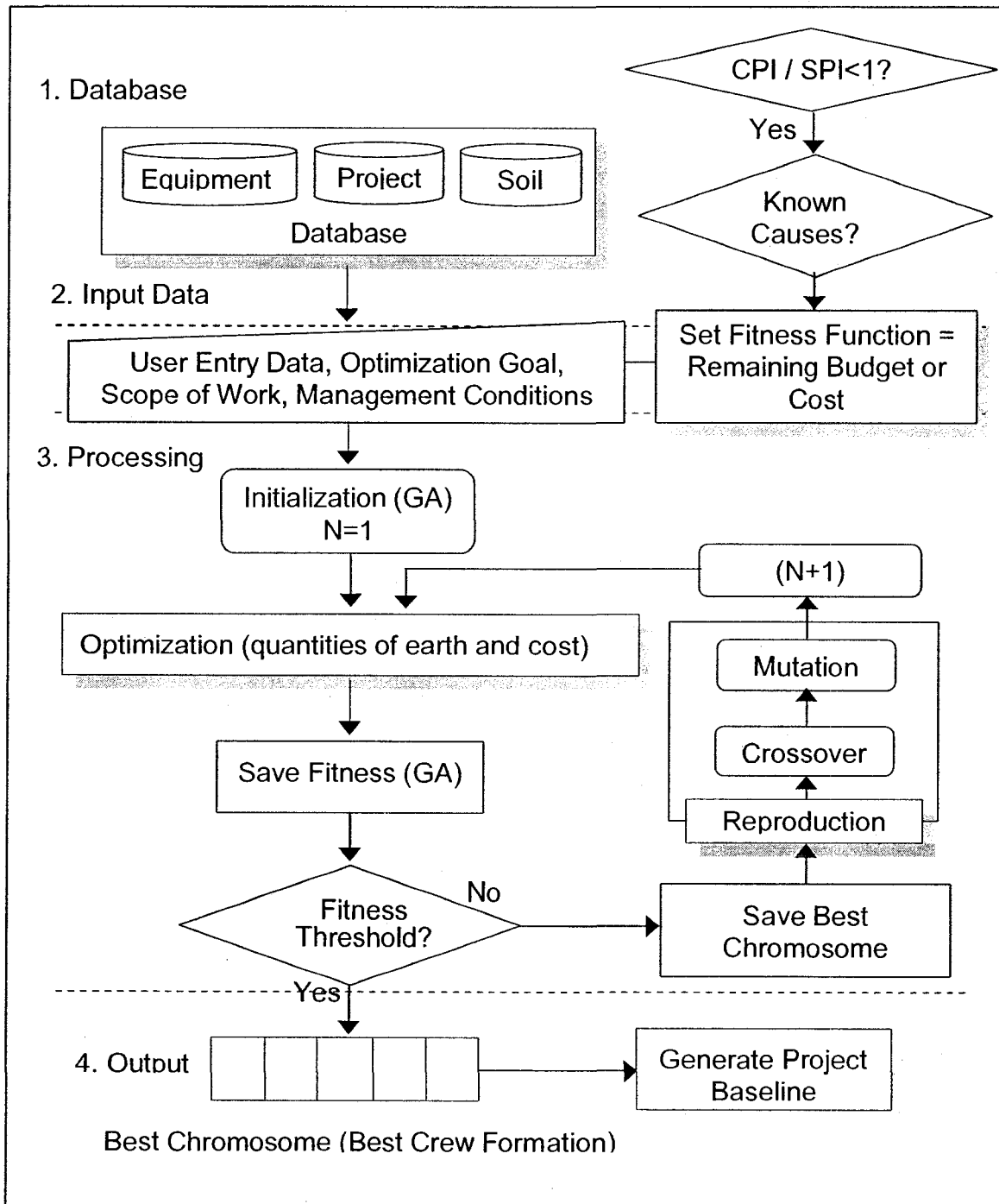


Figure 4-13: Crew optimization module during construction phase

It has been found that using the genetic algorithm as originally introduced to solve this form of optimization problem can lead to an unrealistic solution; therefore, a new rule has been developed. This rule, called the waiting time rule, was developed in an effort to speed up the optimization process and to avoid generating and evaluating hypothetical and unrealistic crew formations. It helps the genetic algorithm to select crew formations in which the number of servers adequately matches the number of customers and vice versa. The value of the waiting time is used to evaluate the fitness and not to calculate the project time. It is calculated as follows:

$$X = ((LP \times NL / TP) - NT) \times LT \quad (4.4)$$

where,

X: Loader waiting time

LP: Loader productivity

NL: Number of loaders in the generated crew

TP: Truck productivity

NT: Number of Trucks in the generated crew

LT: Truck loading time

The closer the waiting time is to zero; the better the match between the servers (Loading units) and the customers (Hauling units). To illustrate the impact of server waiting time on genetic algorithms in selecting near optimum crew formations to minimize construction time, a hypothetical project is considered, as described in Table 4.5.

Table 4.5: Example project

Working hours / day	8 hrs
Schedule days / month	22 days
Soil classification	Dry Clay
Scope of work	10000 m ³
Mobilization cost /day	\$1000
Operation cost/day	\$1000
Field expenses cost / day	\$1000
Optimization goal	Minimize Construction Time
Job and management conditions	Good
Weather conditions	Good
No of travel and return segments	1
Travel speed	30 km/hr
Return speed	40 km /hr
Segment length	10000 m
No of available trucks – model (725)	1
No of available loaders – model (914G)	1000

Applying the genetic algorithms as originally introduced, a crew of one articulated truck and 491 wheel loaders is selected, which is unacceptable (see Figure 4-14). However, when applying the server waiting time rule, the module yields a crew of one articulated truck and one wheel loader. The second result is more acceptable and logical (see Figure 4-15), because adding additional loaders (up to 1000) is not going to increase crew productivity; therefore, the time required to carry out the job is still the same. Since the objective is to minimize construction time, this crew is theoretically correct and can be selected by GA.

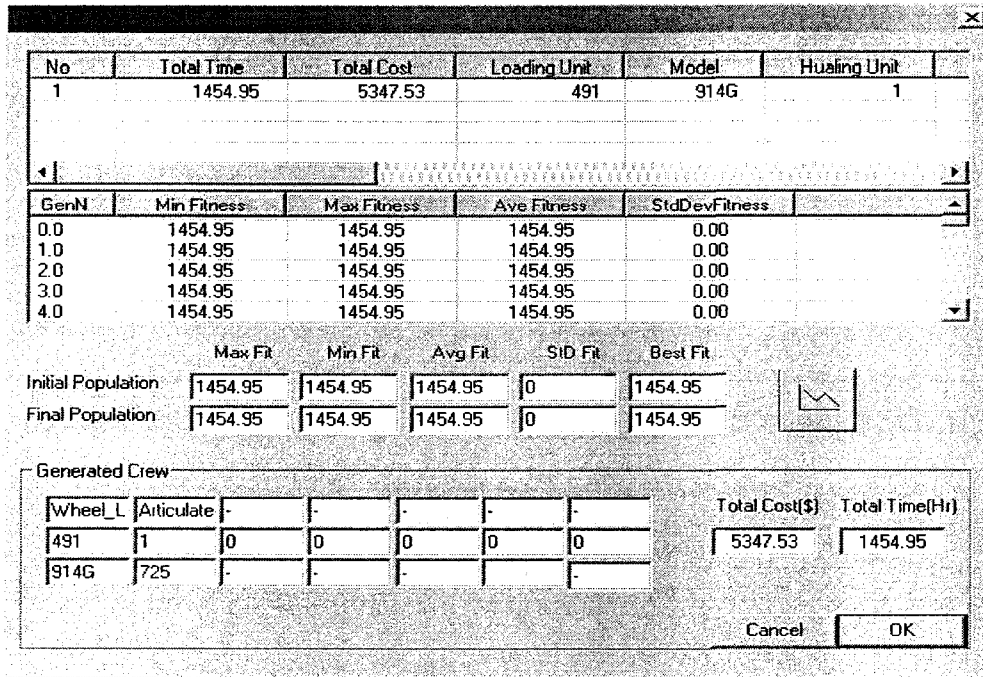


Figure 4-14: Crew formation without using the waiting time rule

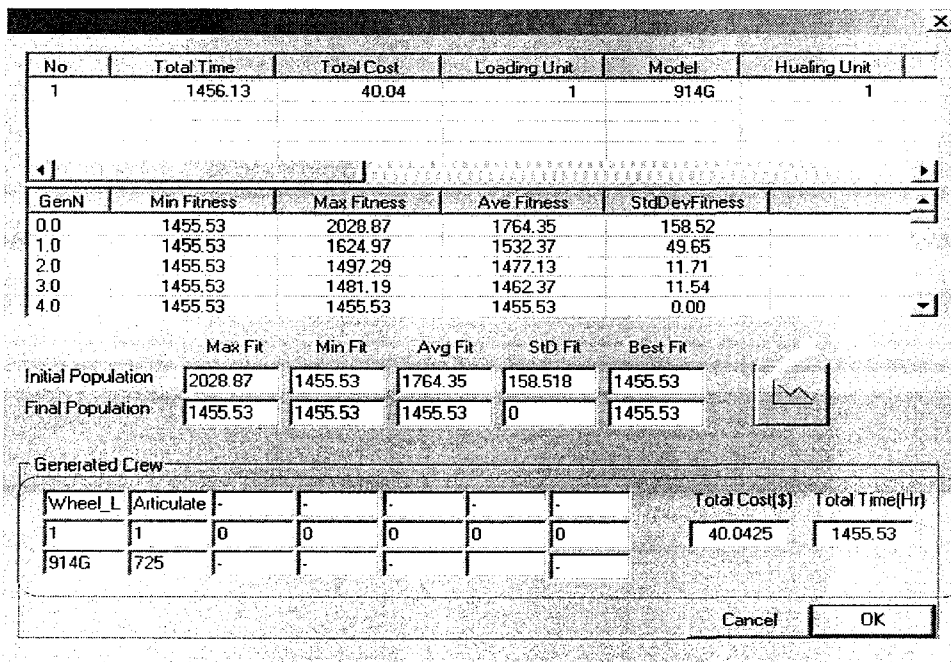


Figure 4-15: Crew formation using the waiting time rule

4.8 Cost Representation

The developed module accounts for direct, indirect, site and equipment setup costs and equipment float costs as decision variables in optimizing earthmoving operations. The procedure employed for computing these costs is outlined below:

In general, earthmoving operations involve three cost categories. They are: (1) excavation and loading, (2) hauling, (3) setup cost, and (4) placement and compaction. Clearly, the first and last cost categories are functions of the quantities of earth to be moved and compacted. The hauling cost, however, is proportional not only to the quantity of earthworks as in earlier models, but it also depends on the topography of the travel roads. The setup cost depends on associated costs such as: (1) land acquisition, (2) site preparation for excavation and/or dumping, (3) construction and maintenance of access roads, and (4) refurbishing and cleanup of the borrow pits and landfill sites. Figure 4-16 represents a flow chart of total project cost.

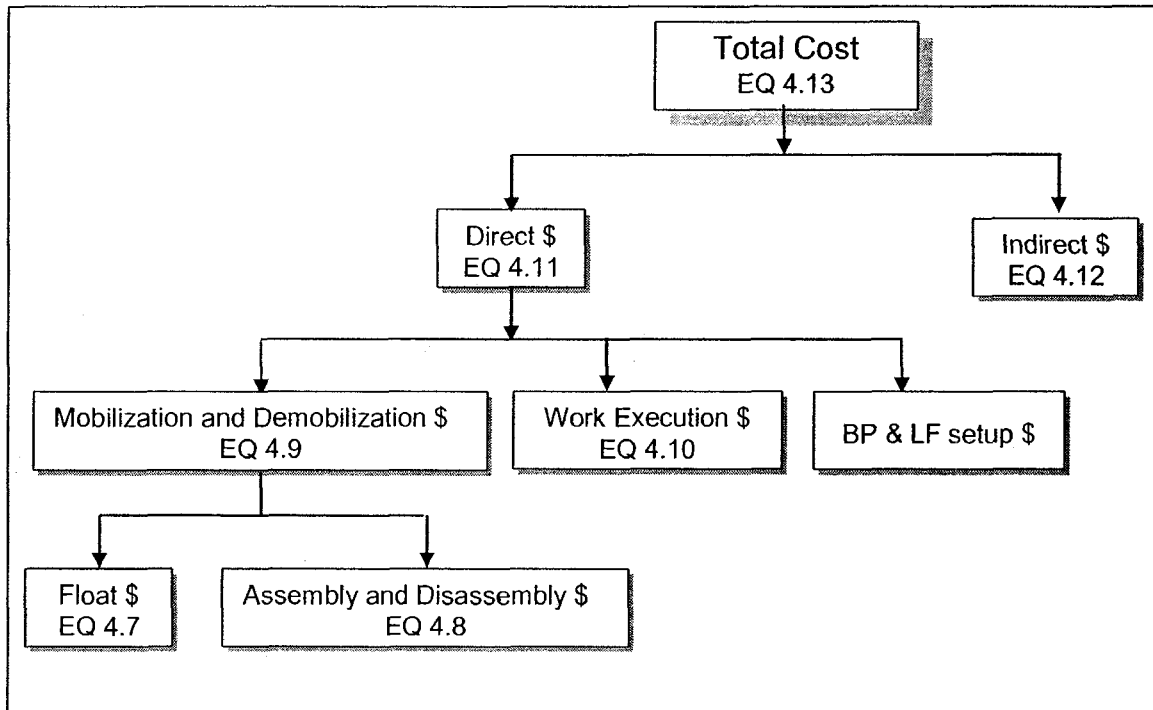


Figure 4-16: Total project cost

Earthmoving operations' direct costs includes: (1) mobilization and demobilization costs of the equipment involved; (2) the cost arising from executing the work at hand; and (3) the setup cost of borrow pits and landfill sites. The mobilization and demobilization costs are those required for mobilizing crew equipment from the contractor's storage area to the project site and back. It includes float cost, if any, assembly and disassembly equipment cost, if any, and time costs incurred due to the equipment remaining idle during the mobilization process. It should be noted that mobilization and demobilization cost was introduced by Hassanien (2002) for scheduling highway construction. They have been adopted in this study after modifications were introduced.

Mobilization and demobilization has a significant affect on the project cost and directly impact the optimization process, particularly on the presence of

obstructions, which divide the project into segments (Hassanien 2002). In order to estimate the total mobilization cost, the module retrieves related data for the equipment involved from the model's database. The retrieved data includes: (1) whether a float is required for transportation and its hourly float cost; (2) whether assembly and disassembly is required on-site and its hourly assembly and disassembly costs; and (3) travel speed on and off-highway.

If a float is required to transport a piece of equipment employed by a crew from the contractor's storage area to the project site or from one borrow pit to another, or from one landfill to another, the float cost can be calculated knowing the time required in that process.

$$T_f = 2 \times \frac{D_f}{V_f} \tag{4.5}$$

where,

T_f : Float time;

D_f : Distance from the contractor's storage area to the project site (considering all available borrow pits and landfill sites); and

V_f : Float travel speed (default = 70 Km/h).

Having calculated the float time, its corresponding cost C_f is expressed as:

$$C_f = T_f \times (RR_f + EHC) \tag{4.6}$$

where,

C_f : Float cost;

RR_f : Hourly rental rate of the float is stored in the model's database

EHC : Equipment hourly cost

The total float cost of transporting a crew composed of "N" equipment from a contractor's storage area to a specific location in the project site or vice versa can be expressed as:

$$TC_f = \sum_{i=1}^{i=N} C_f \quad (4.7)$$

where,

TC_f : Float cost incurred for crew composed of "N" equipment

N : Number of crew equipment items requiring a float for transportation

If setup and assembly of any equipment is required on site, then the cost incurred in assembly and disassembly is retrieved from the model's database.

For a crew composed of "N" pieces of equipment that require assembly on site, the total cost incurred for equipment assembly and disassembly is expressed as:

$$TC_{ad} = \sum_{i=1}^{i=N} (C_{a(i)} + C_{d(i)}) + (T_{a(i)} + T_{d(i)}) \times EHC_{(i)} \quad (4.8)$$

where,

TC_{ad} : Total assembly and disassembly cost for a crew

N : Total number of equipment items requiring on-site assembly

$C_{a(i)}$ and $C_{d(i)}$: Assembly and disassembly costs for equipment (i) of the crew, respectively;

$T_{a(i)} + T_{d(i)}$: Assembly and disassembly time for equipment (i) of the crew,
respectively

$EHC_{(i)}$: Hourly cost for the crew equipment (i)

The total cost incurred in mobilizing a crew is given by adding float and assembly and disassembly costs for mobilization to and from the project site and it can be expressed as follow:

$$C_m = TC_f + TC_{ad} \quad (4.9)$$

where,

C_m : Crew mobilization cost

The cost of executing the work is the equipment costs that arise from executing the work at hand. The duration required for any crew to carry out the work at hand is first estimated knowing the crew's productivity. The corresponding equipment cost is computed by multiplying its hourly cost by the duration (in working hours). It is expressed as:

$$C_c = \sum_{i=1}^t (EHC_i \times NE_i \times DUR) \quad (4.10)$$

where,

C_c : Crew work execution cost

EHC_i : Equipment hourly cost

NE_i : Number of pieces of equipment of the same type in the crew

DUR : Project duration (working hours)

The location and the number of borrow pits and landfill sites are not always fixed; contractors may have the option of selecting their respective number and locations. The selection, in this case, shall be governed by the project time and cost objective. The main question in such situation is how many borrow pits should be established and where to locate them. The landfill and borrow pits site setup costs are considered in the developed optimization module as a decision variable. Therefore, the project direct cost can be calculated by adding mobilization costs, crew work execution cost, and the setup cost of landfill and borrow pit sites. It can be expressed as follows:

$$C_d = C_m + C_c + C_s \quad (4.11)$$

where,

C_d : Project direct cost;

C_m : Crew mobilization cost as defined in Equation (4.9)

C_c : Crew execution cost as defined in Equation (4.10)

C_s : Setup cost of borrow pits and landfill sites

The proposed module here considers indirect cost as a per-day cost (\$/day). It can be expressed as:

$$C_i = DUR \times IND / WH \quad (4.12)$$

where,

C_i : Project indirect cost

DUR : Project duration in working hours

IND : Daily indirect cost (\$/day)

WH: Working hours per day

The total project cost can be expressed as:

$$C_t = C_d + C_i \quad (4.13)$$

where,

C_t : Project total cost

C_d : Project direct cost as defined in Equation (4.11)

C_i : Project indirect cost as defined in Equation (4.12).

4.9 Module Formulation

4.9.1 Estimating the Fitness of a Genetic Algorithm (GA)

As shown in Figures 4.11 and 4.12, the developed module combined GA and LP at GA fitness function. The main function of LP is to select quantities of earth to be moved from different borrow pits and placed at different landfill sites in order to meet the optimization objective. The main task of the fitness function of GA is to evaluate each individual (crew formation) in the population. The value of fitness reflects how optimal the solution is. The fitness function quantifies the optimality of a solution (chromosome) in a genetic algorithm. Upon completing the estimation of the hourly production rate of a crew under evaluation, the linear programming sub-module is activated. It finds a plan by which all the required earth at landfills sites is borrowed from different borrow pits meet the optimization objective taking into consideration the project constraints (Section 4.10). The

decision variables are the amounts of the cubic meters of earth to be transported from borrow pit to landfill.

If the objective is to minimize a project's total cost, the fitness function is calculated by adding the indirect cost to the direct cost. The direct cost is estimated based on the time required for the crew to complete the scope of the work. The equipment direct cost includes owning and operating costs, and equipment float and mobilization costs, if required. Indirect cost has two components: one is time dependent and the other is time independent. They include the user daily cost, if applicable, project mobilization and demobilization cost, and field expenses cost.

4.9.1.1 Minimizing Project Time

In this case, the module searches and selects the crew that minimizes the project time regardless of its associated cost, but a match between the loading and hauling units is still accounted for.

$$\text{Total_Time(Fitness)} = \sum_{i=1}^n \sum_{j=1}^m (Q(i,j)/\text{Prod}) + X \quad (4.14)$$

where,

Total_Time : Project total time

Q(i,j): Quantity to be moved from borrow pit (i) to landfill site (j)

Prod : Crew productivity

X : Server waiting time

4.9.1.2 Minimizing Project Direct Cost

In this case, the module searches and selects the crew that minimizes the project direct cost regardless of its indirect cost. The fitness function of GA is equalized to the LP output. The objective function of LP can be expressed as follows:

$$\text{Project Direct Cost(fitness)} = \sum_{i=1}^n \sum_{j=1}^m (C_d/Q)(i,j) \times Q(i,j) \quad (4.15)$$

where,

n : Number of available borrow pits

m: Number of landfill and disposal sites

Q(i,j): Quantities of earth to be moved from borrow pit (i) to landfill site (j)

C_d : Project direct cost as defined in Equation (4.11)

$(C_d/Q)(i,j)$ is the unit cost of moving one cubic meter from borrow pit (i) to landfill site (j)

4.9.1.3 Minimizing Total Cost

Minimizing the project total cost is treated in a manner similar to what is known as “A+B” bidding (Hassanien 2002), which was introduced to minimize public inconvenience arising from construction operations in urban centers. This can be achieved by encouraging contractors to develop project plans that are capable of shorting project duration. The module here uses an objective function to minimize project direct and indirect costs. In this case, the optimization module takes into consideration the daily indirect cost as a decision variable.

$$\text{Total_Cost(Fitness)} = \left(\text{Project Direct Cost} + \left(\text{DUR} \times \frac{\text{IND}}{\text{WH}} \right) \right) \quad (4.16)$$

where,

DUR : Project duration in working hours

WH: Scheduled working hour per day

IND: Daily indirect cost

4.10 Module Constraints

The developed module considers the following constraints:

- The constraint of the quantities of earth at borrow pits is defined as the amount of the transported earth from one borrow pit (i) to different landfills (j). The module accounts for the imbalance between the cut and fill quantities. In most earthmoving projects, either the cut volume exceeds the fill or the fill exceeds the cut (Son et al 2005), and it can be expressed as:

$$\sum_{i=1}^n \sum_{j=1}^m Q(i, j) \leq Q(i) \quad (i = 1, 2, \dots, n; j = 1, 2, \dots, m) \quad (4.17)$$

- The constraint of the quantities of earth at landfill site is defined as the amounts of transported earth from different borrow pits (i) to the landfill site (j), and it can be expressed as:

$$\sum_{j=1}^m \sum_{i=1}^n Q(i, j) \leq Q(j) \quad (i = 1, 2, \dots, n; j = 1, 2, \dots, m) \quad (4.18)$$

- The available resources constraint is defined as the amount of the resources available (equipment) to contractors. The genetic algorithm accounts for the available resources constraint every time a new crew is configured.

4.11 Interim Statistics

Throughout the computational process, interim statistics related to the fitness of the chromosomes are gathered and stored in an external file. These statistics include: (1) the generation number; (2) maximum fitness; (3) minimum fitness value; (4) average Fitness; (5) standard deviation Fitness, and (6) best chromosome. The following are the functions coded in VC++ for statistical analysis and for saving the best chromosome.

```
ga.getComputeStatisticsEvery(1)
ga.statistics(j).averageFitness
ga.statistics(j).minimumFitness
ga.statistics(j).maximumFitness
ga.statistics(j).stdDevFitness
ga.getBestChromosomeGeneration()
ga.getSaveBestChromosome()
```

Sets/Gets decide whether to check if a chromosome was present in the last population before evaluating it. If this property is set to true and the last population contained an identical chromosome, the fitness is simply copied from the last population instead of being computed again. This function can significantly speed up the evolution for problems in which the objective function is computationally intensive. By default, this property is set to false.

4.12 Summary

This chapter presented a methodology developed for optimizing earthmoving operations utilizing genetic algorithms (GA), linear programming (LP), and geographic information systems. The components of the developed module were described. The Pathfinder Algorithm developed in the GIS environment is also described in detail along with an example to illustrate its capability to select near-optimum traveled roads.

The waiting time rule, developed in the genetic algorithm to speed up the optimization process by avoiding the selection and evaluation of unrealistic crew formations, was presented. This chapter also describes the combination of genetic algorithm and linear programming to carry out the optimization process. The optimization methodology takes into account the resources available to contractors, the quantities of earth to be moved, construction site conditions, soil type, and topography of the traveled roads that connect different landfill and borrow pit sites. In addition, it accounts for site setup and the indirect costs associated with those operations. The formulation of the developed module was described along with its calculation.

Chapter 5: Tracking and Control Module

5.1 Introduction

In large-scale earthmoving operations, tracking process consists of the following tasks: (1) collecting data from construction sites; (2) measuring actual performance; (3) forecasting project time and cost at targeted dates; (4) calculating cost and time variances; and (5) taking corrective action(s), if needed.

The tracking process of this class of projects is a difficult task. This difficulty is due to: (1) the need for collecting a large amount of performance data from construction sites; (2) the time needed for analyzing this data to estimate actual performance; and (3) the difficulty of exchanging information among project team members in a short period of time lag.

This chapter presents a newly developed module that aims at circumventing some of the identified limitations in current practice as presented in Chapter 2. It also aims at easing the difficulties stated above. The developed module automates : (1) onsite data collection, (2) estimates actual performance, and (3) forecasts project cost and time at any set date (Alshibani and Moselhi 2007). The chapter describes in detail the developed modules' main components and focuses primarily on the use of GPS as data collection tool. The chapter describes also the use of GPS data as a new method to estimate onsite productivity and forecast project time and cost. The module uses the earned value concept introduced by U.S.A. Department of Defense in 1967 and technique of project ratio introduced by Eldin and Hughes (1992), and introduces

modifications that allow for more accurate forecasting of project time and cost at any future set date. The module has been implemented in prototype software using Microsoft Visual C++ employing Microsoft Foundation Classes (MFC).

5.2 Overview of The developed Module

As shown in Figure 5-1, the module consists of four main components. They are: (1) GPS receiver units; (2) GIS map; (3) database; and (4) developed Graphical User Interfaces (GUI). The GPS receivers are used to collect performance data from construction sites in near real-time by attaching GPS units to tracked haulers. This unit may vary from small units to complex systems. It consists of an antenna to receive the GPS signal. It also consists of a processor that converts the signal to practical information (see Figure 5-2). The collected data can then be extracted once the signal is received and passed on to the processor, where computer software translates the information for the user. The GIS map is employed to store, manipulate, automate data acquisition, displaying geographically moving equipment on the map as layers, and to analyze collected spatial data. The database is designed to host the data needed for calculation. This data includes: (1) the spatial data collected by the GPS receivers for tracked equipment on construction sites; (2) the swell and shrinkage factors for various types of soil; (3) project information data; and (4) information about equipment available to contractor such as its specifications and hourly cost. The GUI module is designed to acquire non-graphic data such as data pertinent to job and management conditions, indirect cost, and actual cost data, etc. It also generates progress reports in two formats, tabular and graphical. In addition to the above

main components, five algorithms are developed to carry out all necessary computations in the developed tracking module. These algorithms are:

1. Cycle time algorithm
2. Estimating productivity algorithm
3. Performance indices algorithm
4. Performance forecasting algorithm
5. Performance variances algorithm

The developed tracking module performs its analysis by taking the following steps: (1) collecting onsite data using GPS receivers; (2) mapping the collected data that represents moving equipment by transforming their respective GPS positioning data (longitude, latitude, and altitude) into the Geographic Information System (GIS) to develop a graphical representation; (3) analyzing the collected GPS data to estimate cycle time, determine the number of cycles (trips) that tracked equipment makes within a particular period; (4) estimating onsite productivity rate; (5) measuring project actual performance; and (6) forecasting project time and cost.

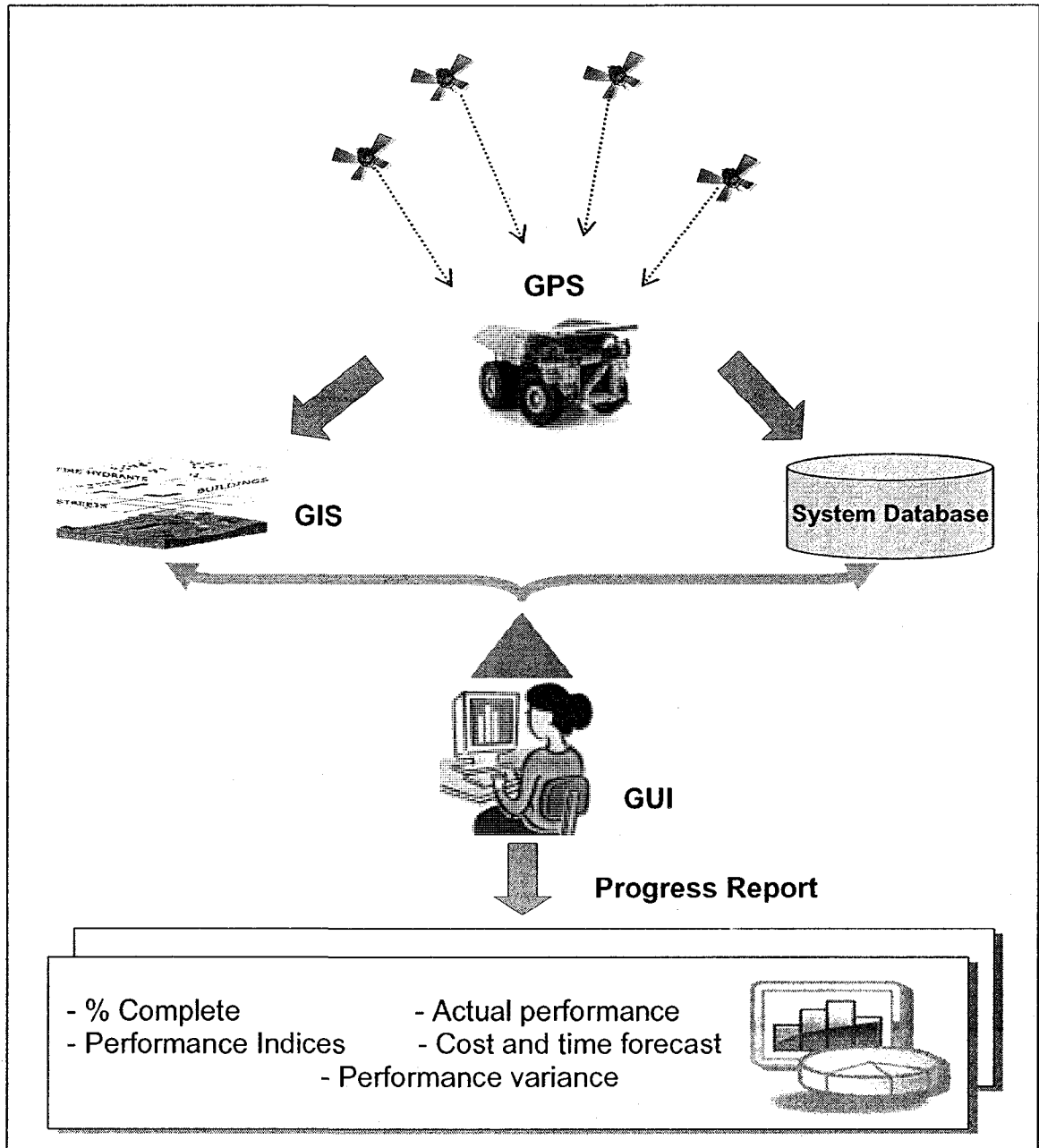


Figure 5-1: Tracking module overview

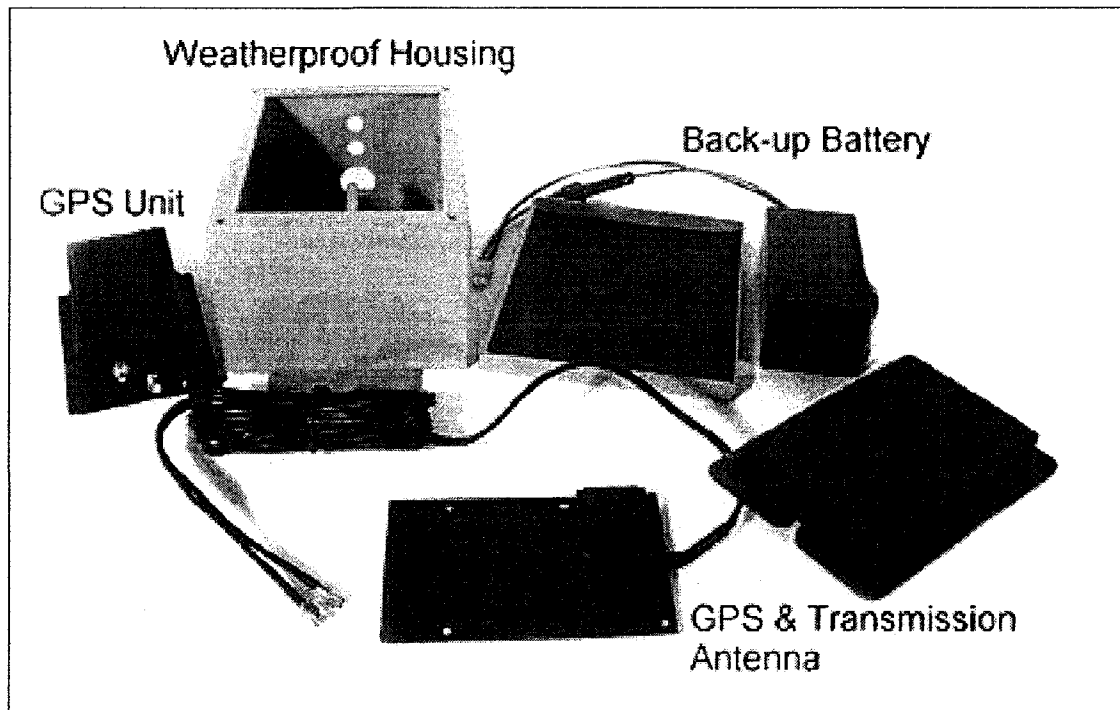


Figure 5-2: GPS receiver unit

Compared to other tracking models, the developed module has a number of features including: (1) it merges global positioning system with geographic information system to automatically collect and geographically represent site data in near real time; (2) it estimates onsite productivity based on positioning data collected by GPS; (3) it forecasts project time and cost at any set future date; and (4) it reconfigures crew formation dynamically while project is progressing as form of corrective action by calling crew optimization module to ensure the completion of project within its budget and time.

5.3 Design of The developed Module

The developed tracking module has been designed to allow easy integration of its components with other components of the developed model. This design

permits the optimization module to be called to reconfigure the crew as a form of corrective action if there is deviation from the plan. The design also facilitates the data flow among all elements of the developed module. The database is at the core of the module where the needed data for computation is housed.

The design of Graphical User Interface (GUI) is carried out in a way that facilitates data entry and minimizes redundant data input. GUI allows for accepting both graphic and non-graphic data. The graphic data is accepted via GIS sub-module that was developed using Map-Object 3.2 library introduced by ESRI. Map-Objects library is a powerful collection of embeddable mapping and GIS components that can be used by developers to create applications that include maps and GIS capabilities. The Map-Objects is used to allow for easy communication with spatial data. It also enables the user to represent the data collected by GPS, graphically in GIS map. The non-graphic data is entered by the user through a set of interface dialog windows. The tracking module is activated through setting out tracking parameters. The developed module is implemented in prototype software that can operate independently or interactively with the developed optimization module. Figure 5-3 depicts the data flow in the developed module.

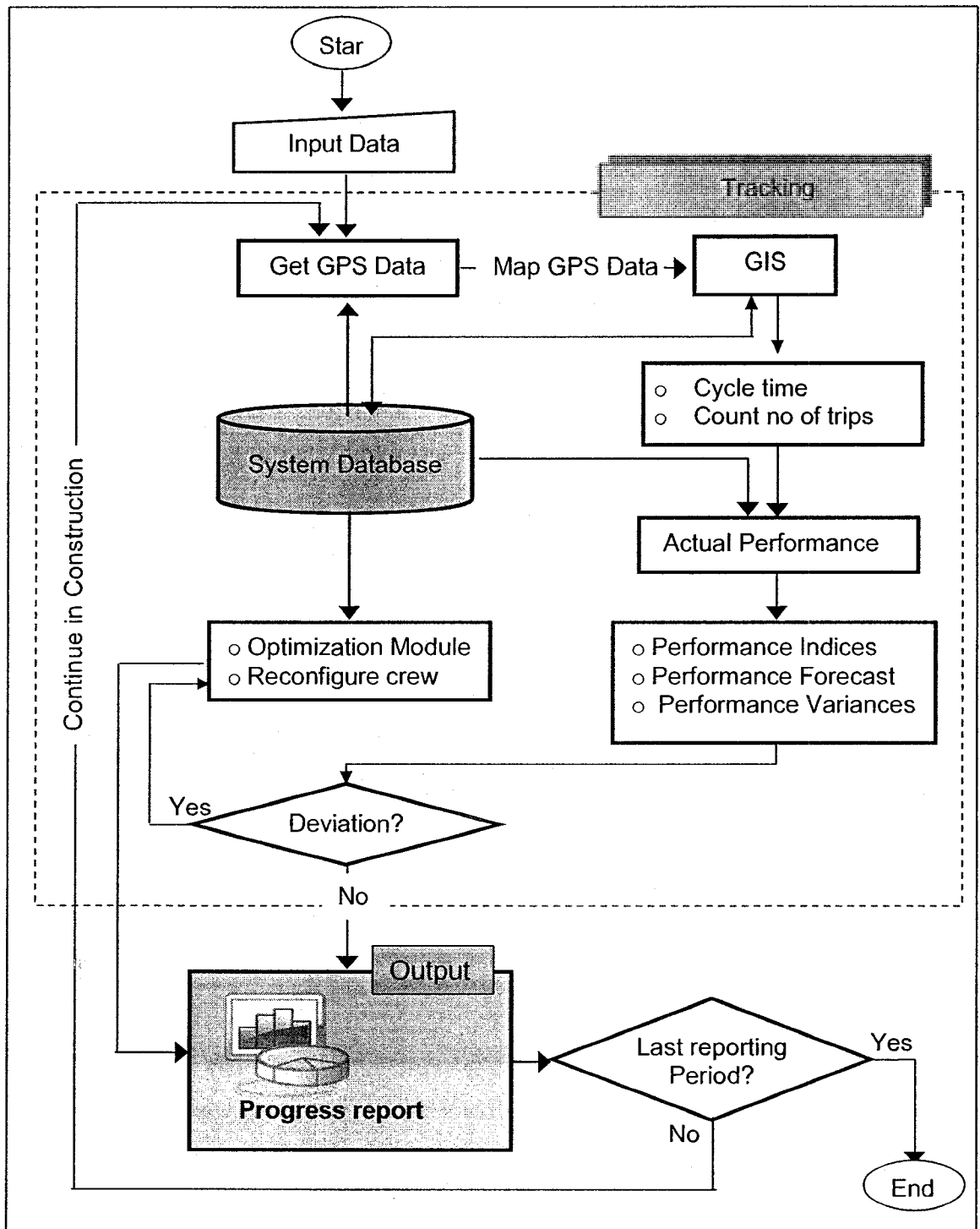


Figure 5-3: Data flow in the developed tracking module

5.4 Site Data Collection

Onsite data collection is a corner stone in tracking and controlling earthmoving operations. It involves the collection of large volume of data on a daily basis. This data is needed to measure and evaluate actual performance of ongoing operations. The effectiveness of any data collection system is measured based on the cost and accuracy of the collected data, and the time required for collection (Moselhi and El-Omari 2006). The literature reveals that manual methods used for data collection are costly, time consuming, and not necessarily accurate (Navon 2007). For those reasons, the construction industry has switched to the use of new technologies to automate onsite data collection. The most widely used automated system in earthmoving operation is On Board Instrumentation Systems (OBIS). The system relies on the replacement of sensors on many locations on equipment to detect abnormal conditions in any of the machine's system. The main function of these sensors is to: (1) diagnose mechanical health of tracked equipment to improve productivity; (2) measure physical parameters such as temperature, pressure, and control lever position and (3) estimate onsite productivity. The main disadvantage of the system is its high cost and its inability to estimate the idle time in loading and dumping areas.

In order to rectify disadvantages of current data collection systems, a new methodology is developed. The method utilizes spatial technology including GPS and GIS to collect and graphically represent onsite data. The GPS is used as data collection tool, whereas GIS is used to store and visualize the collected

GPS data as a powerful tool for data acquisition. The GPS is selected as a data collection tool for the following reasons (Kannan, 1999):

1. It offers the match between the form of data required to assess project's performance and the format of collectable data
2. It is inexpensive and it offers cost effective system
3. It is suitable for collecting data of outdoor operations such as earthmoving
4. It does not require human involvement onsite
5. It does not require trained personal
6. A single receiver can replace several observers on site
7. GPS receiver can be easily mounted and detached on any equipment
8. It ensures timely information flow among project team members
9. It is cost effective
10. GPS is capable of collecting numerous amounts of data in a timely manner
11. The accuracy of the GPS is much greater than that of an observer or camera as long as there is an open sky without any effect of obstacles as in case of using a camera
12. It automates the data collection process
13. The activities duration of earthmoving operations and the cycle time of hauling unit can be calculated based on collected data
14. It does not require any physical sensors

5.4.1 Data Capturing and Processing

In order to avoid collecting unnecessary data and since the main purpose of collecting GPS data is to estimate onsite productivity, the data is collected in wide time intervals. Using this interval helps in data reduction and processing. As shown in Figure 5-4, the following steps are taken in the developed method to collect onsite data:

1. Attaching GPS receiver to tracked truck (Figure 5-5)
2. Capturing position data of moving equipment
3. Transforming the collected data into personal computer using Microsoft ActiveSync and ArcPad software
4. Loading collected data for graphical representation into GIS map using the developed GUI.
5. Applying the developed rules to determine truck cycle time (Section 5.4.2)
6. Counting number of trips that have been made in a particular period of time set by the user.
7. Estimate onsite productivity (Section 5.5.1).

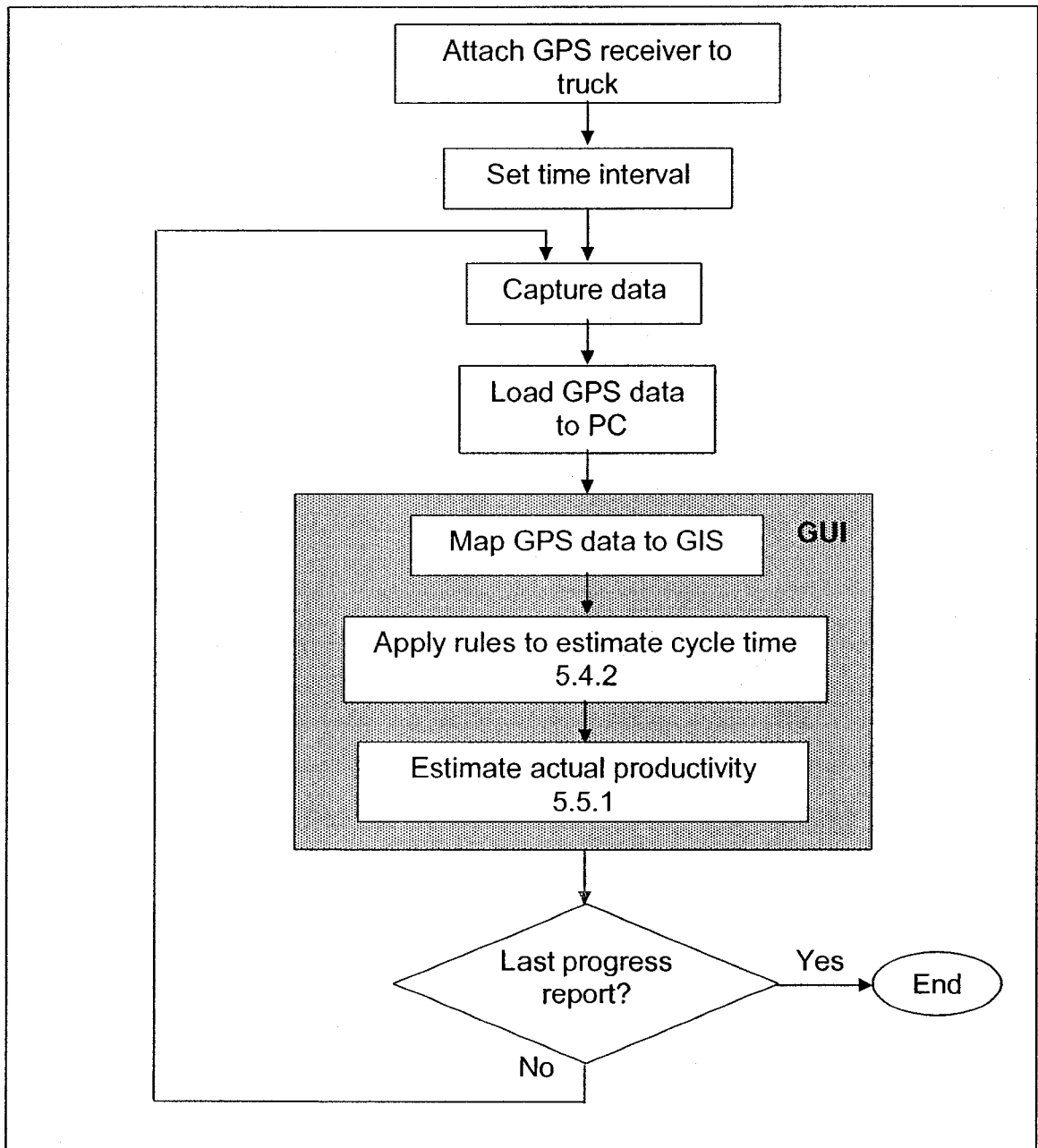


Figure 5-4: Data collection process

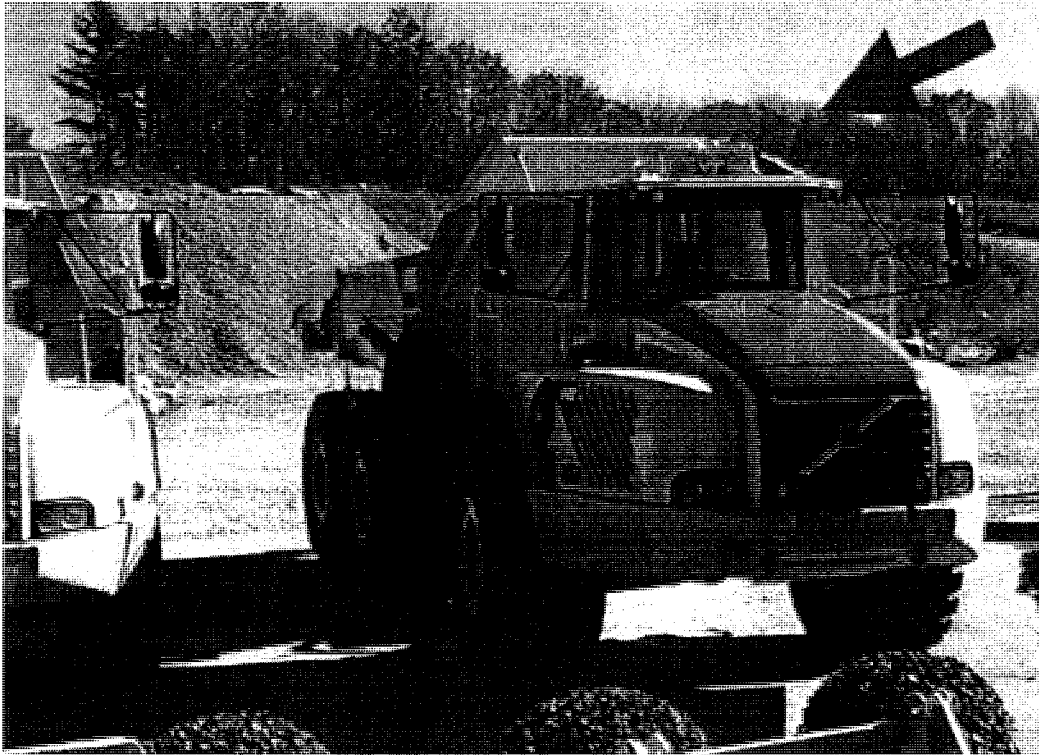


Figure 5-5: Attached GPS receiver to truck

The collected GPS data includes position data (altitude, latitude, and longitude), time and date (Figure 5-6). This data is used to determine the time needed for various cycle time components such as loading, hauling, returning, and dumping by applying the developed rules described in Section 5.4.2. After the completion of presenting GPS data graphically, the user can then explore the road segments length and grade in tabular format as presented in Figure 5-7.

Attributes of Export_Output_2					
FID	Shape^	Latitude	Longitude	Elevation	
0	Point	39.507152	-106.81379	100.22	
1	Point	39.507152	-106.81389	100.22	
2	Point	39.507152	-106.81409	100.22	
3	Point	39.507229	-106.81419	100.22	
4	Point	39.507229	-106.81439	100.22	
5	Point	39.507306	-106.81449	100.22	
6	Point	39.507461	-106.81469	100.22	
7	Point	39.507538	-106.81499	100.22	
8	Point	39.507615	-106.81519	100.22	
9	Point	39.507692	-106.81539	100.22	
10	Point	39.507769	-106.81569	100.22	
11	Point	39.507846	-106.81579	100.22	
12	Point	39.507924	-106.81599	100.22	
13	Point	39.507924	-106.81629	100.22	
14	Point	39.508001	-106.81639	100.22	
15	Point	39.508078	-106.81649	100.22	
16	Point	39.508078	-106.81669	100.22	
17	Point	39.508155	-106.81679	100.22	
18	Point	39.508155	-106.81689	100.22	
19	Point	39.508232	-106.81689	100.22	
20	Point	39.508232	-106.81699	100.22	
21	Point	39.508232	-106.81709	100.22	
22	Point	39.508309	-106.81709	100.22	
23	Point	39.508387	-106.81719	100.22	
24	Point	39.508387	-106.81739	100.22	

Record: 1 Show: All Selected Records (0 out of 1152 Selected)

Figure 5-6: Sample of GPS data

Based on the position data, the module determines whether the equipment is waiting to load, traveling, returning, or waiting to dump. Detailed description of developed rules to calculate hauling unit's cycle time is presented in Section 5.4.2.

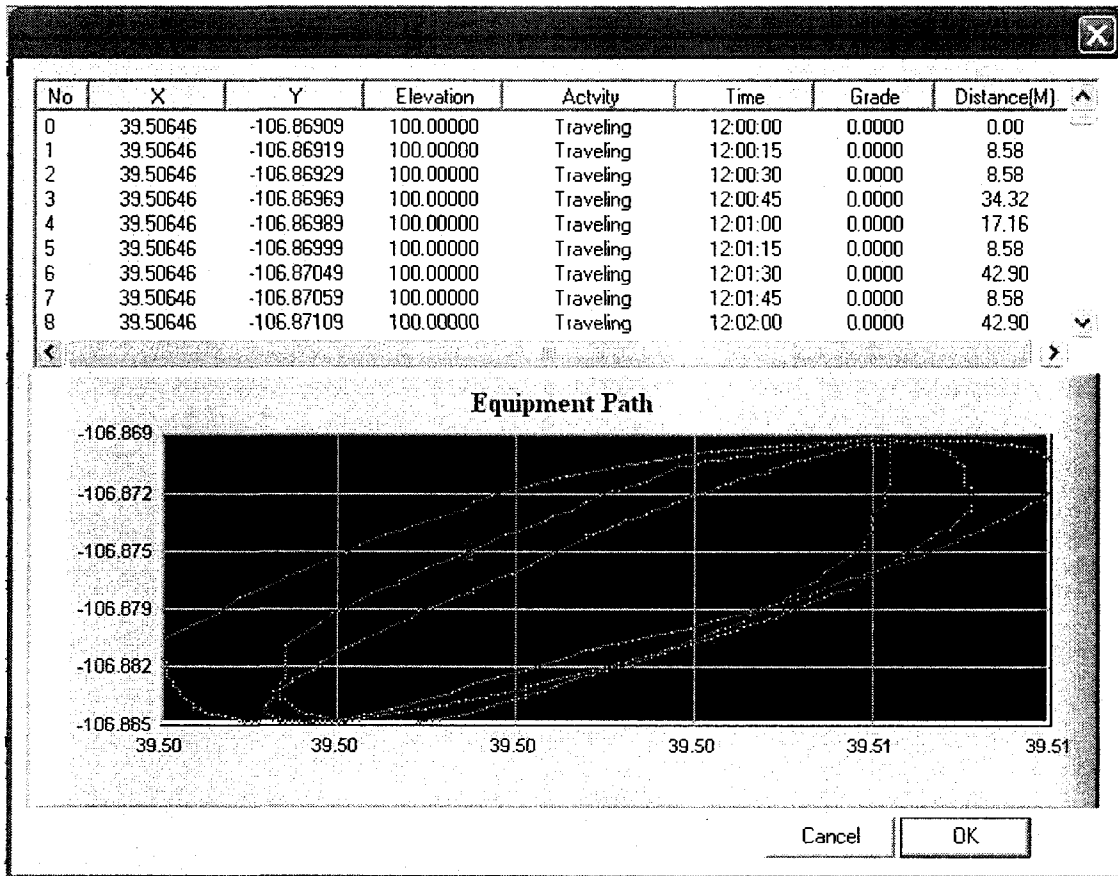


Figure 5-7: Graphical representation of GPS data

Figure 5-8 depicts “add layer” function and Figure 5-9 represents the user interface of loading GPS data. The function enables the user to load the shape file of GPS data into GIS map. This function is activated by pushing “Load GPS data” pushbutton in the main screen of the developed tracking prototype. Mapping the collected GPS data creates a plan view of equipment position throughout the tracked period (Figure 5-10). This graphical representation is enhanced by using the developed drawing tool. The drawing tool allows the user to draw boundaries of loading and dumping areas to facilitate calculation of identifying arrival and departure times that are required to calculate cycle time.

```

////////////////////////////////////
// CHyGisMapDLG message handlers

void CHyGisMapDLG::OnBTNLoadShap()
{
    UpdateData();
    AddLayer(m_map);
    CMoLayers layers(m_map.GetLayers());
    CMoMapLayer pLayer(layers.Item(COleVariant((short)0)));
    m_LayerCombo.AddString(pLayer.GetName());
    m_MoveEquip.AddString(pLayer.GetName());
    CButton *chkLayer;
    chkLayer = new CButton;
    chkLayer->Create(pLayer.GetName(), WS_CHILD | WS_VISIBLE |
        BS_AUTOCHECKBOX | BS_LEFT,
        CRect(618, 70+(layers.GetCount()-1)*20, 700, 90+(layers.GetCount()-1)*20), this, 0x11+1*layers.GetCount()-1);
    UpdateData(FALSE);
}

```

Figure 5-8: Function of adding GPS data as layer

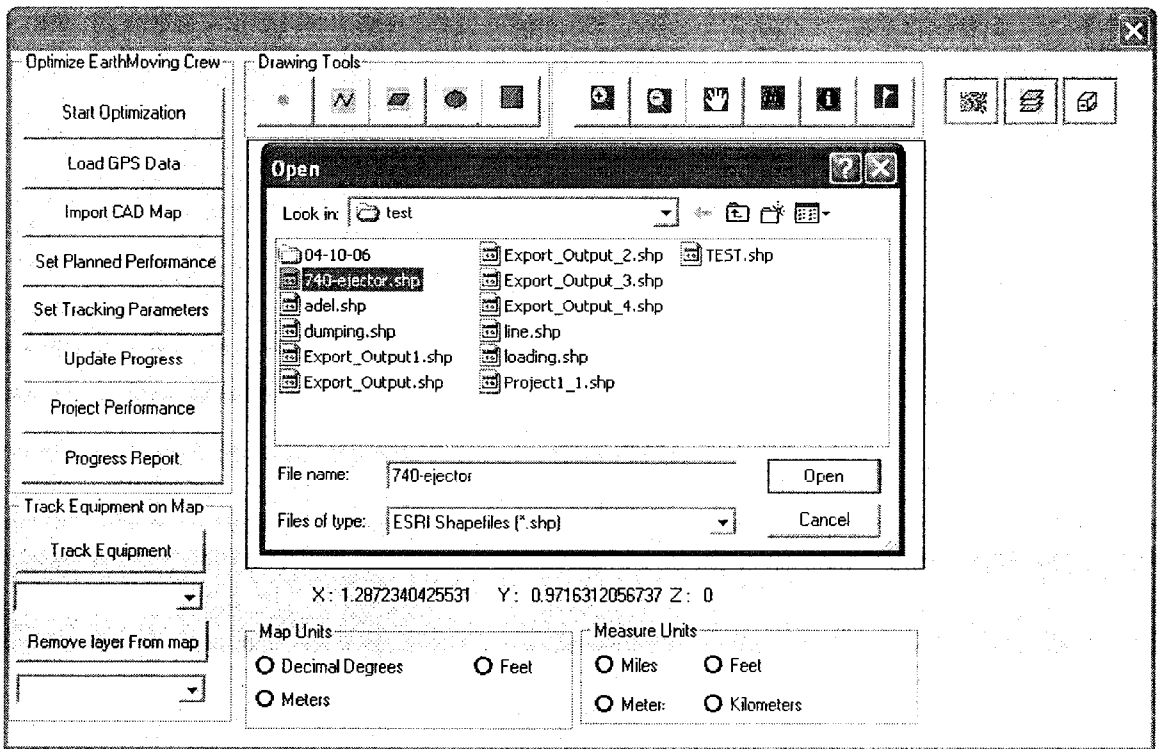


Figure 5-9: Selecting shape file of GPS data

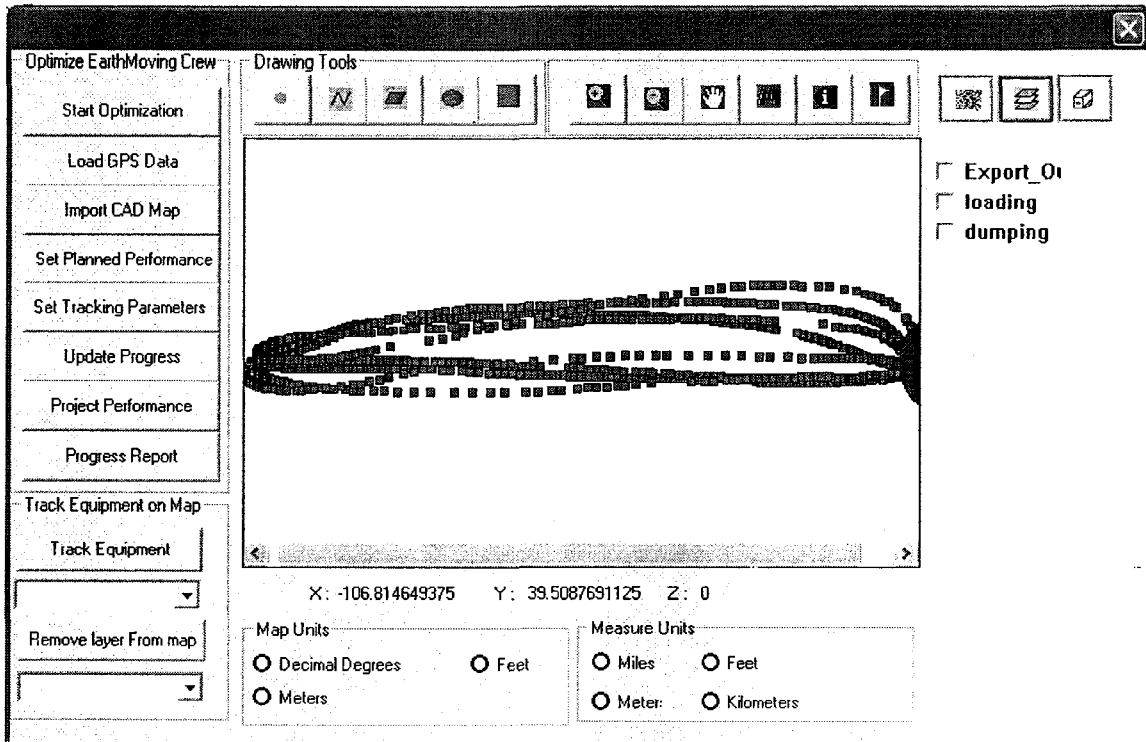


Figure 5-10: Plan view of moving equipment

5.4.2 Cycle Time Calculation

The main purpose of collecting onsite data by GPS is the estimation of onsite crew productivity. Estimating onsite productivity requires the determination of number of trips that hauling unit makes per hour. This requires the estimation of cycle time of hauling unit. Calculating cycle time of a hauler accurately is essential to estimate onsite productivity. Hence, an algorithm has been developed to calculate cycle time of hauler unit using GPS data.

The cycle time consists of four main activities (loading, traveling, dumping, and returning). The loading time is assumed as the time that the truck spends in the loading area. It gives a clear picture of the crew formations and if the number of loaders matches the number of haulers. It assists in identifying idle time. Such

information helps project managers in identifying cause(s) behind any unacceptable performance, if any. The travel time is the time required to haul the excavated material from loading area to dumping area (Figure 5-11). Dumping time is the time that the truck spends in the dumping area to dump its load. It can identify if there is any congestion in dumping area. The return time is the time required for the truck to travel back from dumping area to loading area (Figure 5-12). The travel and return time assists in identifying the characteristics of traveled road. It should be noted that the loading and dumping time include direct loading and dumping time plus maneuver time in loading and dumping areas.

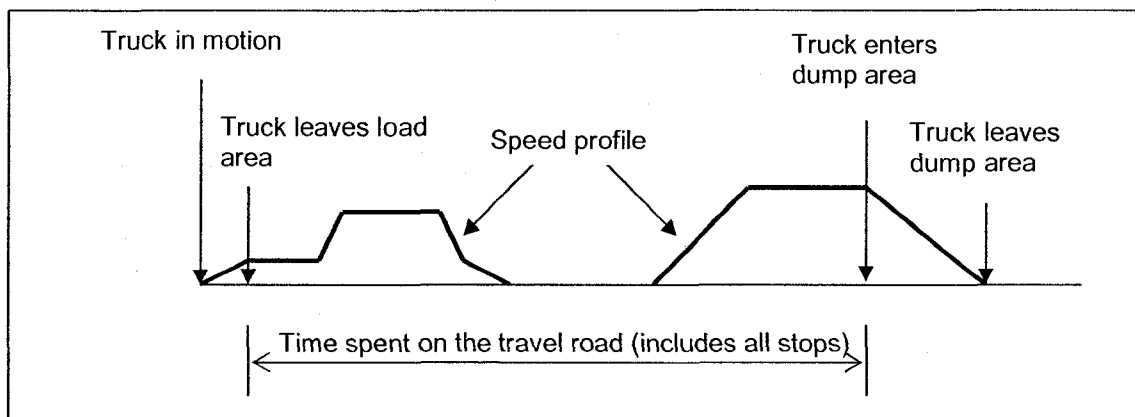


Figure 5-11: Travel time (Kannan, 1999)

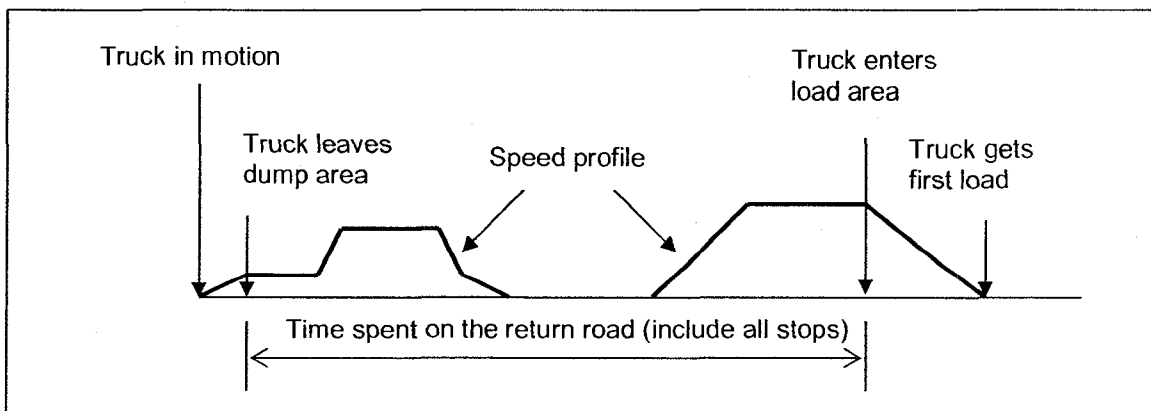


Figure 5-12: Return time (Kannan 1999)

After mapping GPS data into GIS map as depicted in Figure 5-10, the algorithm starts processing and analyzing GPS data to determine cycle time of a hauler. The user initially has to draw boundaries of loading and dumping areas on GIS map using the developed drawing tools. The parameters of those boundaries such as their position data and radius are saved in the model's database for later use. After defining the boundaries of loading and dumping areas, the user has to set report period of tracking. The algorithm afterward starts determining hauler's cycle time, number of trips, and then estimate onsite productivity based on GPS data. In order to determine the duration of cycle time activities and to count the number of trips using GPS data, two methods were tested. First method was based on the use of the hauler speed information provided by GPS. In this method, the loading and dumping times are determined when the speed of moving hauler is equal to zero, whereas the traveling and returning times are determined when the speed is greater than zero. It was found that using this method can lead to wrong determination. For example, if the equipment is broken-down during traveling or returning trip, the module would consider the hauler is in loading or dumping area. Recognizing that, the focus was moved to the use of distance and time data provided by GPS. In this case, the developed algorithm has to test all points that represent the traveling route of moving hauler. The test is carried out to determine if the hauler is on loading, traveling, dumping, or returning activity. The algorithm considers the status of the hauler is changed, as it crosses the boundary from one area to another, and the time at which the boundary was crossed is identified. This method can be summarized as follow:

1. The algorithm first counts the number of points representing the traveling route.
2. The algorithm then extracts the position data (latitude, longitude, and altitude) of point (N) under consideration.
3. The algorithm after that determines the distance between the position of this point and the center of the loading and dumping area using Haversine formula as follow:

$$\Delta\text{Long} = \text{Lon2} - \text{Lon1}$$

$$\Delta\text{Lat} = \text{Lat2} - \text{Lat1}$$

$$a = (\sin(\Delta\text{Lat}/2))^2 + \cos(\text{lat1}) * \cos(\text{lat2}) * (\sin(\Delta\text{long}/2))^2$$

$$C = 2 * \arcsin(\min(1, \sqrt{a}))$$

$$R = \text{earth's radius (mean radius} = 6,371\text{km)}$$

$$d = R * C \tag{5.1}$$

where,

C: Great circle distance in radians

R: Earth's radius (mean radius = 6,371 km)

4. Having calculated the distance, the algorithm next compares this distance with the radius of loading and dumping area. If the distance were smaller than or equal to the radius of loading or dumping area, the hauler would be recognized in loading or dumping area. The dumping time is calculated by summation of the time fractions when the hauler is inside the dumping area, whereas the loading time is calculated by summation of the time fractions when the hauler is inside the loading area. It is essential to note that the

calculated time includes positioning, maneuvering, and direct loading time. If the distance were greater than the radiuses of loading and dumping area, the hauler would be recognized to be either in traveling or returning activities. The travel and return time can be distinguished by the direction of the moving unit. For example, if the direction were from loading into dumping area, the time would be for travel. The algorithm determines the travel time as soon as the hauling unit leaves the loading area and just before it arrives to dumping area. The module determines the return time as soon as the unit leaves the dumping area and just before arriving to loading area. Figure 5-13 depicts the developed algorithm used to calculate cycle time, whereas Figure 5-14 presents part of the function used to estimate the cycle time as coded in Visual C++

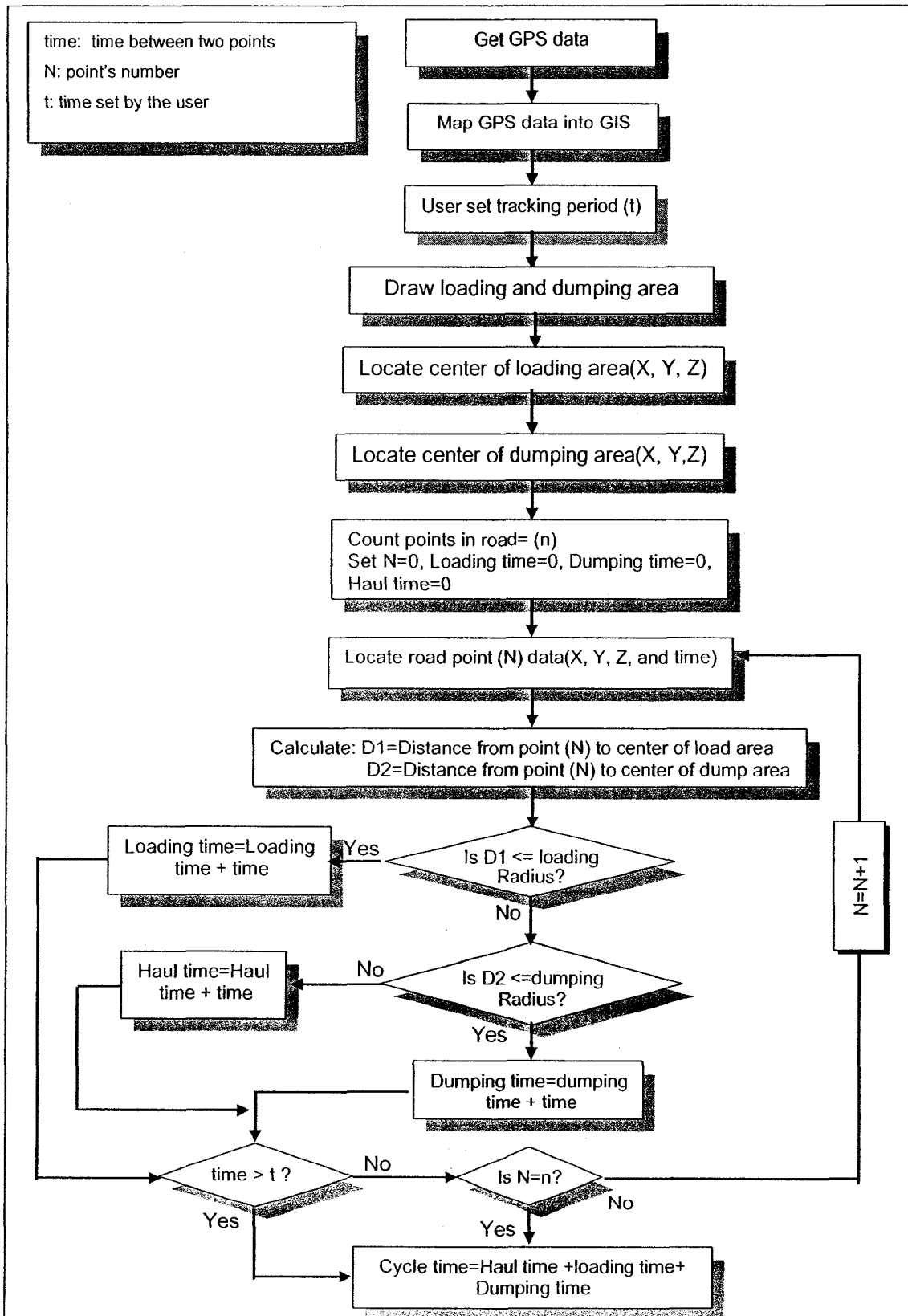


Figure 5-13: Algorithm of calculating cycle time


```

    }
}
//Tracking The path
CMapLayer pLayer(layers.Item(COLEVariant(TEXT(text))));
CRecordset mRst(pLayer.GetRecords());
CFields mFields(mRst.GetFields());
int limit = mRst.GetCount();
mRst.MoveFirst();
for (int ii = 0; ii < limit; ii++)
{
    sequence.Format("%i", ii);
    UpdateData();
    CField mShape(mFields.Item(COLEVariant("Shape")));
    CPoint mPoint(mShape.GetValue().pdispVal);
    TRACE("Point %d: X is %7.5f, Y is %7.5f, Z is %1.5f.\n",
        mPoint.GetX(),
        mPoint.GetY(),
        mPoint.GetZ());

    x1=mPoint.GetX();
    y1=mPoint.GetY();
    z1=mPoint.GetZ();

    x2=mPoint.GetX();
    y2=mPoint.GetY();
    z2=mPoint.GetZ();

    Xposition=mPoint.GetX();
    Yposition=mPoint.GetY();

    //to see if the point is inside or out side the loading area and dumping area
    Distance_To_Dumping=(acos(sin(deg2rad*Yc)*sin(deg2rad*Yposition)+cos(deg2rad*Yc)*
        cos(deg2rad*Yposition)*cos(deg2rad*(Xposition-Xc)))*6371.0*1000;

    Distance_To>LoadingCenter=(acos(sin(deg2rad*Yc>Loading)*sin(deg2rad*Yposition)+cos(deg2rad*Yc>Loading)*
        cos(deg2rad*Yposition)*cos(deg2rad*(Xposition-Xc>Loading)))*6371.0*1000;

    CField MyTimeField(mFields.Item(COLEVariant(TEXT("Timestamp"))));
    tagVARIANT TIME = MyTimeField.GetValue();
}
}

```

Figure 5-14: Function of determination of travel time

5.5 Computation Process in the Developed Module

A flow chart that depicts the computational procedure in the developed tracking and control module is shown in Figure 5-15. The computation process involves determination of:

1. Crew onsite productivity
2. Project performance indices
3. Time and cost forecast,
4. Time and cost variances

5.5.1 Estimating Onsite Crew Productivity

Estimating onsite productivity is a key element in reporting project progress. Formerly, this estimation is conducted using data collected from construction site

by human observers. Unlike previous models, the developed module automatically estimates onsite productivity using GPS data. Compared with other manual and automated methods for estimating onsite productivity, the developed method has interesting features including: (1) it estimates crew productivity based on data collected by GPS receivers; (2) it is a cost effective method compared to other methods; (3) it does not require human involvement; and (4) it allows for quick response for any unacceptable performance.

After the estimation of the hauler cycle time and number of trips that the hauler makes in certain period as described in Section 5.4.2, the module estimates onsite productivity. The data needed for the calculation is retrieved from two sources. The first source is the central database and the second source is the data entered by the user interactively through a set of interface dialog windows. The data that are retrieved from the database include soil data (swell/shrinkage and fill factors) and equipment data (i.e. capacity). The data entered by the user includes the job, weather, and management conditions. The actual productivity for hauler units can be estimated as follows:

$$P_a = N_h \times N_t \times C \times ff \quad (5.2)$$

where,

P_a : Estimated onsite productivity per hour

N_h : Number of hauling units in the crew being considered

N_t : Number of trips the hauling unit made in one hour (5.4.2)

C: Hauling unit capacity taking in consideration soil type, which is retrieved from the system's database

ff: Fill factor.

It is worth noting that Equation 5.2 can be used to other hauling unit such as scrapers and it can be easily adapted to suit other equipment such as compactors. As shown in Figure 5-15, after estimating the crew onsite productivity, the project's performance indices are determined and project time and cost are forecasted. If deviation from as planned are found and the cause of this deviation is not known, the optimization module is then recalled to reconfigure the crew as a form of corrective action as presented in Chapter 4.

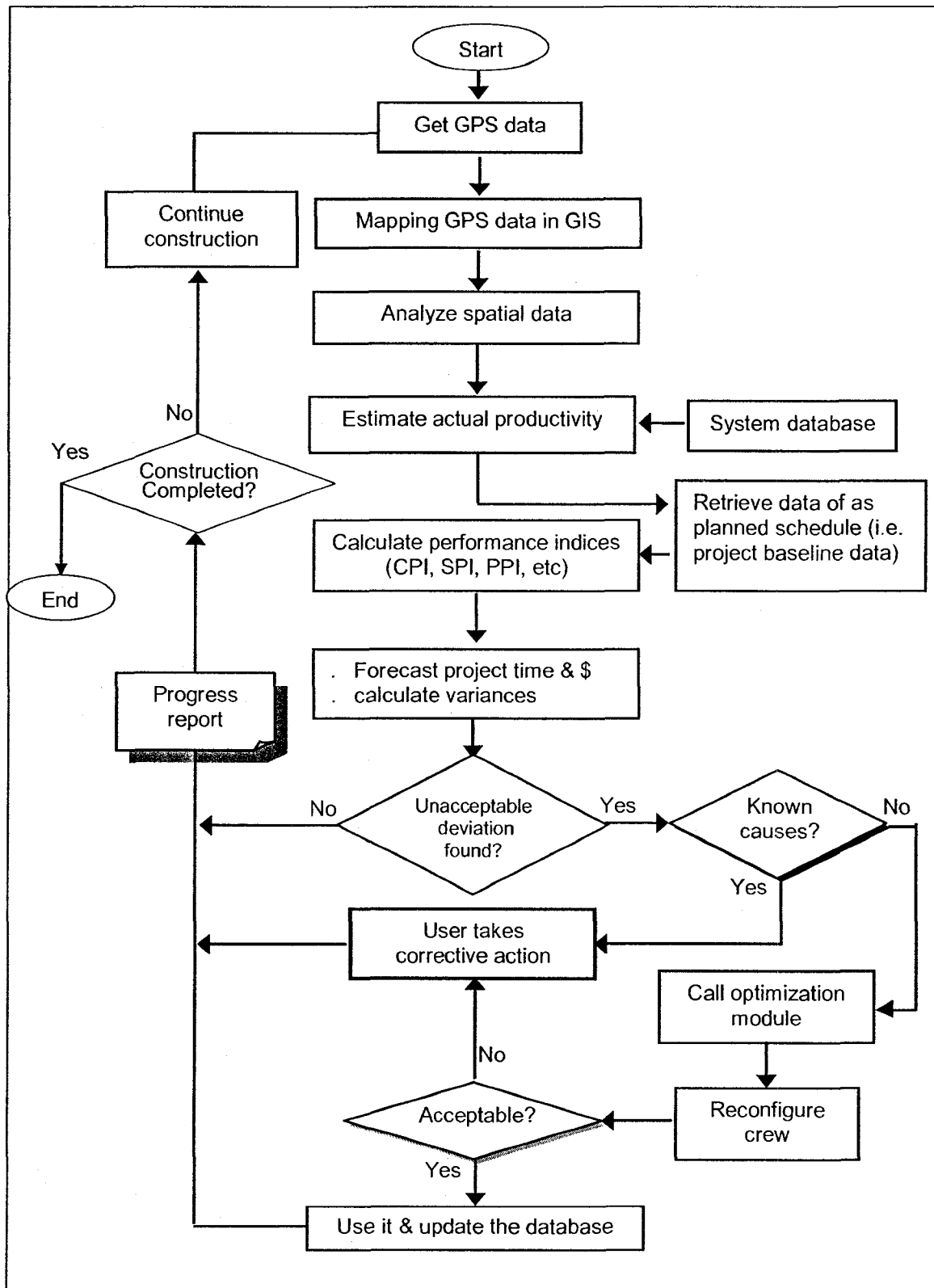


Figure 5-15: Computational process of estimating onsite productivity

5.5.2 Project Performance Indices

Measuring project's performance in a timely and effective manner is an important task. It allows managers to diagnose and identify areas in need of awareness, giving them the opportunity to take management action in a timely fashion. This section represents the calculation of a set of performance indices carried out by the developed module.

Upon the completion of estimating the crew onsite productivity as presented in Section 5.5.1, the module progresses with the measurement of the projects' time and cost status at the report date and forecasts it at any future set date. The project's status is represented by different performance indices and associated variances and forecasts. These indices include:

1. Productivity Performance Index (PPI),
2. Schedule Performance Index (SPI),
3. Cost Performance Index (CPI),
4. Queuing Length Index (QLI),
5. Queuing Waiting Time Index (QWI),
6. Resources Utilization Indices

These indices are used to identify the possible cause(s) of unacceptable performance. As shown in Figure 5-16, if any of these indices falls within an unacceptable range that is set by the user, the module offers the user two options based on the causes of unacceptable performance. If the cause(s) is (are) known, such as inclement weather, equipment breakdown, or/and a strike, the user can take the appropriate corrective actions. Otherwise, the module calls

the optimization module to reconfigure the crews being used (Moselhi and Alshibani 2007-a). In this case, the module sets the fitness function to the value of the remaining time and/or cost to completion so that the crew can be reconfigured in order to meet these project new constraints.

5.5.2.1 Productivity Performance Index (PPI)

This index provides a measure finishing the project within its targeted schedule and it is used here to forecast project duration. As to using project ratio technique, the index can be expressed as:

$$PPI = \frac{(Whr/Q)_b}{(Whr/Q)_a} \quad (5.3)$$

where,

PPI: Productivity performance index

(Whr/Q)_a : Actual to-date working hours per unit of work

(Whr/Q)_b : Budgeted working hours per unit of work

As of using the earned value concept, the index can be expressed as:

$$SPI = \frac{BCWP}{BCWS} \quad (5.4)$$

where,

SPI: Schedule performance index

BCWP : Budgeted cost of work performed

BCWS : Budgeted cost of work scheduled

5.5.2.2 Cost Performance Index (CPI)

The cost performance index (CPI) provides a good measure as to how close a project will be completed within its targeted budget. It is used to forecast project cost as presented in Section 5.5.4. Using the project ratio technique, the CPI can be expressed as:

$$\text{CPI} = \frac{(\$ / Q)_b}{(\$ / Q)_a} \quad (5.5)$$

where,

CPI: Cost performance index

(\$/Q)b: Budgeted cost of unit rate;

(\$/Q)a: Actual cost to date of unit rate

Using the earned value concept, the index can be expressed as:

$$\text{CPI} = \frac{\text{BCWP}}{\text{ACWP}} \quad (5.6)$$

where,

ACWP : Actual cost of work performed

In order to find the exact cause(s) of an unacceptable performance, the module adopts additional project's performance indices that were introduced by McCabe and AbouRizk (2001). These indices are:

5.5.2.3 Queuing Length Index (QLI)

The index is important when there is a space limitation or when there are obstructions that divide project segments. This index applies to crews in which

equipment (customer) depends on other equipment (server) and it can be expressed as:

$$(QL)_{i-j} = \frac{m(QL)_a}{m(QL)_p} \quad (5.7)$$

where,

$(QL)_{i-j}$: Queue length Index for customer j (truck) to server i (loader);

$m(QL)_a$: Average actual queuing length

$m(QL)_p$: Acceptable queue length as defined by the user

IF $m(QL)_a < m(QL)_p$, then the following corrective actions should be considered.

- decrease the number of servers
- increase the number of customers

IF $m(QL)_a > m(QL)_p$ then the following corrective actions should be considered:

- increase the number of servers
- decrease the number of customers

5.5.2.4 Queuing Waiting Time Index (QWI)

It is the time, in which the equipment spends waiting in queue relative to an acceptable range set by the user. The developed module determines the actual waiting time by summing all waiting time of tracked equipment inside the loading area as explained in Section 5.4.2. It is a good indicator of the crew formations, productivity, and it can be express as:

$$(QW)_{i-j} = \frac{(QW)_a}{(QW)_p} \quad (5.8)$$

where,

$(QW)_{i-j}$: Queuing waiting time index

$m(QW)_a$: Average actual equipment waiting time, to be determined from data collected by GPS

$(QW)_p$: Equipment waiting time as set by the user.

If $(QW)_a < (QW)_p$ or less than the acceptable range set by the user, then the following corrective actions are required to keep the customers busy:

- Decrease the number of the servers.
- Increase the number of the customers

5.5.2.5 Resources Utilization Indices

This includes three indices that, in general, provide assessment of idle time and inefficient utilization of equipment. They are; Customer Delay Index (CDI); Server Quantity Index (SQI), and Matching Index (MI).

The CDI 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 that equipment as:

$$(CD)_j = (1/CT)_j \sum_{i=1}^k DT_i \quad (5.9)$$

where,

$(CT)_j$: Average cycle time of customer j

DT_i : Average delay time in the queue in each operation cycle

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.

The SQI is to account for unused servers that are assigned to project and left unused. Although they may not affect the productivity, they affect the project total cost and may lead to cost overrun. It can be expressed as:

$$(SQ) = Sa/Sp \quad (5.10)$$

where,

Sp: Resources assigned to the project

Sa : Actual working resources at the site

The MI is used to measure the match between the number of haulers and the number of loaders to give maximum efficiency and it can be expressed as follow:

$$MI = \frac{N_h \times L_{ct}}{N_l \times H_{ct}} \quad (5.11)$$

where,

N_h : Number of haulers

L_{ct} : Loader cycle time

H_{ct} : Hauler cycle time

N_l : Number of loaders

N_h : Number of haulers

Table 5.1 shows evaluation criteria of the performance indices

Table 5.1: Performance indices evaluation criteria

Performance index	Ratio	Criteria	Description
Cost performance index	$\frac{BCWP}{ACWP}$	\geq Threshold	Cost performance is acceptable
		$<$ Threshold	Cost performance is unacceptable
Schedule performance index	$\frac{(Whr/Q)_b}{(Whr/Q)_a}$	\geq Threshold	Schedule performance is acceptable
		$<$ Threshold	Schedule performance is unacceptable
Queuing Length Index	$\frac{m(QL)_a}{m(QL)_p}$	$>$ Threshold	Queuing Length is unacceptable
		\leq Threshold	Queuing Length is acceptable
Queuing waiting time index	$\frac{(QW)_a}{(QW)_p}$	$>$ Threshold	Queuing waiting is unacceptable
		\leq Threshold	Queuing waiting is acceptable
Resources Utilization Indices			
Customer Delay index (CDI)	$(1/CT)_j \sum_{i=1}^k DT_i$	$>$ Threshold	Customer Delay is unacceptable
		\leq Threshold	Customer Delay is acceptable
Server Quantity Index (SQ)	S_a / S_b	$>$ Threshold	Server Quantity is unacceptable
		\leq Threshold	Server Quantity is acceptable
Matching Index (MI)	$\frac{N_h \times L_{ct}}{N_l \times H_{ct}}$	\geq Threshold	Crew formation is acceptable
		$<$ Threshold	Crew formation is unacceptable

5.5.3 Work Progress

Work progress is another essential function in tracking, controlling, and in applying the earned value concept. The literature indicates, in general, methods for measuring work progress with respect to: (1) project's expenditure; (2) installed quantities; and (3) earned value. The first group is clearly focused on cost and reports project progress as the ratio of the actual project cost to-date to that budgeted. Without binding cost to the physical progress, that provides

incomplete status for the project. This limitation leads to the introduction of the second group.

The second group focuses on physical accomplishment and provides a reasonable indicator for the status of the project schedule. However, it does not provide a complete picture for the project status. The use of different units of measurement has been a major difficulty in the application of this method. Different units prevent the summation of subcomponents to determine the progress of a work item. In addition, the summation of different work items with different units cannot be used to measure the work progress at the project level. Moreover, the work progress of work items that have the same units of measurement was affected by other qualifications that were not based on the installed quantities. For example, although the quantities of earth moved in the first unit would be equal to the earth moved in the last unit in highway construction, the cost of both would be significantly different.

Recognizing these limitations, the proposed module adopts the earned value method to report project progress. It considers the budgeted cost of work schedule (BCWS), actual cost of work performed (ACWP), and budgeted cost of work performed (BCWP). The BCWP (earned value) is expressed herein terms of the quantities of work in place as reported by the following Equation:

$$PC = \frac{Q_a}{Q_b} \times 100 \quad (5.12)$$

where,

PC : Percent completed

Q_a : Installed (filled) quantity

Q_b : Budgeted quantity at the same reporting time

5.5.4 Deterministic Method for Cost and Time Forecasting

In an effort to overcome the limitations identified in Section 2.6.2 on current used forecasting methods, a new methodology for forecasting time and cost is developed (Alshibani and Moselhi, 2007). The developed method adopts the earned value concept developed by U.S.A Department of Defense (1967) and the technique of project ratios introduced by Eldin and Hughes (1992). The method also introduces modifications that allow for more accurate forecasting of project time and cost at any future set date (Alshibani and Moselhi 2007).

The developed method provides a range of possibilities. It forecasts project time and cost using two assumptions: (1) the established performance at the report date will continue until completion; and (2) the remaining work will be performed as planned. These assumptions provide a range of possibilities (minimum and maximum). In order to improve the accuracy of the developed forecasting method, an adaptive self-learning adjustment factor is applied. The adaptive factor is generated at each reporting period and it is the ratio of actual versus forecasted performance. This simple factor continuously adapts to the project environment and systematically reduces the gap between the forecasted and actual project status. Other attractive feature of the developed forecasting method is that instead of blocking out an entire period in which exceptional

conditions are known to have prevailed such as strike, the developed method determines the performance index for this period based on the level of performance achieved by the contractor during normal conditions just before the occurrence of such unusual conditions. For example, if a strike occurred in the second period (2-1) as presented in Figure 5-16, instead of blocking out this period entirely, its performance index can be calculated at normal conditions just before the strike occurs.

Applying the proposed method requires the generation of three S-curves. The first represents the BCWS; the second represents the BCWP; and the last represents the ACWP. Upon the completion of forecasting the project time and cost, the cost variance at any date is calculated by subtracting the forecasted cost from the budgeted cost of work schedule at that date. The cost variance at completion is calculated by subtracting the budgeted cost at completion (BCAC) from forecasted cost at completion. Figure 5-17 represents a flow chart of the computation process of the proposed forecasting method. Detailed description of this calculation is presented in following section.

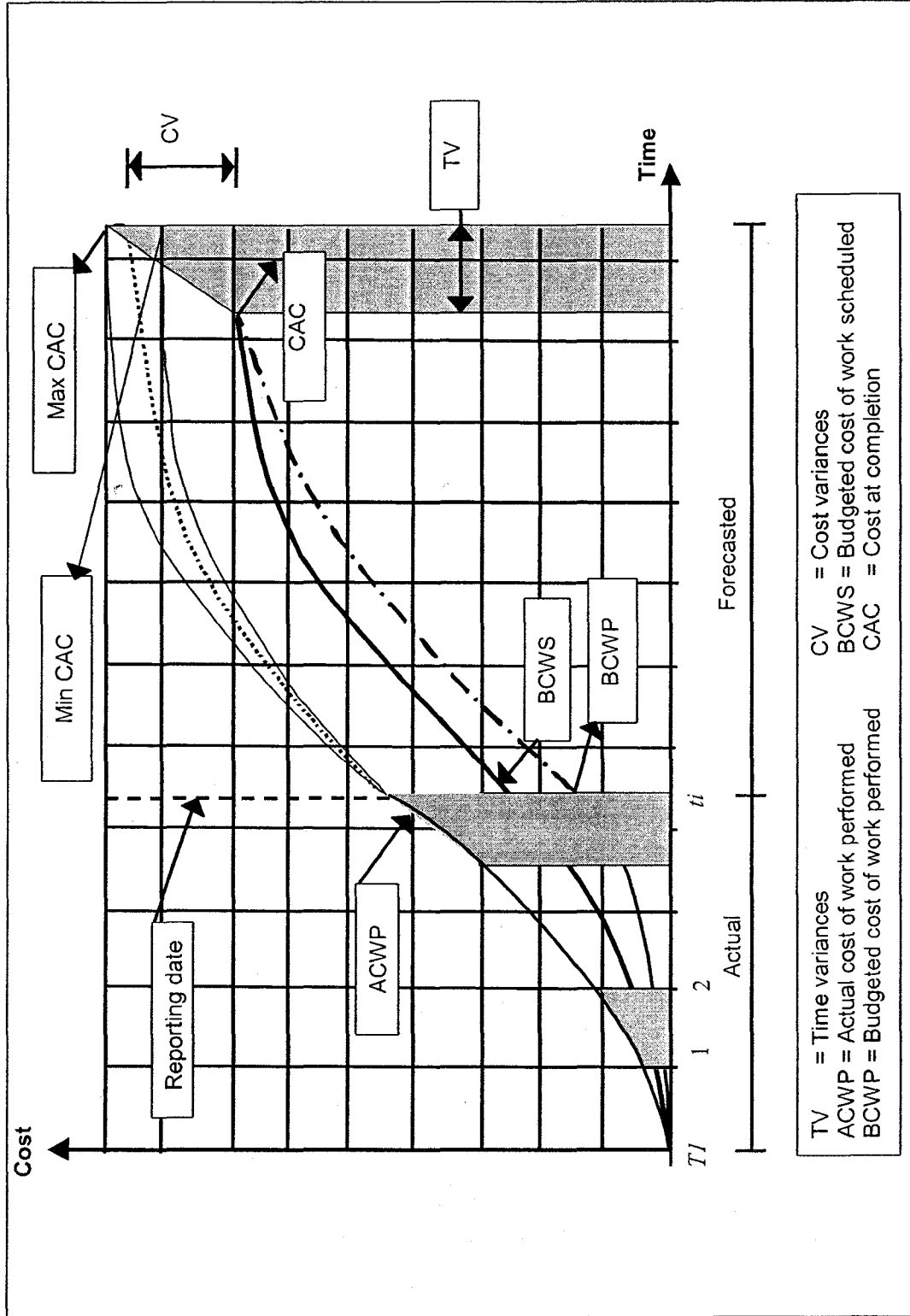


Figure 5-16: Cost and time forecast

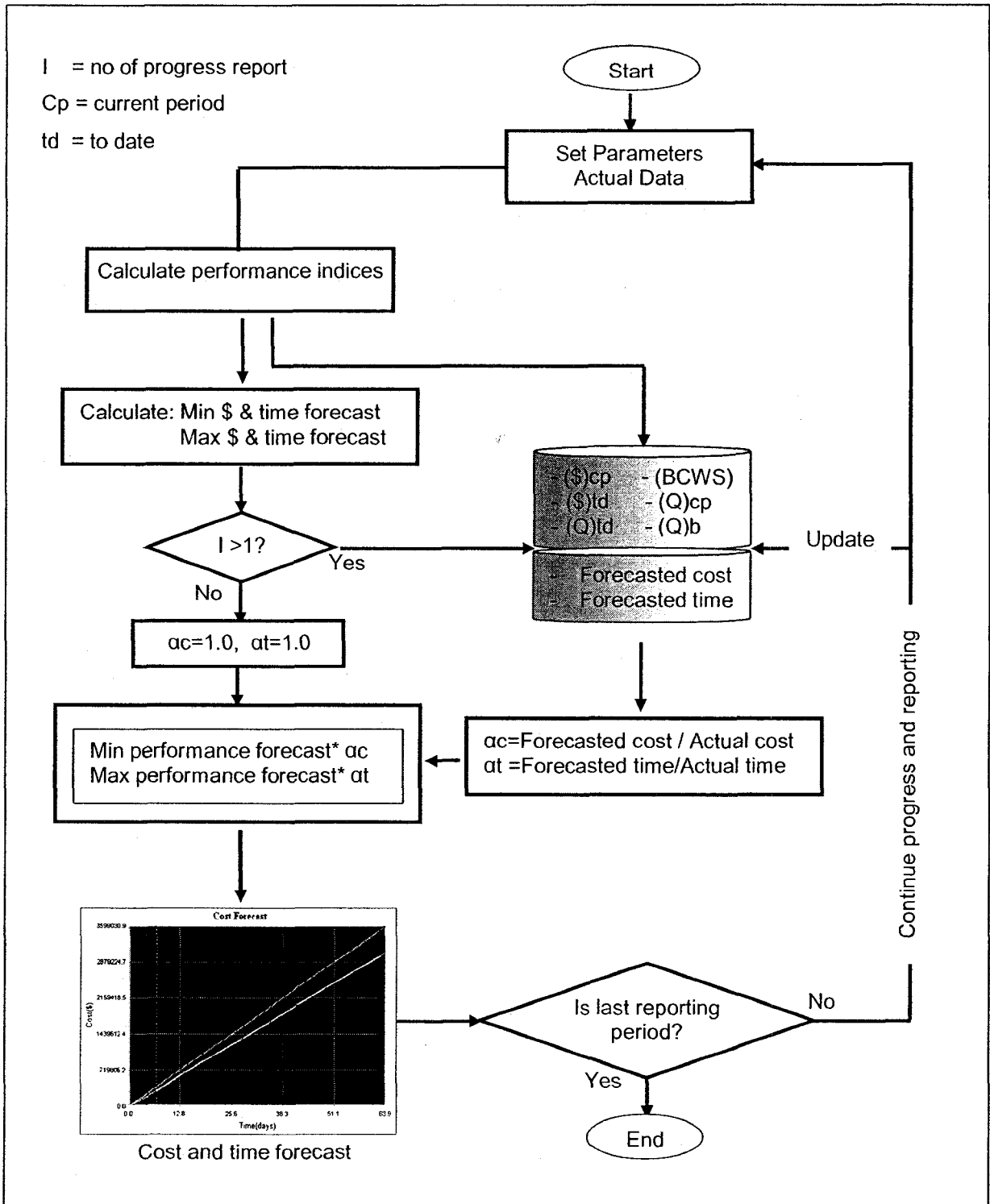


Figure 5-17: Computational process of forecasting method

5.5.4.1 Computation Procedure in the Forecasting Module

Having determined the project performance indices as presented in section 5.5.2, the project cost and time can be forecasted at any targeted future dates. Using the project ratio technique, forecasted cost and time at any point in time ($ti-t1$) can be calculated as follows:

$$C1_{ti-t1} = \left(ACWP + \left(\left(\frac{ti-t1}{\text{project time}} \right) \times (Q)b - (Q)a \right) \times (\$/Q)b \right) \times \alpha_c \quad (5.13)$$

$$C2_{ti-t1} = \left(ACWP + \left(\left(\frac{ti-t1}{\text{project time}} \right) \times (Q)b - (Q)a \right) \times (\$/Q)\text{average} \right) \times \alpha_c \quad (5.14)$$

$$T1_{ti-t1} = \left((Whr)td + \left(\left(\frac{ti-t1}{\text{project time}} \right) \times (Q)b - (Q)a \right) \times (Whr/Q)b \right) \times \alpha_t \quad (5.15)$$

$$T2_{ti-t1} = \left((Whr)td + \left(\left(\frac{ti-t1}{\text{project time}} \right) \times (Q)b - (Q)a \right) \times (Whr/Q)\text{average} \right) \times \alpha_t \quad (5.16)$$

where,

$C1_{ti-t1}$: Cost forecast1@ $ti-t1$

$C2_{ti-t1}$: Cost forecast 2@ $ti-t1$

α_c : Adaptive cost and it is calculated as follow:

$$\alpha_c = \text{Forecasted Cost/Actual Cost}$$

α_t : Adaptive time and it is calculated as follow:

$$\alpha_t = \text{Forecasted Time/Actual Time}$$

It should be noted that the cost and time adaptive factors are equal to one in the first report.

$T1_{ti-t1}$: Time forecast1@ ti-t1

$T2_{ti-t1}$: Time forecast2@ ti-t1

ti-t1: Time interval on horizon time

(Q)b : Budgeted quantities;

(Q)a : Actual quantities up to report date

(\$/Q)average: Average actual cumulative to date unit cost rate and it includes the normal unit cost rate achieved by contractor in case there are exceptional conditions that are known to have prevailed in certain period of time.

(Whr/Q) average: Average actual to-date unit working hours and it includes the normal productivity rate achieved by contractor in case there are exceptional conditions that are known to have prevailed in certain period.

Using the earned value concept, forecasted cost and time at any point in time (ti-t1) can be calculated as follow:

$$C1_{ti-t1} = \left(ACWP + \left(\left(\frac{ti-t1}{\text{project time}} \right) \times BCAC - BCWP \right) \right) \times \alpha_c \quad (5.17)$$

$$C2_{ti-t1} = \left(ACWP + \left(\left(\frac{ti-t1}{\text{project time}} \right) \times BCAC - BCWP \right) / (CPI)_{\text{average}} \right) \times \alpha_c \quad (5.18)$$

$$T1_{ti-t1} = ((Whr)_{td} + (ti - (\% \times (Whr) b)) \times \alpha_t \quad (5.19)$$

$$T2_{ti-t1} = ((Whr)_{td} + (ti - (\% \times (Whr) b)) / (SPI)_{\text{average}} \times \alpha_t \quad (5.20)$$

where,

(CPI)average: Average to date cost performance index and it includes the normal CPI achieved by contractor in case of exceptional conditions that are known to have prevailed at certain reporting periods.

(SPI)average: Average to date schedule performance index and it includes the normal SPI achieved by contractor in case there are exceptional conditions that are known to have prevailed at certain reporting periods.

% : Percent complete to date

(Whr) td : Actual to date working hours

(Whr) b : Budgeted working hours

The Determination of two values results in forecasting a range rather than a single crisp value. This could prove useful to project managers to examine the forecasted values, decide on which is more applicable to case at hand, and allow for reasoning about the forecasted project status. Equations (5-13 and 5-14) and Equations (5-17 and 5-18) will give different values defining the forecasted range of project cost in this case. Similarly, Equations (5-15 and 5-16) and Equations (5-19 and 5-20) will give different values defining the forecasted project time.

3. Cost and Time Variances

The performance variances are determined by subtracting the performance forecasted from the as planned at particulate time interval. The cost variance (CV) is determined by subtracting forecasted cost from budgeted cost at that

point in time. Similarly, the time variance (TV) is determined by subtracting forecasted time from that planned.

$$CV_{t_i-t_1} = \left(\frac{t_i - t_1}{\text{project time}} \right) \times (Q)_b \times (\$/Q)_b - \left(\frac{C1_{t_i-t_1} + C2_{t_i-t_1}}{2} \right) \quad (5.21)$$

$$TV_{t_i-t_1} = \left(\frac{t_i - t_1}{\text{project time}} \right) \times (W_{hr})_b - \left(\frac{T1_{t_i-t_1} + T2_{t_i-t_1}}{2} \right) \quad (5.22)$$

where,

$CV_{t_i-t_1}$: Cost variance at $(t_i - t_1)$ in horizon time

$TV_{t_i-t_1}$: Time variance at $(t_i - t_1)$ in horizon time and measured in working hours

5.6 Input and Output Data in the Developed Tracking Module

As shown in Figure 5-18, the developed tracking and controlling module retrieves the needed data (input) from three sources. The first source is the data collected by GPS revivers. The GPS data consists of the data representing position of the tracked equipment on site. This data includes (altitude, longitude, latitude, date, speed, and time). The second source is the central database of the developed model. 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 information 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 by the user through a set of dialog windows. This data includes actual

cost data, job and management conditions, progress report options, and tracking technique used.

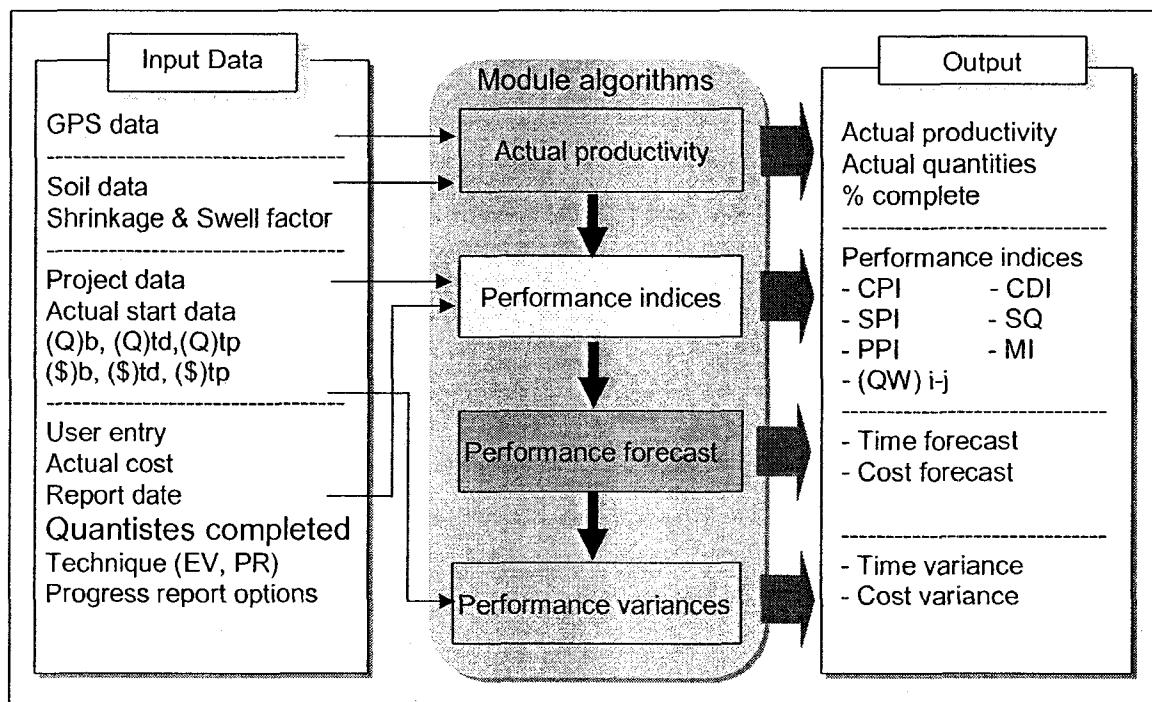


Figure 5-18: Tracking module input and output data

5.7 Summary

In this chapter, the developed tracking and control module of earthmoving operations using spatial technologies is described. The basic components of the module and the interconnectivity among them were also described. The module layout is presented and the data required is also described. A method developed to estimate onsite productivity and forecast project cost and time are explained. The developed performance indices for tracking and control and their calculation are also presented. The two techniques used in the forecasting project cost and

time including earned value concept and project ratios are also discussed and the modifications made in this study are presented.

Chapter 6: Computer Implementation

6.1 Introduction

This chapter describes the implementation of the proposed model in prototype software. The software has been developed using object-oriented programming and Microsoft Foundation Classes (MFC), and has been coded using visual C++ V.6. The developed software operates in Microsoft Windows' environment. Microsoft Access is employed as the database management system. The software consists of main two components: (1) crew optimization, and (2) tracking and control. These components can operate independently or jointly. The main functions of crew optimization component are to: (1)select optimum crew formation to carry out the work at hand; (2) select the quantities of earth to be moved from different borrow pits and placed them at different landfills sites so as to meet the optimization objective set by the user, and (3) generate project baseline. These outputs are stored in the system's database for later use by the tracking component during construction phase.

In addition to using of VC++, the map-objects library developed by ESRI is used to develop the GIS sub-module and Pathfinder algorithm in GIS environment to extract data from GIS map. The GIS sub-module used for acquiring and analyzing spatial data in planning stage and during construction, whereas the Pathfinder algorithm is used to: (1) select the optimal travel roads; and (2) feed crew optimization and tracking and control modules with spatial data. Figure 6-1 depicts input and output of the developed system.

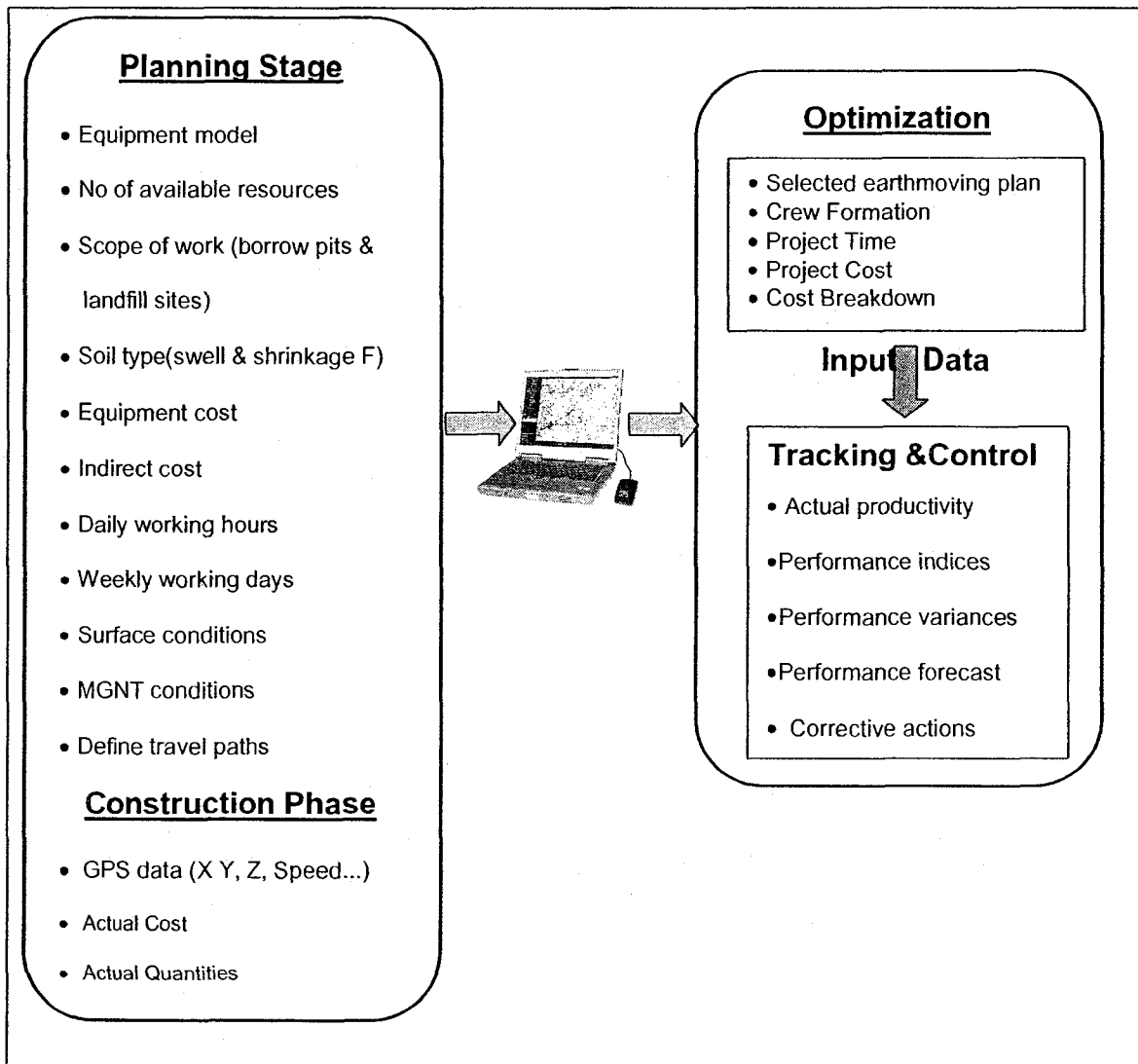


Figure 6-1: Input and output of the developed system

6.2 Criteria for the Selection of Development Tools

In developing the proposed model, different tools had to be considered. The tool selection process considers certain features of these tools such as the tool availability, ability to integrate with other software systems, ability to conduct a heavy and complex computation in short time, and ability to provide a user-friendly interface. Since planning, tracking, and controlling earthmoving

operations require a complex degree of calculations, forecasts, rules, and they require a large volume of data. Therefore, the development tool should be capable of providing a powerful support for data exchange, data storing, data retrieving, and interfacing with currently available and widely used GIS map. In addition, the memory capacity must be made available in order to accommodate the combination and integration of different software that have to be activated at the same time. Therefore, it is preferable for the developed system to be able to run on a personal computer with reasonable memory consumption and reasonable hardware requirements. For the above-stated reasons and because of its capability for integrating with map-objects 3.2, and its ability for carrying out complex calculation, and providing a user-friendly interface, VC++ V. 6.0 has been selected for use in the development of the proposed system.

6.3 System's Architecture

As cited in Chapter 3, the proposed model incorporates four main modules to plan, track, and control earthmoving operations. The first module is the database module to store the needed data. The second module is the crew optimization module to serve in planning stage to select near optimum crew formation and select earthmoving plan using the genetic algorithm technique (GA) and linear programming with the help of GIS map. The third module is the tracking and control module. This module serves during construction phase for monitoring and tracking earthmoving operations. It retrieves spatial data collected by GPS receivers to estimate the onsite productivity and applies the earned-value concept or project ratio technique. The fourth module is the reporting module. It

generates tabular and graphical reports in the planning and during construction phase. The system architecture is designed to allow for flexible integration among the system different modules and expansion and change without affecting the rest of the system. Adding a new module for another type of project scheduling, can easily integrate within the system. Figure 6-2 represents the developed system's breakdown structure, which incorporates seven levels. The system is developed using:

1. Global Positioning System (GPS) to serve as data collection tool for moving equipment on site to estimate crew onsite productivity
2. Geographic Information System (GIS) to serve for acquiring and analyzing spatial data, and displaying data collected by GPS on a GIS map
3. Microsoft Access is employed as the database management system
4. Microsoft Visual C++ programming language to serve as a media for the integration and development of various modules and algorithms
5. Map-objects 3.2 library developed by ESRI to develop the proposed Pathfinder application in GIS environment

The proposed system has interesting features including the following characteristics: (1) it integrates spatial technologies (GIS map and GPS) to plan, track and control earthmoving operations; (2) it automates onsite data collection and processing it in near real-time; (3) it nearly optimizes crew configuration and quantities of earth to be moved from different borrow pits and placed it at different landfills sites in planning and dynamically during construction phase; (4)

it tracks equipment in construction site in near real-time and generates project progress report; and (5) it forecasts the project cost and time at any future set date.

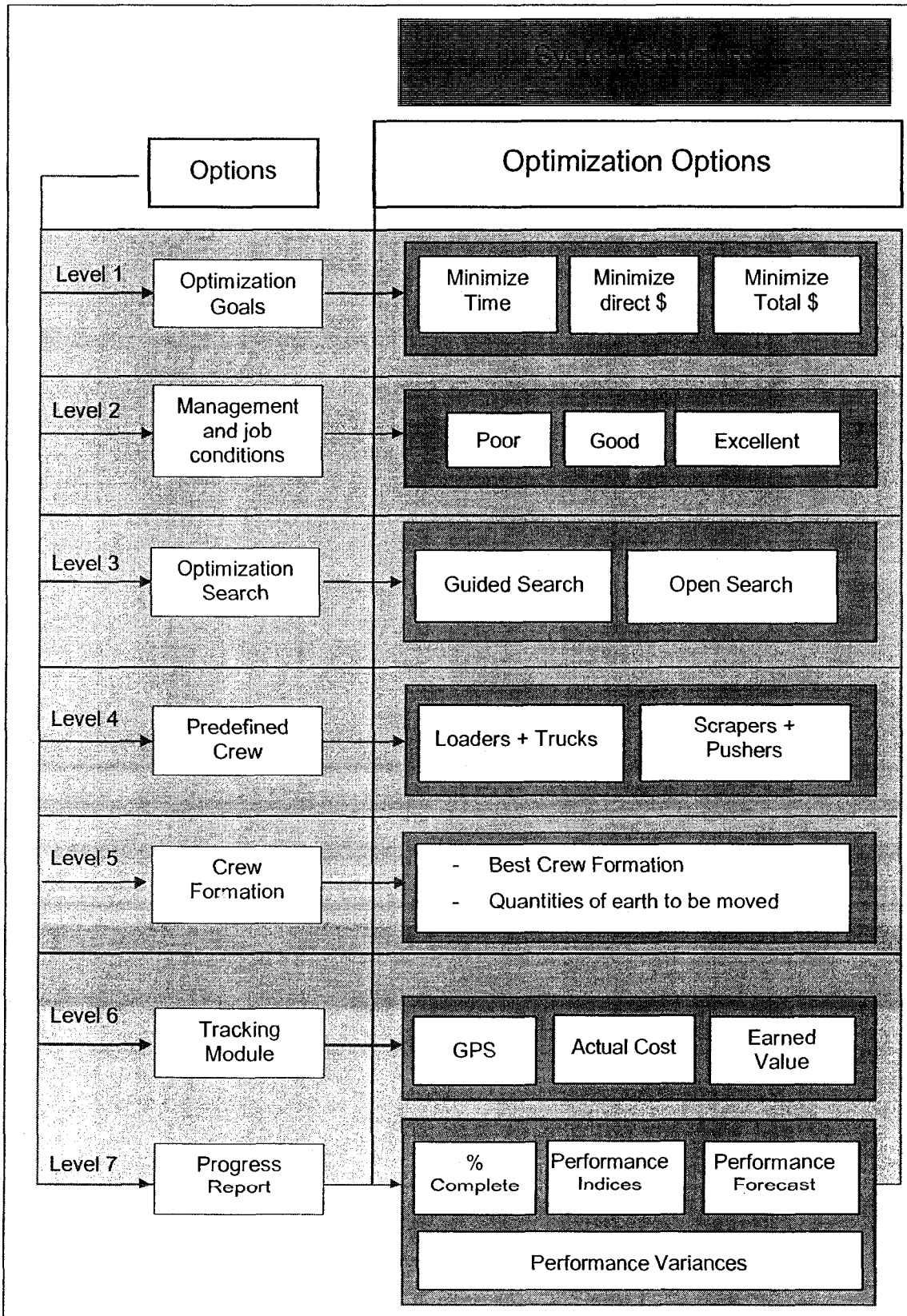


Figure 6-2: System breakdown structure

6.4 Data Flow of the Proposed System

The system, in the planning and construction phases, commences by accepting data from the user and from the systems' database. The system accepts both graphic and non-graphic data. In the planning phase, the data required for selecting optimum crew formation entered interactively by the user through a set of interface dialog windows and retrieved from the systems' database. The data retrieved from the database include soil (swell and shrinkage factors), equipment (hourly cost, capacity, model etc), and project data (cost data, job and management conditions). During the construction phase, however, the system receives the needed data interactively from the user through a set of dialog windows and automatically from a GPS receiver (s) using GIS sub-Module. The data from the user includes the actual cost and installed quantities for each reporting period. The data flow in the proposed system is depicted in Figure 6-3.

Upon the completion of the input data and selection of options as shown in Figure 6-2 (level 1 to level 4), the optimization prototype triggers and automatically transfers the required data from the database. The user is then requested to key in additional data related to project indirect costs, selections of hauling routes, etc. The system after that progresses with the optimization analysis, selects the optimal crew formation, determine the quantities of earth to be moved, and estimates project time and cost.

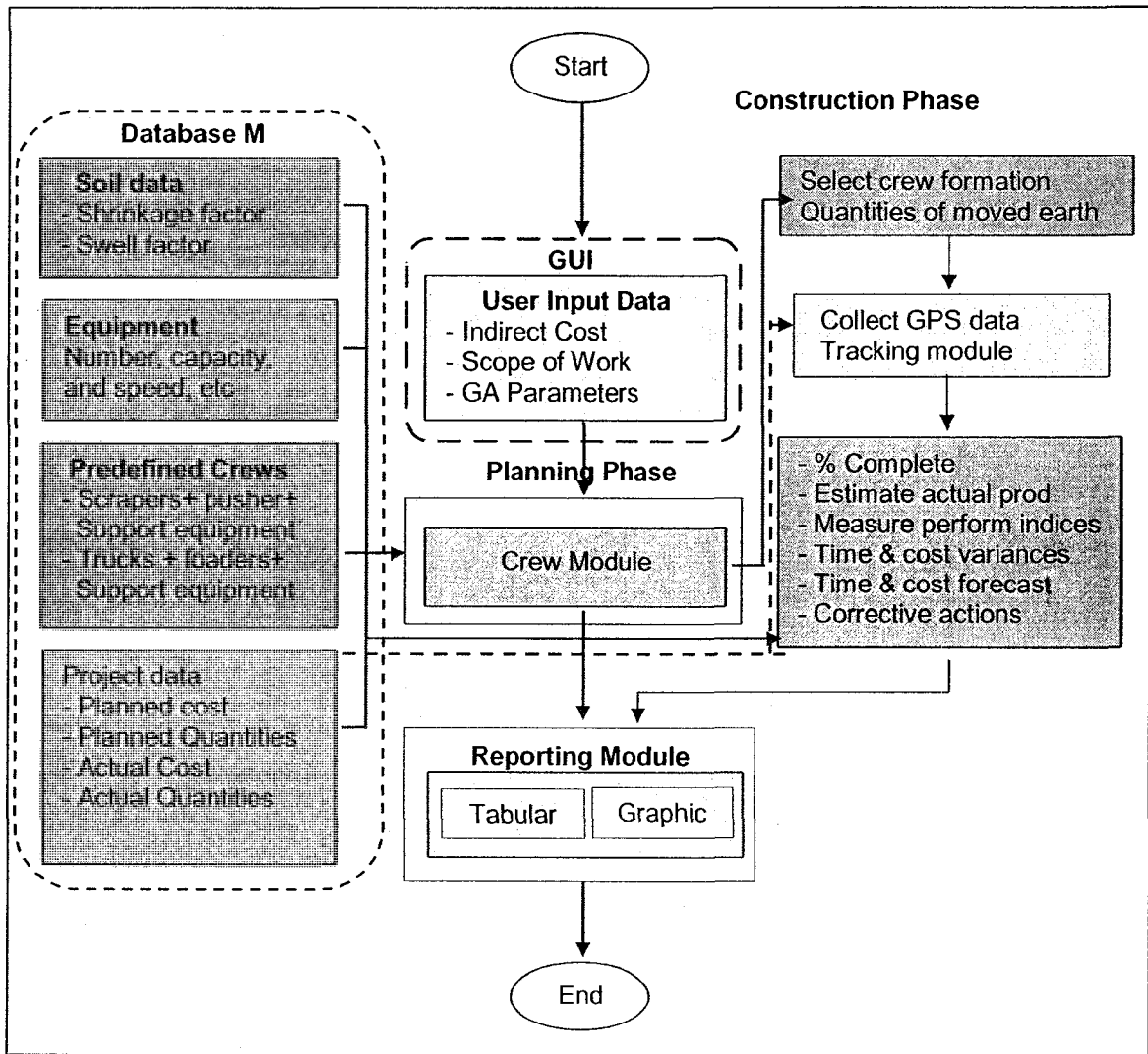


Figure 6-3: Data flow in the developed system

The analysis of the optimization module is essentially performed using the genetic algorithm technique and linear programming as described in Chapter 4. The optimization process is carried out through a set of Dialog Windows (Appendix A). Having selected the near optimum crew formation and after starting construction, the tracking module can then be activated through setting out of tracking parameters. It automatically progresses with the crew productivity analysis, measurement of project schedule and cost status at the report date, and forecasts time and cost at any date set in the time horizon interval. The

analysis is essentially performed based on the user selection of tracking parameters.

The project status is represented by the cost performance index, the schedule performance index, the productivity performance index, and associated variances and forecasts. The system calculates these indices using the earned-value concept or project ratios technique and modified versions of these techniques. It should be noted that the project performance is measured based on the performance of the equipment attached by GPS receiver as representative of other hauling equipment. The main reason behind using such methodology is to overcome the limitations of the availability of GPS receivers and to minimize the process expenses. At the end, the system generates a progress report containing percent complete, performance indices, cost and schedule forecast, and cost and schedule variances at report date and any set date. The user at this stage can explore the project performance during reporting period and up to date. This exploration is achieved using properties page Dialog Window.

6.5 GIS Sub-Module

As cited in Chapter 4, the GIS sub-module has been designed to enhance the optimization and control modules. In planning stage, the sub-module feeds the optimization module with information about travel roads, whereas, during construction, it feeds the tracking module with information about moving equipment so that the equipment cycle time can be determined and the onsite productivity can be estimated. This information includes X, Y, and Z coordinates.

It also presents the data collected by GPS in the map as layer by transforming its position data (X, Y, Z coordinate) to graphical representation. The GIS sub-module is implemented using object-oriented programming and map-objects library developed by ESRI. It is coded using VC++ v.6.0. The sub-module can directly load the spatial data collected by GPS into the system. The GIS sub-module is further improved by developed drawing tool that enable the user to interact directly with the project GIS-map in planning stage and during construction.

6.6 Graphical User Interface (GUI)

The graphical user interface incorporates menus, toolbars, drawing tools, and dialog windows. They are built utilizing object-oriented programming and employing Microsoft Foundation Classes (MFC). This enables the utilization of predefined classes to carry out several functions. The user interfaces have been designed and implemented in a way that facilitates data entry and minimizes redundant data input. Fifty user interfaces have been designed and coded to facilitate: (1) entering project data such as (e.g., scope of work, indirect cost, etc); (2) crew equipment data; (3) soil type; and (4) travel road characteristics. Figure 6-4 depicts a list of the designated dialog windows. The main functions of the proposed system have been coded as public functions in order to facilitate data exchange among them.

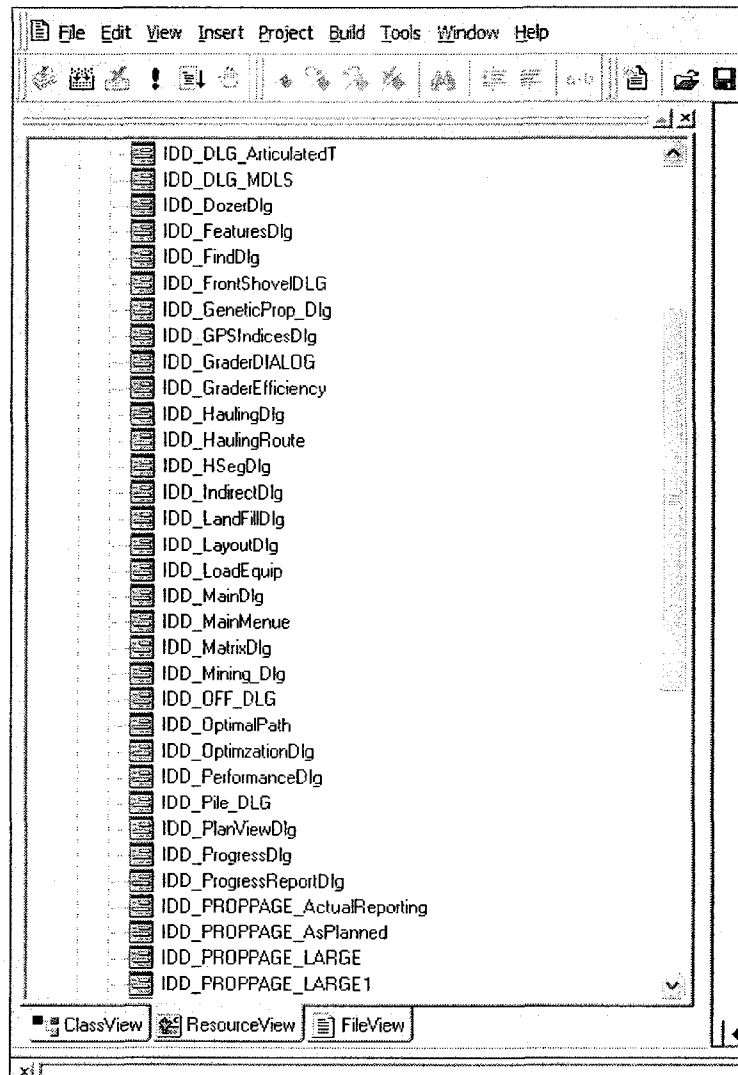


Figure 6-4: Developed system dialog windows

Further to the above, different control classes are used to facilitate the interaction between the user and the system's different modules. These controls include Pushbuttons, Combo boxes, Check boxes, Radio buttons, and map control in addition to developed drawing tools. The system's main dialog window is first displayed upon the activation of the system. As shown in Figure 6-5, this dialog window offers the user either to start optimizing planning of earthmoving operations by activating the optimization module or to work with the tracking and

control separately. The main dialog window consists of one main view in the center to: (1) display GIS map; (2) display moving equipment; or (3) draw different traveled roads. The central view is designed to occupy approximately 60% of the main screen. It displays the data collected by GPS receivers. Converting data to information using graphical representation and visualization techniques is a powerful form of data analysis (Kannan, 1999). The moving equipment is presented as layer in the GIS map. The left side of the main screen displays the table of contents of the project layers (moving construction equipment on site). The right side consists of a set of push buttons to access the system different modules and functions. The top of the screen displays support functions for mapping such as viewing and drawing tools.

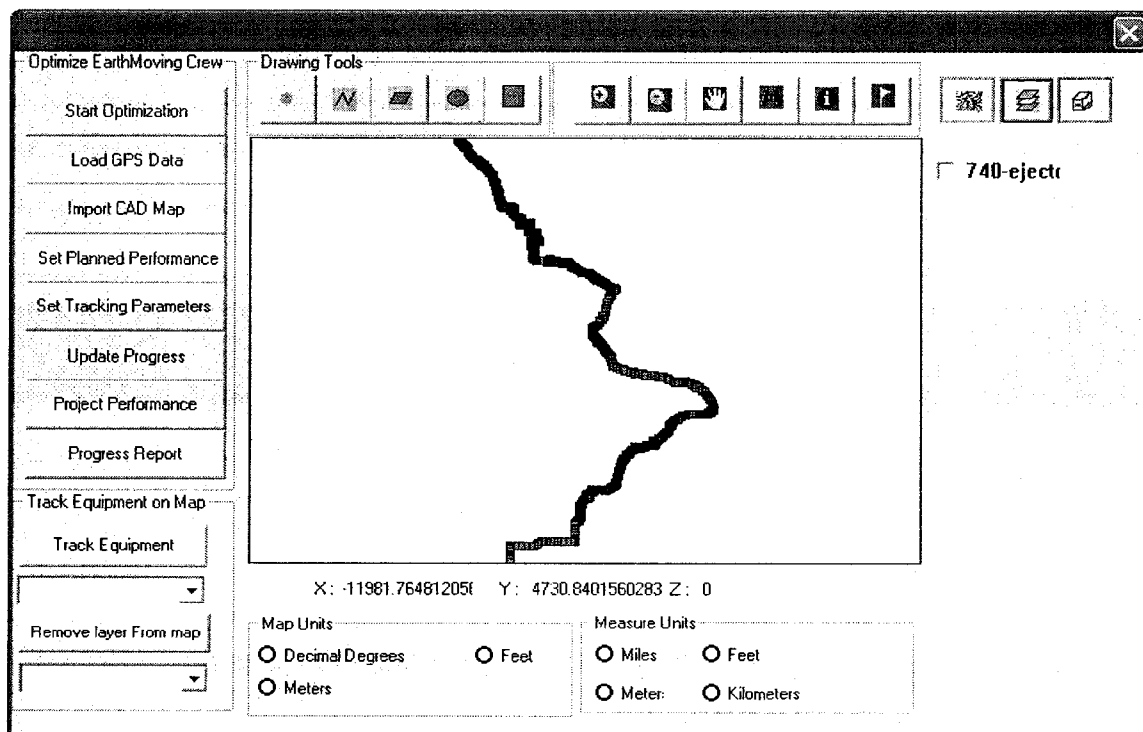


Figure 6-5: Developed system main dialog window

Figures 6-6, 6-7 and 6-8 depict example of such windows. Other dialog windows are included in Appendix A.

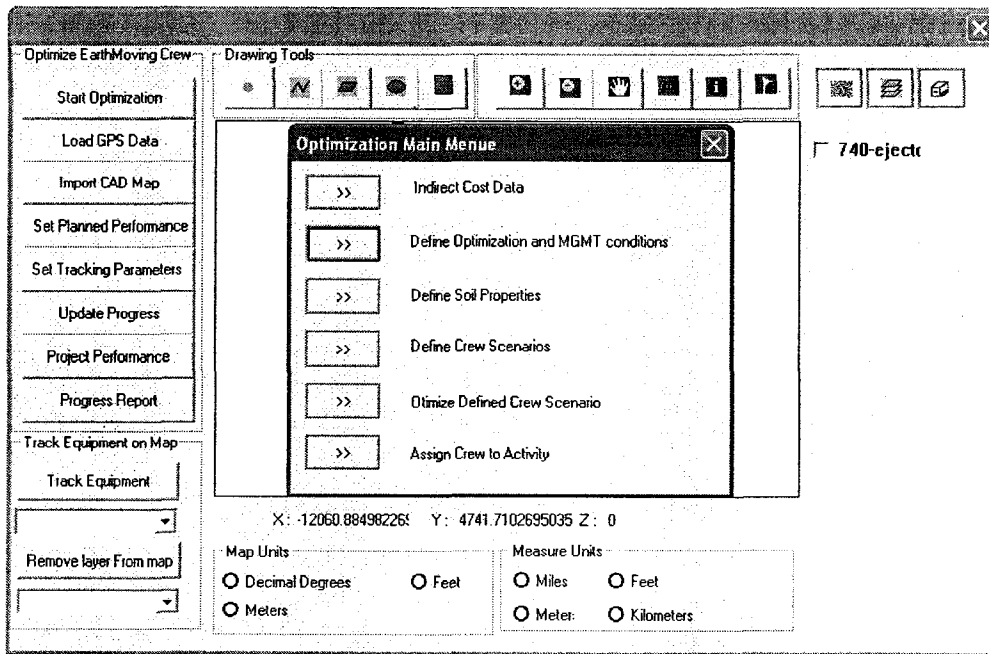


Figure 6-6: Main dialog window of optimization module

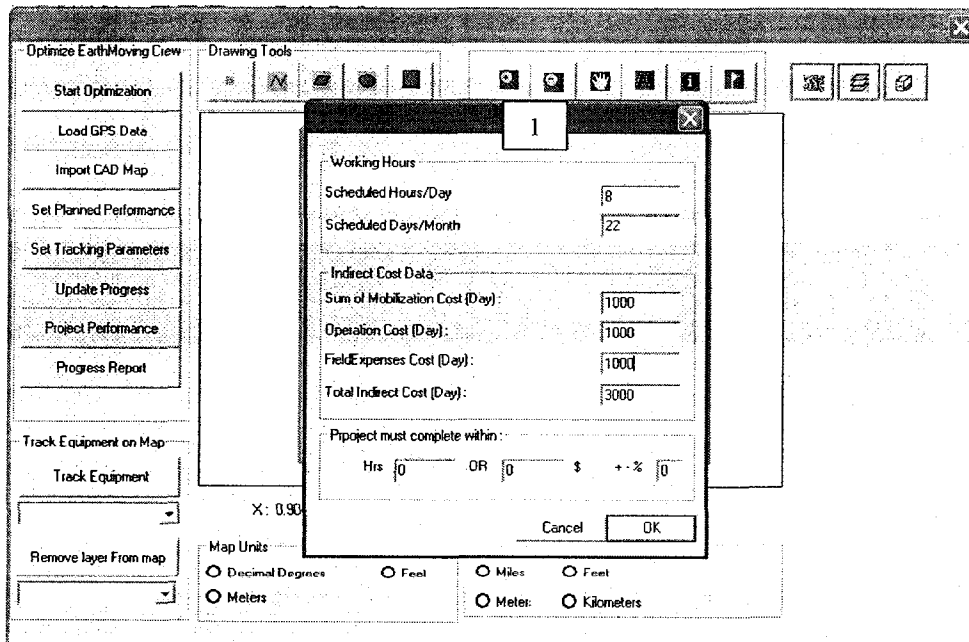


Figure 6-7: Dialog window of project's indirect cost

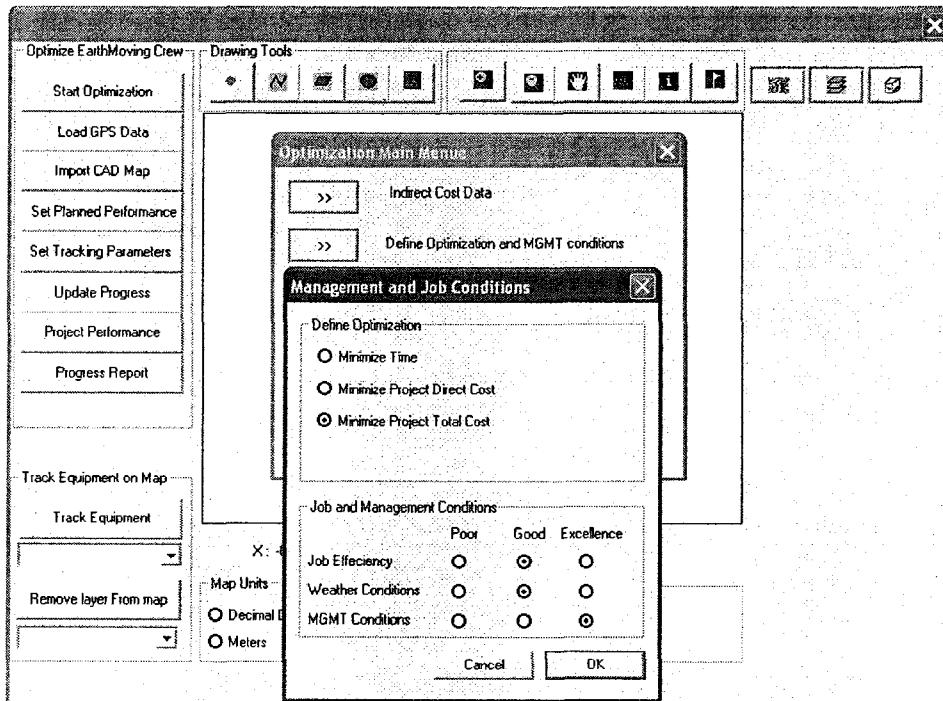


Figure 6-8: Dialog window of defining optimization

6.7 Model Validation

A real case project is considered to validate the developed optimization module. The project was originally analyzed by Marzouk and Moselhi (2004) using simulation optimization technique and it will be referred to later as SimEarth. To enable a comparison, the phase three construction of Saint-Marguerite-3 (SM-3) dam project is considered. The phase involves moving 2,500,000 m³ (bank volume) of moraine (Loose Density (t/ m³) = 1.66, Bank Density (t/ m³) = 2.02) from a borrow pit located at a distance of approximately 15 km from the project site. The dam is considered the highest rock-fill dam in Quebec. It is located on Saint-Marguerite River, 700 Km northeast of Montreal as shown in Figure 6-9. This location was chosen to benefit from a 330 m water head, seven times the

height of Niagara Falls. Table 6.1 depicts the characteristics of the travel road from Impervious Moraine to the dam site.

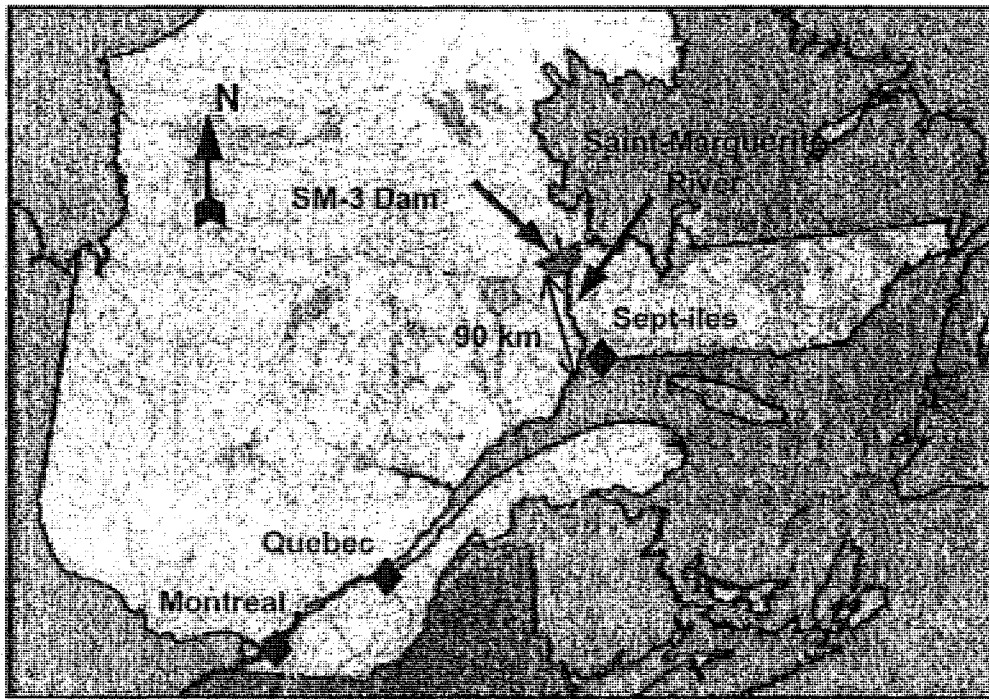


Figure 6-9: Dam location across the Saint-Marguerite River (Marzouk 2002)

Table 6.1: Haul road from IM to the dam (Marzouk 2002)

Segment No	Length(m)	Grade (%)	RR (%)	TR (%)
1	973	-5.5	5	-0.5
2	709	1.7	5	6.7
3	824	4.9	2	6.9
4	1167	1.9	2	3.9
5	899	0.7	2	2.7
6	1023	-0.5	2	1.5
7	1415	-5.9	2	-3.9
8	891	-0.5	2	1.5
9	962	0.4	2	2.4
10	708	-0.2	2	1.8
11	949	-0.6	2	1.4
12	1031	1.4	2	3.4
13	1006	-0.6	2	1.4
14	787	0.1	2	2.1
15	710	-0.2	2	1.8
16	955	3.3	2	5.3
17	185	0	2	2
Total	15,194			

To dry the dam site during construction, a temporary diversion tunnel was excavated and a rock fill cofferdam was constructed as depicted in Figure 6-10. The data used in this case study is presented in Table 6.2. The characteristics of the travel roads (i.e. lengths, number of segments per road and the grade of each segment) were determined from the contour drawings, which establish the profiles of the proposed travel roads. Figure 6-11 depicts the borrow pits and the dumping zone locations relative to the dam.

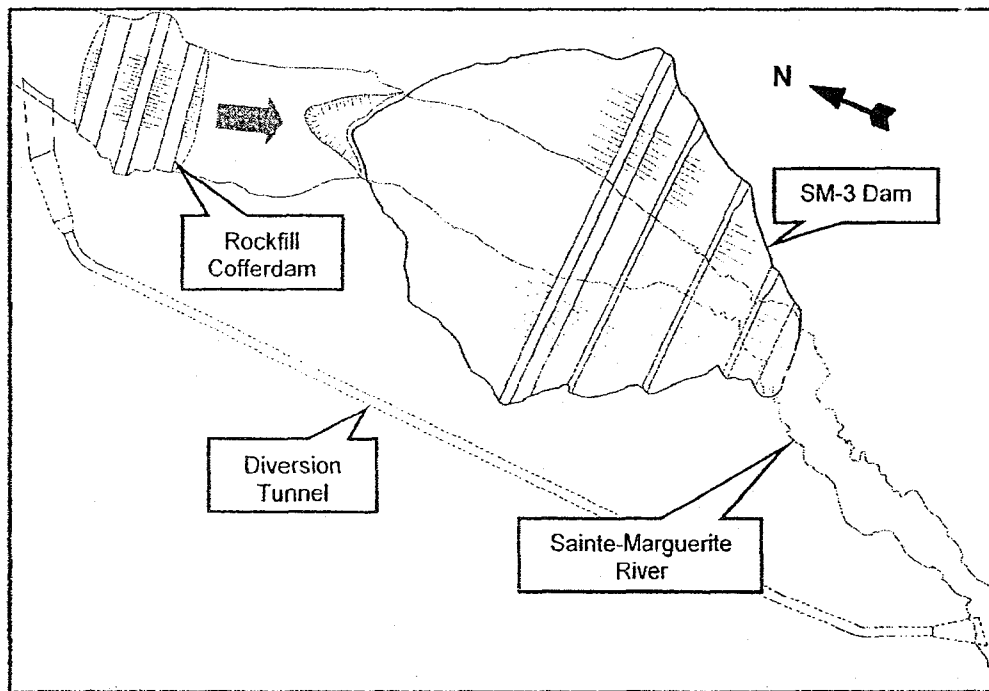


Figure 6-10: Temporary diversion tunnel and rock fill dam (Marzouk, 2002)

Table 6.2: Data of the dam

Height:	171 m
Length at crest:	378 m
Crest width:	10 m
Base elevation:	500 m
Crest elevation:	410 m
Max. normal water level:	407 m
Min. normal water level:	393 m
Total volume of fill:	6.3 million m ³

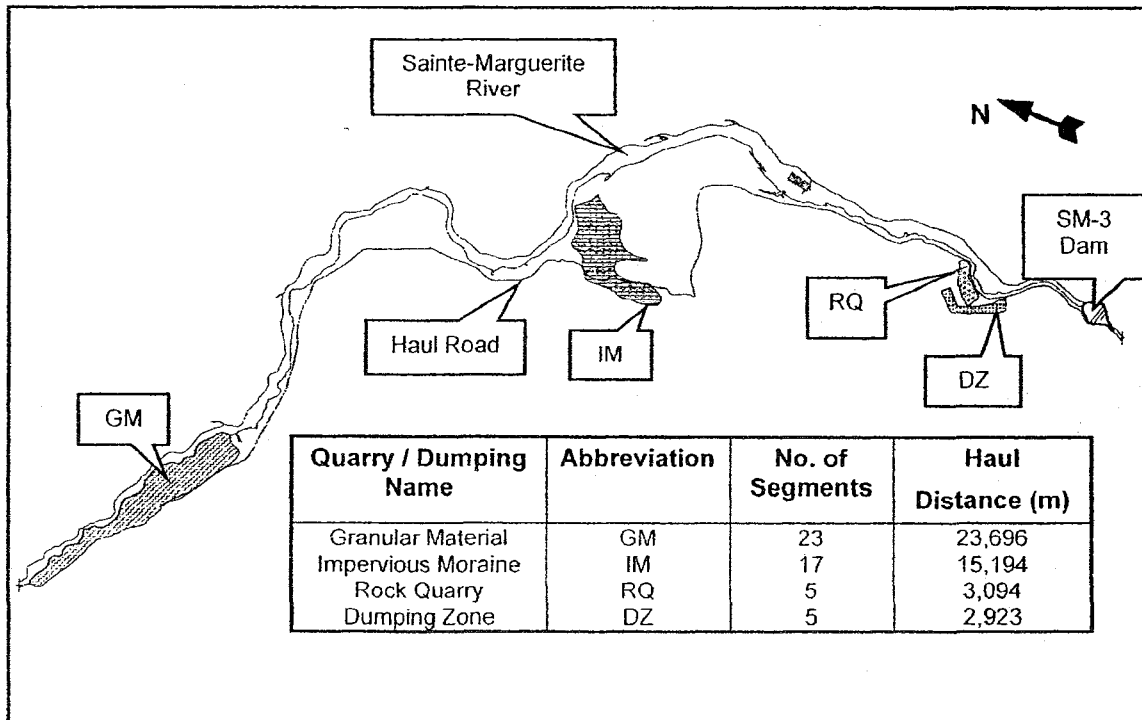


Figure 6-11: Quarry and dumping zones (Marzouk 2002)

The characteristics of the equipment available to contractor and the project data are summarized in Tables 6.3 and Table 6.4, respectively. The developed module is tested in selecting near-optimum crew formations to minimize project duration and total cost.

Table 6.3: Characteristics of the available equipment

Loaders (Loader Type)	
Model	CAT 992G
Available Number	10
Bucket Capacity (m ³)	12.3
Hourly Owning & Operating Cost (\$/hr)	300
Haulers Unit (Off –highway truck)	
Model	CAT 777D
Available Number	50
Payload (ton)	81.7
Hourly Owning & Operating Cost (\$/hr)	215
Dozer	
Model	CAT D&R
Available Number	10
Cycle Production (m ³)	27
Hourly Owning & Operating Cost (\$/hr)	150
Soil Compactor	
Model	CAT CS-583C
Available Number	10
Cycle Production (m ³)	19.1
Hourly Owning & Operating Cost (\$/hr)	90

Table 6.4: Project data

Parameter	value
Scheduled daily hours	8 hours
Number of working days per month	22 days
Time-related indirect cost(dollars/month)	\$500,000
Time independent indirect cost(dollars)	\$1,000,000

The result of the analysis obtained using the developed module was compared to those obtained using the model of SimEarth as shown in Tables 6.5 and 6.6. The results as can be seen from the tables are in good agreement. It should be noted that however, the result obtained using the developed module represents an improvement over the model used in SimEarth. For example, in case of minimizing project duration, although, both models selected the same number of

trucks (50 units); the project duration was different. This difference is due to the selected number of loaders.

Table 6.5: Output of the developed module

Objective	Crew configuration ^a	Total cost (\$)	\$/ m ³	Duration
Minimum Duration	(9,50,5,6)	14,700,000	5.89	780
Least cost	(3,42,3,4)	13,711,722.4	5.48	936

(N1,N2,N3,N4); N1: number of loaders; N2: number of haulers; N3: number of spreaders; N4: number of compactors.

Table 6.6: Output of SimEarth

Objective	Crew configuration	Total cost (\$)	\$/ m ³	Duration
Minimum Duration	(8,50,8,6)	17,436,553	6.97	927
Least cost	(4,47,5,7)	16,432,754	6.57	994

On one hand, SimEarth selected just eight loaders. This selection resulted in reduction of crew productivity, which led to longer project duration (927 hours) and unnecessary cost due to idle time of equipment. Unlike the model used in SimEarth, the developed model selected nine loaders, which match better the number of selected trucks and consequently resulted in increased crew productivity and in reduction of project duration (780 hours). Further, SimEarth selects eight dozers and six compactors to minimize project duration. In this case, the number of compactors is smaller than the number of dozers. This has been changed in case of least cost, in which SimEarth selected five dozers and seven compactors. This change is attributed to the lack of consideration of the relation between dozers and compactors productivity. This has led to the selection of unnecessary compactors and dozers units that do not increase crew productivity but increase crew total cost. Based on the comparison between the

developed module and SimEarth, the proposed module offers the following improvements:

1. Development of server waiting time rule in selecting crew configuration to speed up the optimization process and avoid generating, evaluating, and selecting unrealistic crew formations.
2. Developed of waiting time rule helps the genetic algorithm to select a crew formation in which the number of servers reasonably matches the number of customers and vice versa.

Figures 6-12 and 6-13 show statistical analysis of initial and final populations in least cost case.

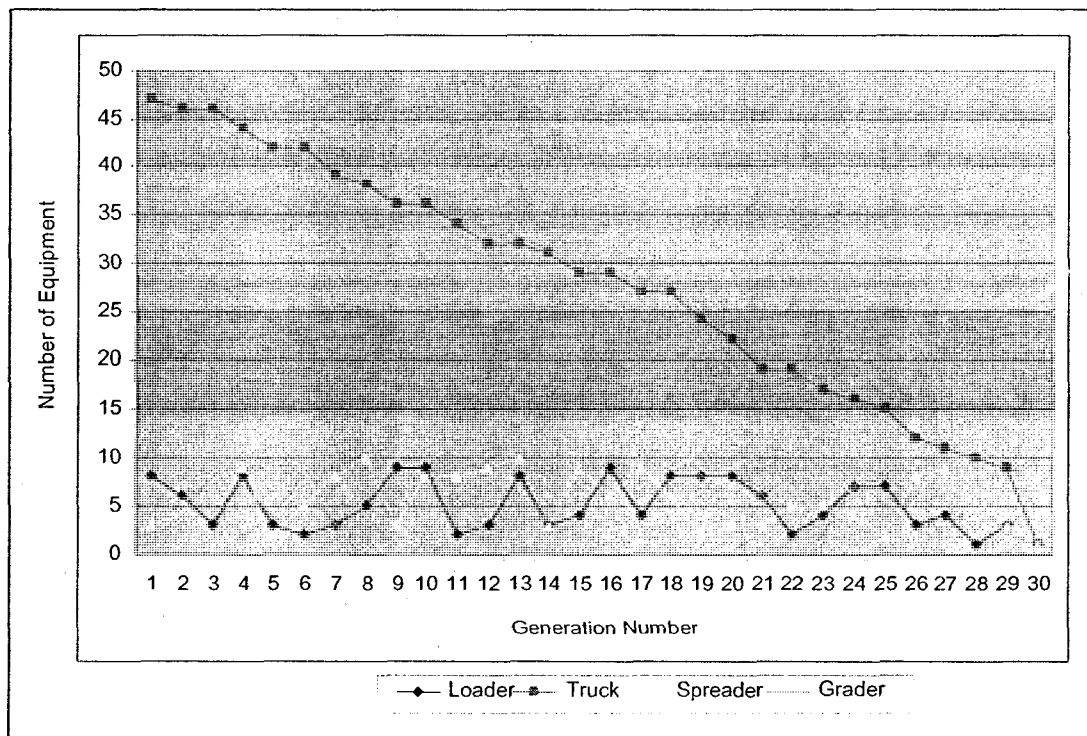


Figure 6-12: Statistical analysis in initial population

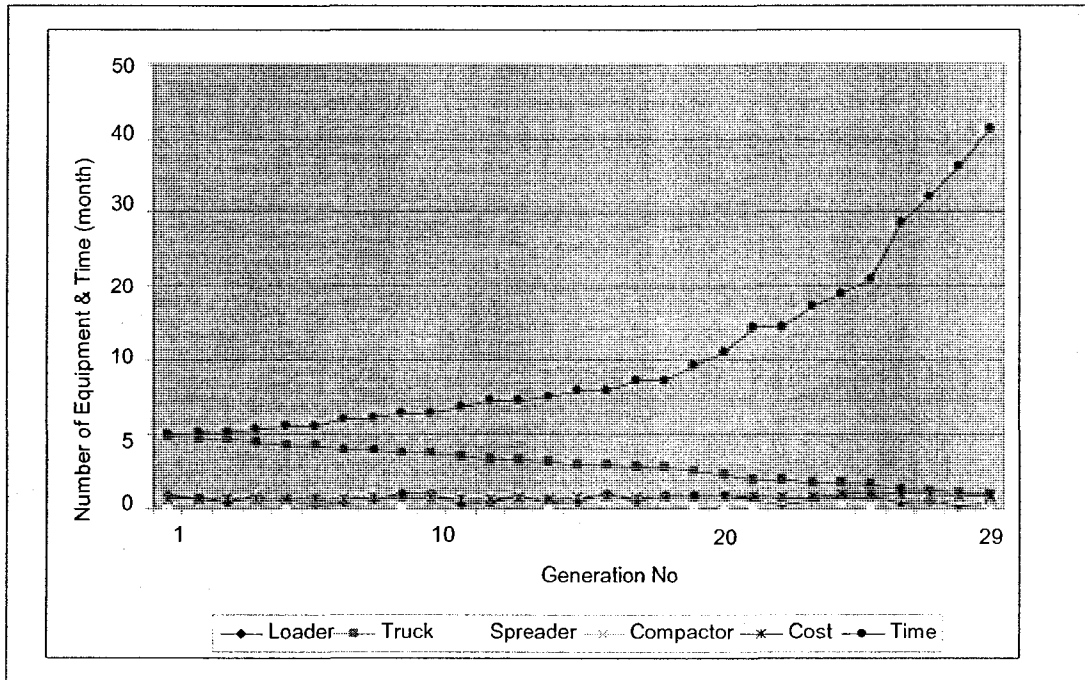


Figure 6-13: Statistical analysis (least cost)

6.8 Example Applications

Two case examples were analyzed to demonstrate the essential features of the developed model beyond those demonstrated in the earlier case. The first example is considered to illustrate the capabilities of the developed model in optimizing earthmoving operations considering multi borrow pits and landfill sites. The second case is analyzed to illustrate the capability of the developed model in tracking and control of earthmoving operations.

6.8.1 Case Example 1

The project involves moving of 87,000 Bm³ (bank cubic meters) of earth from three locations, referred to later as borrow pits and haul the excavated material to three designated areas, referred to later as landfill sites. The capacity and setup

cost of the borrow pits and landfill sites is shown in Table 6.7. The material is dry, loose sand, weighting 2700 lb per BCY. The work should be carried out using a fleet of equipment from a given set of equipment, available to the contractor. It is required to select three crew configurations that respectively, minimize project direct cost, minimize project time, and minimize project total cost. Figure 6-14 depicts a possible plan of the project site.

Table 6.7: Characteristic of borrow pits and landfill sites

	Distance to contractor storage area (KM)	Setup cost (\$)	Capacity(m ³)
LF 1	2	1500	25000
LF 2	2	1800	28000
LF 3	2	2000	34000
BP 1	3	800	40000
BP 2	3.3	1000	35000
BP 3	4	900	30000

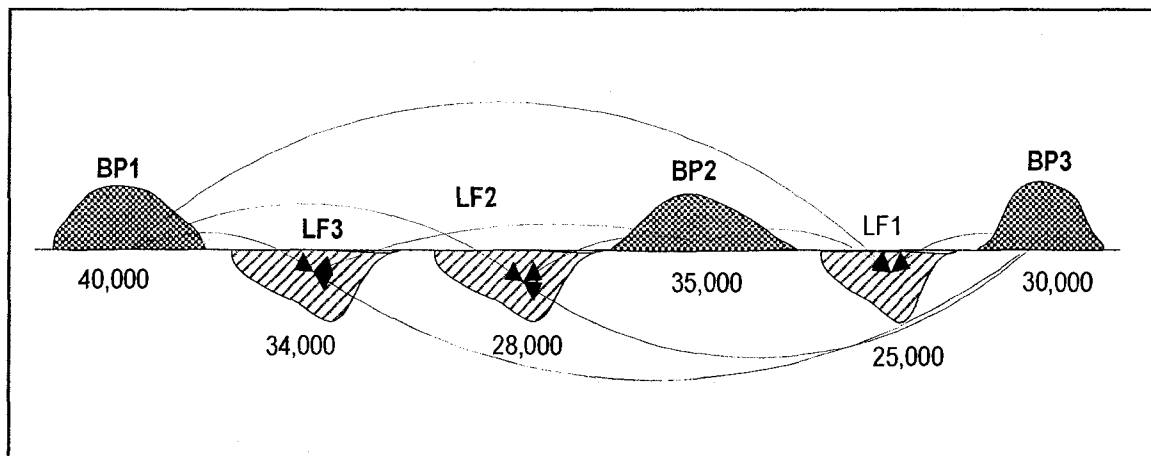


Figure 6-14: Earthmoving plan

The job and management conditions are assumed good and weather condition is an excellent. The earth is excavated using a wheel loader (992G). The earth is hauled using (777D) truck. The available number of loaders is five loaders and its

hourly cost is \$185/hr, whereas the available number of trucks is thirty-five trucks. The truck struck capacity is 42 m³ and its hourly and operating cost is \$ 212.95/hr. In addition, the crew consists of spreading and compacting equipment. The characteristics of travel roads connect borrow pits and landfill sites are presented in Table 6-8.

Table 6.8: Characteristics of traveled roads connect borrow pit and landfill sites

Path Name	No of segments	Segment No	Length of segments(m)	Grade resistance (%)	Rolling resistance (%)	Allowed speed
BP1-LF1	3	1	500	3	5	60
		2	450	1	4	60
		3	500	2.5	5	60
BP1-LF2	4	1	300	3	5	60
		2	400	2	5	60
		3	250	1	5	60
		4	220	3	5	60
BP1-LF3	2	1	600	2	5	65
		2	400	3	5	65
BP2-LF1	3	1	350	3	4	65
		2	400	2	4	65
		3	500	4	4	65
BP2-LF2	3	1	400	0	9	65
		2	280	0	9	65
		3	420	0	9	65
BP2-LF3	2	1	800	0	6	65
		1	1200	2	6	65
BP3-LF1	2	1	800	2	5	65
		2	850	3	5	65
BP3-LF2	3	1	700	4	6	65
		2	750	5	6	65
		3	350	4	6	65
BP3-LF3	1	1	2200	4	10	65

The travel roads have 23 different segments, grade, and rolling resistances. Using manual method to estimate travel and return speed and time is time consuming and not accurate. As presented in the screen printout (Figure 6-15), the developed optimization module estimates travel and return speed and their

associated time in a way that is more efficient. It accounts for segment length, grade, rolling resistance, and acceleration.

	LandFill LF1	LandFill LF2	LandFill LF3
Borrow Pit BF	6.61	5.77	4.74
Borrow Pit BF	5.71	6.82	9.06
Borrow Pit BF	7.22	11.49	19.18

Figure 6-15: Hauling time in minutes

The variables are the equipment used in forming crews including:

1. Thirty-five CAT 777D trucks; five 992-wheel loader; nine 24H grader and six CAT CS-583C compactor.
2. Quantities of earth to be moved

The Constraints are:

1. 992 wheel loader: \$ 185/hr and amount is an integer between 1 and 5
2. CAT 777D trucks: \$ 212.95/hr and amount is an integer between 1 and 35
3. CAT CS-583C compactor: \$ 90/hr and amount is an integer between 1 and 6
4. 24H (Global) grader: \$ 100/hr and amount is an integer between 1 and 9
5. Capacity of borrow pits and required earth at landfill sites

6. allowed speed

As it can be seen from Figures 6-16, 6-18, and 6-19, the module has selected neither to move any earth from borrow pit 1 to landfill 1, borrow pit 2 to landfill 3, borrow pit 3 to landfill 2, and borrow pit 3 to landfill 3. The module, in selecting the quantities of earth to be moved, accounts for factors including capacity of borrow pits, required earth at landfill sites, site setup cost, travel and return time, and travel road conditions.

Three crews formation have been selected to minimize project time, project direct cost, and project total cost. In the case of minimizing project time, the module forms a crew of 5 loaders, 33 trucks, 6 graders, and 3 compactors. The module has selected the maximum available number of loaders to maximize crew productivity and to finish the project in shortest possible time (Figure 6-16). Figure 6-17 presents 80 different crews formations generated in the initial population. It should be noted that the chromosomes (crews) were sorted from best to worse so that the top 25 percent is used for random selection to carryout the genetic operators functions as presented in Section 4.5.2. In the case of minimizing project direct cost, the module forms a crew of 3 loaders, 14 trucks, 3 graders, and 1 compactor (Figure 6-18). To minimize project total cost, the module forms a crew of 4 loaders, 20 trucks, 4 graders, and 2 compactors (Figure 6-19).

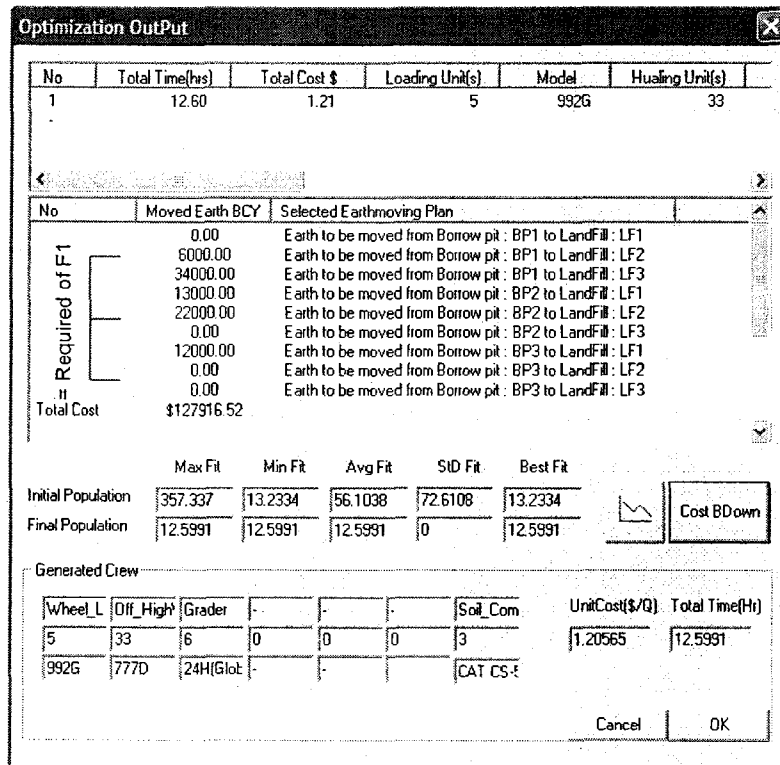


Figure 6-16: Minimize project time

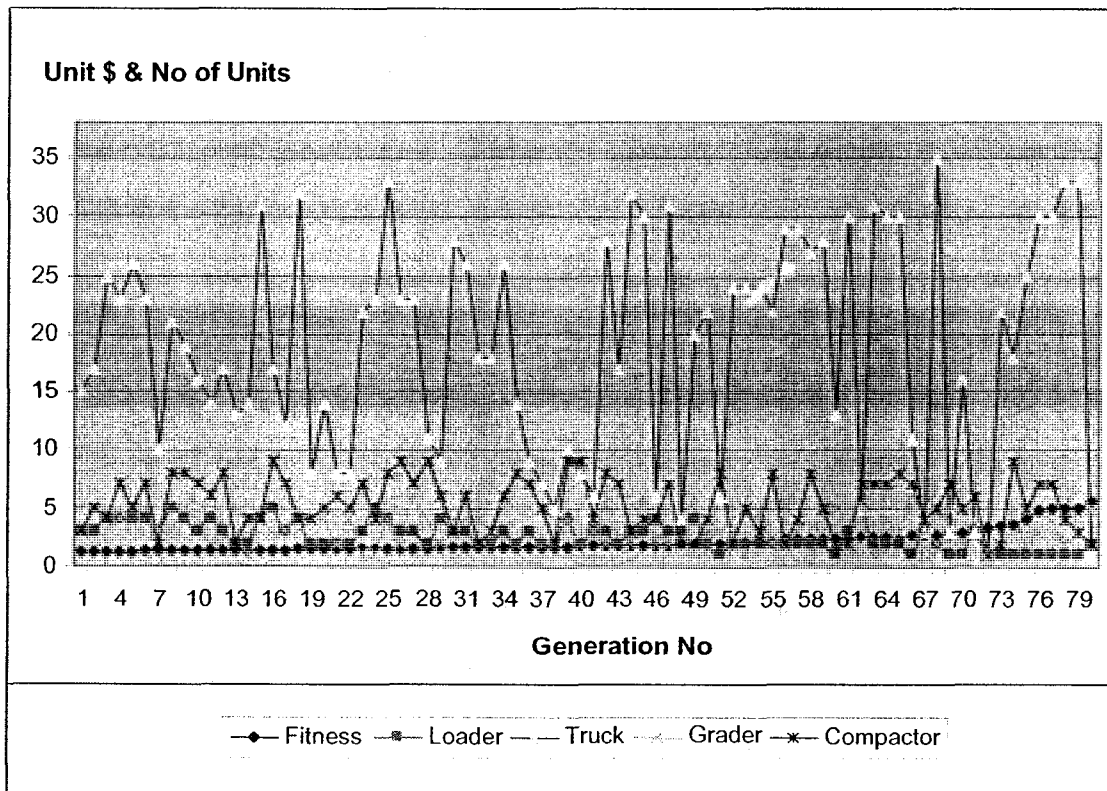


Figure 6-17: Crews formation in initial population

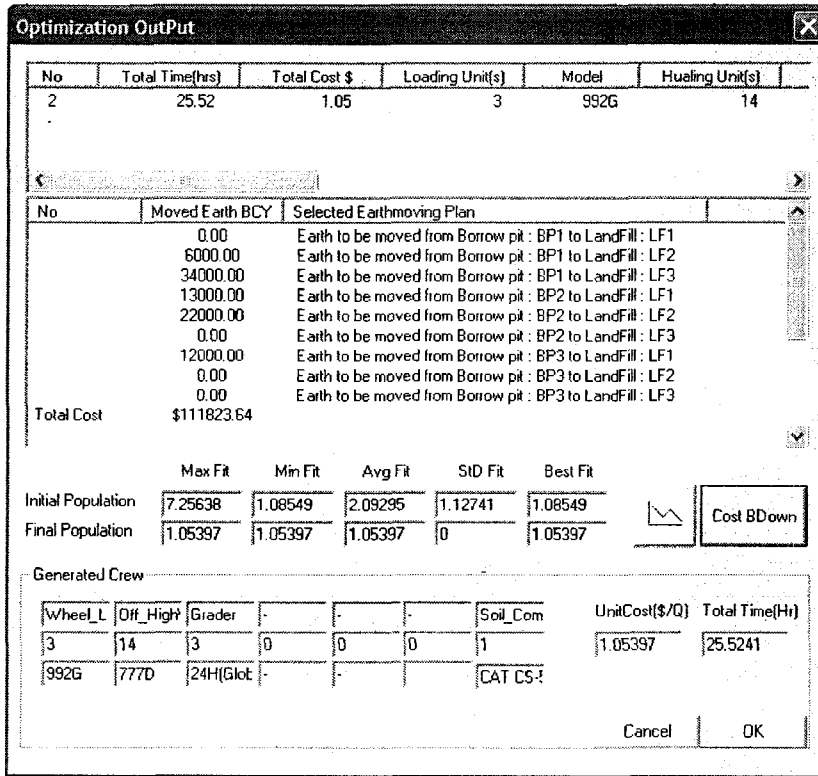


Figure 6-18: Minimize project direct cost

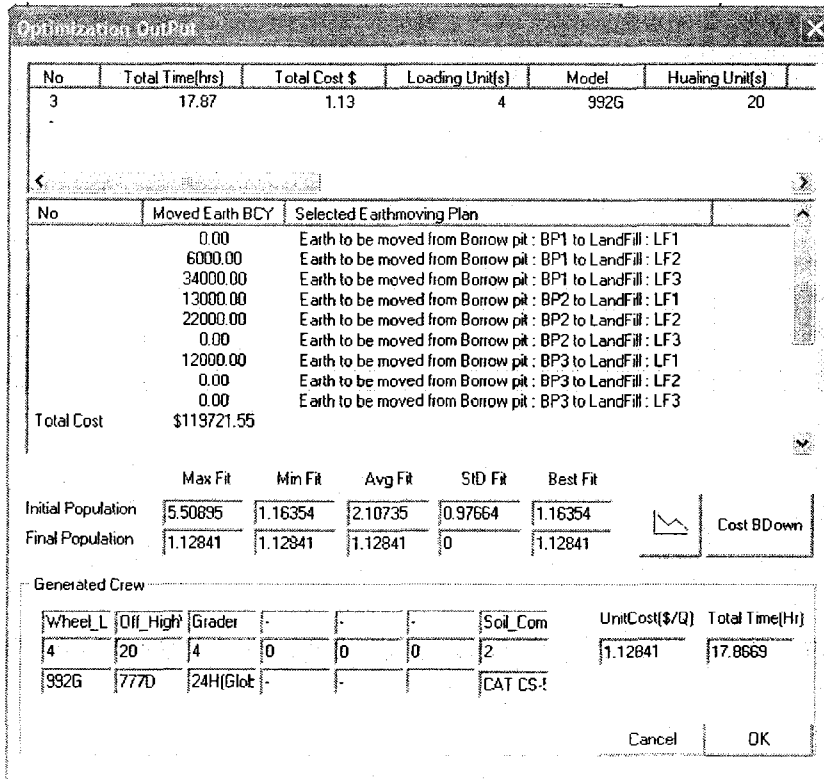


Figure 6-19: Minimize project total cost

Table 6.9 presents the three selected crews formation. Figure 6-20 depicts that the unit cost of the best individual of the initial population in case of minimizing direct cost is \$ 1.085, and the unit cost of the best individual passed to \$1.053 in the 200 generation. For the second case (minimizing total cost), the local minimum is \$ 1.1635 and the unit cost of the best individual passed to \$1.128 in the 135 generation.

Table 6.9: Selected crews formation

Objective	Wheel Loaders	Trucks 777D	Graders	Compactors	\$/ m ³	Time (hr)
Minimize Time	5	33	6	3	1.20	12.6
Minimize Direct Cost	3	14	3	1	1.05	25.5
Minimize Total Cost	4	20	4	2	1.12	18.0

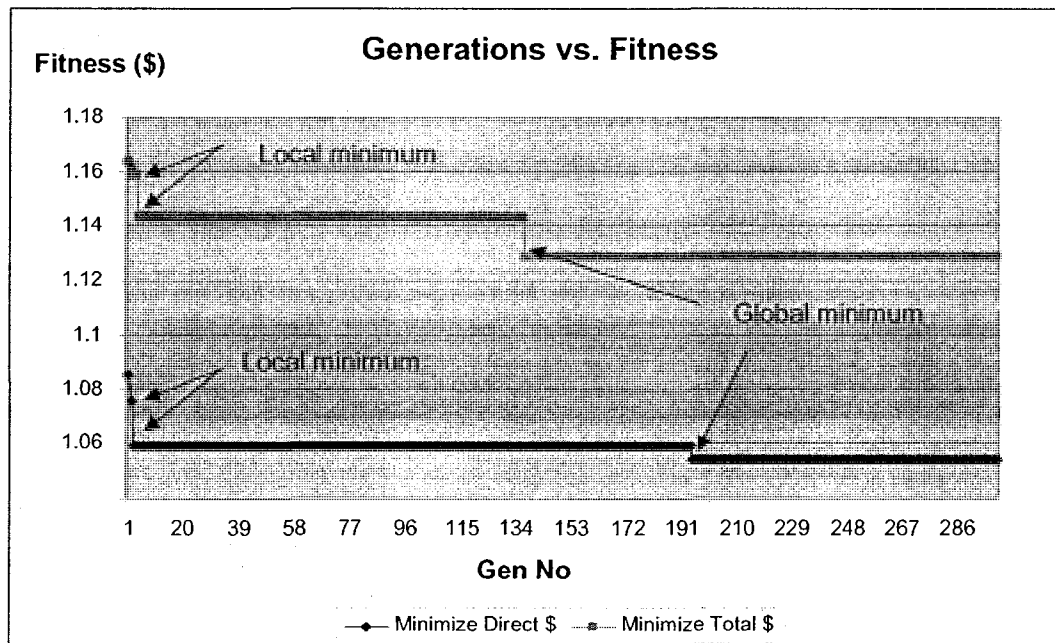


Figure 6-20: Minimizing project direct cost vs. minimizing project total cost

As shown in Table 6.10, the module provides different possible solutions, which can be used in viewing the effect of changes in the module output. For example,

crew 4 and crew 6 show that increasing the number of compactors does not necessary increase the crew productivity as long as the number of trucks remains the same.

Table 6.10: Part of the module output

Crew	Loaders	Trucks	Graders	Compactors	Unit cost (\$)	Time (hrs)
1	3	15	3	3	1.163	23.822
2	3	17	5	2	1.222	21.931
3	4	25	4	5	1.223	15.983
4	4	23	7	4	1.263	16.349
5	4	26	5	5	1.27	15.748
6	4	23	7	5	1.277	16.349
7	3	10	2	3	1.282	35.733
8	5	21	8	3	1.287	17.016
9	4	19	8	5	1.325	18.807
10	3	16	7	4	1.33	22.748
11	4	14	6	2	1.33	25.524
Near optimum	4	20	4	2	1.12	17.86

6.8.2 Case Example 2

The project involves excavating and moving 1,000,000 m³ (bank volume) of moraine (loose density =1.66 t/m³ and bank density=2.02 t/m³) from a borrow pit located at a distance of approximately 2 km from the project site. The allowed speed on the travel road is between 20 and 30 KM per hour for traveling and returning, respectively. The characteristics of the equipment available to contractor are summarized in Table 6.11. The crew formed by optimization module to carry this job consists of three loaders (994 CAT), twenty-five hauling units (740-Ejector), two graders (24H (Global)), and two compactors. The project baseline provided by the optimization module is presented in Figure 6–21. Table 6.12 summarizes the actual cost and quantities accomplished in three reporting periods.

Table 6.11: Characteristic of crew equipment

Loaders (Loader Type)	
Model	CAT 992G
Available Number	2
Bucket Capacity (m ³)	12.3
Hourly Owning & Operating Cost (\$/hr)	185
Haulers Unit (Off -highway truck)	
Model	CAT 725
Available Number	42
Travel Speed / Return Speed	30 / 50
Hourly Owning & Operating Cost (\$/hr)	215
Spread Equipments(Grader)	
Model	24H(Global)
Available Number	9
Task	Mixing Material
Hourly Owning & Operating Cost (\$/hr)	100
Soil Compactor	
Model	CAT CS-583C
Available Number	3
No of Passes	4
Hourly Owning & Operating Cost (\$/hr)	90

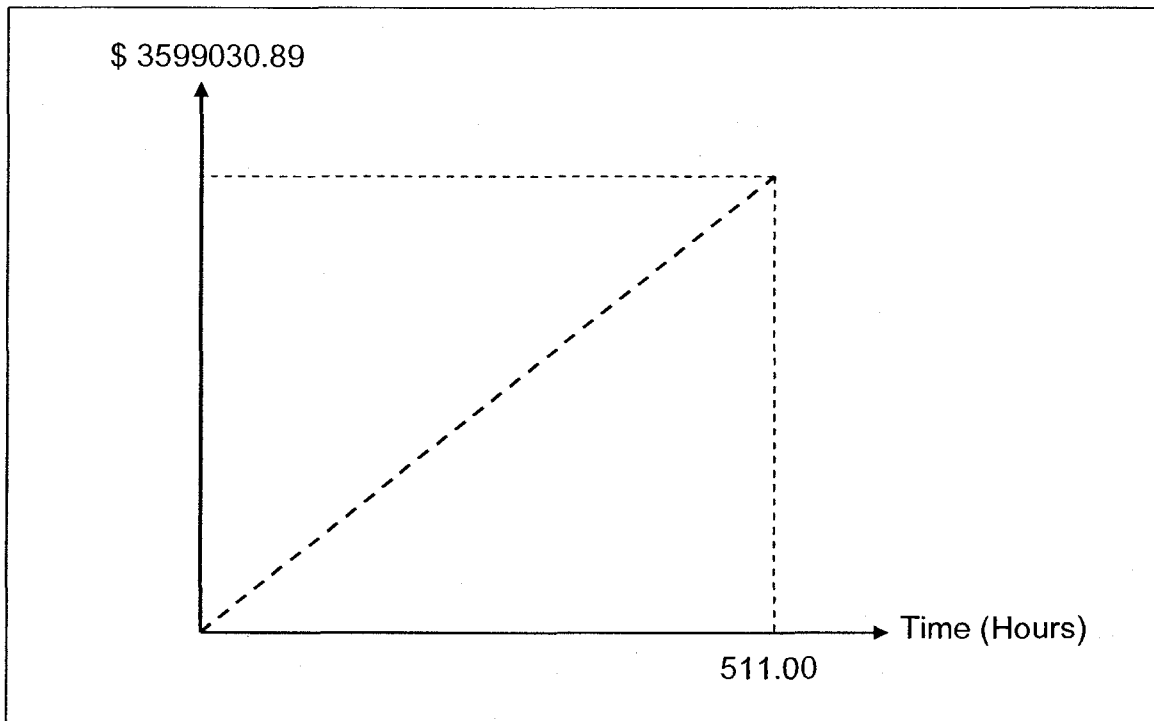


Figure 6-21: Project baseline

Table 6.12: Progress reports data

Report No	(Q)td (m ³)	(Q)tp(m ³)	Equipment	(\$)td	(\$)tp
1	100,000	100,000	Loaders	45,000	45,000
			Trucks	250,000	250,000
			Compactors	1000	1000
			Graders	11,000	11,000
2	220,000	120,000	Loaders	102,600	57,600
			Trucks	580,000	330,000
			Compactors	11,800	10,800
			Graders	23,000	12,000
3	400,000	180,000	Loaders	185,400	82,800
			Trucks	1,078,600	498,600
			Compactors	26,200	14,400
			Graders	41,000	18,000

The proposed module takes the main steps to carry out the tracking process include downloading the GPS data, estimating the crew onsite productivity, determining the project performance, and forecasting project time and cost.

Step 1:

The user, if selects to use GPS data, is required to open the folder where the GPS data file is stored. The data is saved in shape file. Having the file is located, the user then pushes "Open" button as presented in Figure 6-22.

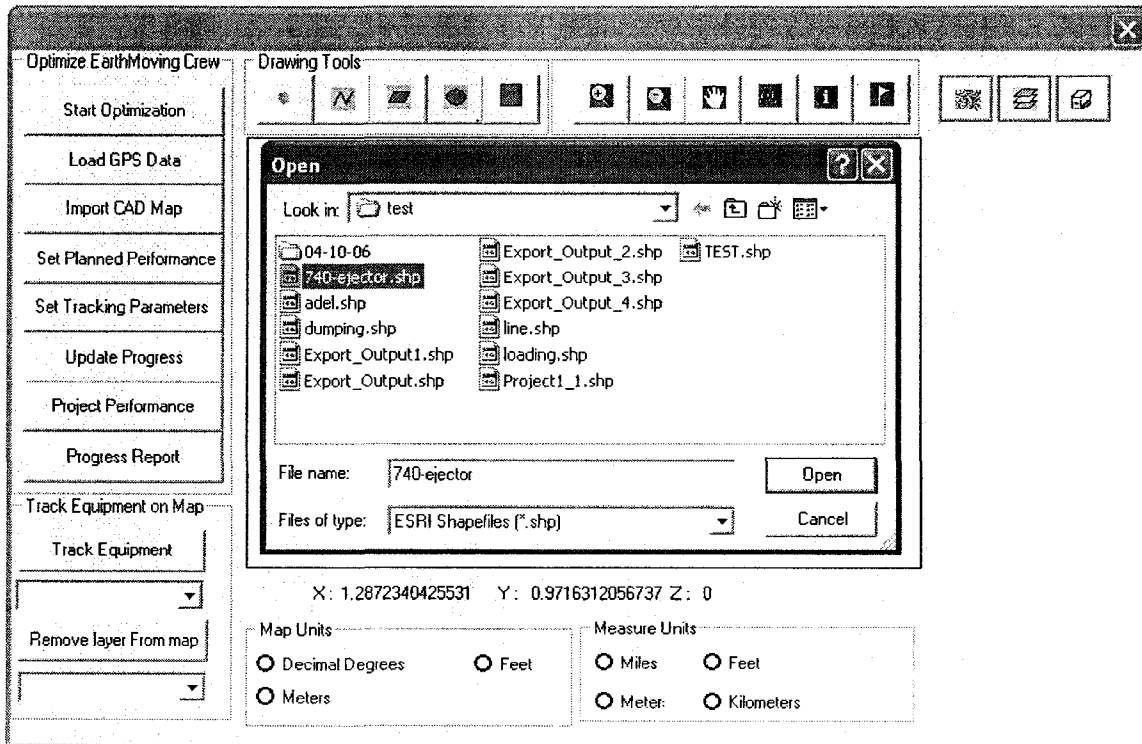


Figure 6-22: Locate GPS data file

Step 2:

Upon opening the data file, the module then automatically transfer the spatial data into GIS map for graphical representation as shown in Figure 6-23.

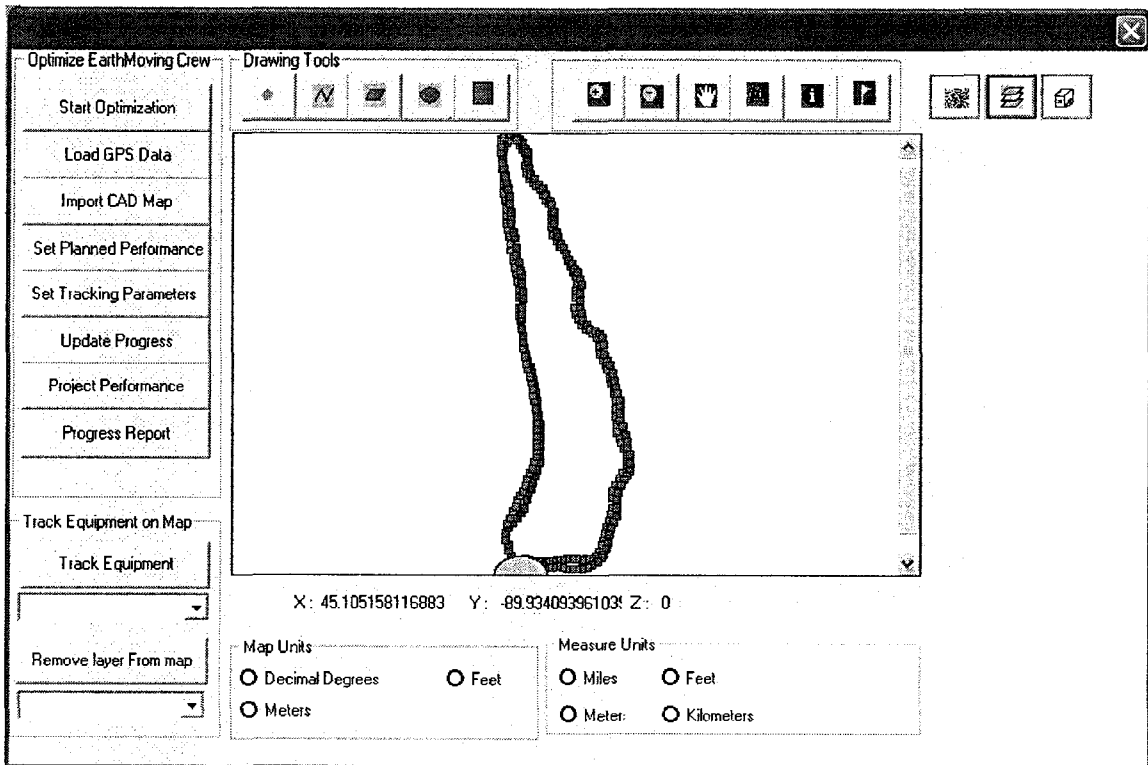


Figure 6-23: Graphical representation of GPS data

Step 3:

At this stage, the user is required to set the acceptable range of planned performance including length of the queuing; customer time delay; actual server quantities; and queuing waiting time; productivity index; cost performance index; and schedule performance index (Figure 6-24).

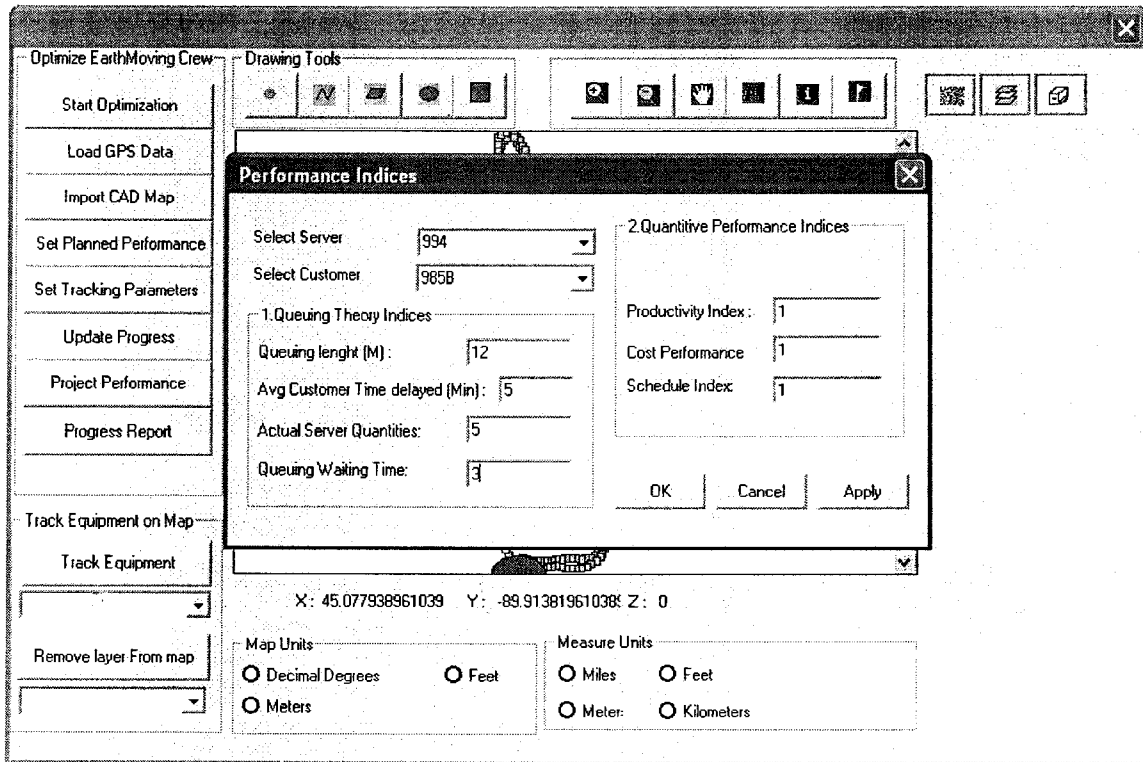


Figure 6-24: Setting planned performance indices

Step 4:

The user is required to set the tracking options such as level of details required, method of estimating onsite productivity, tracking technique used, and the frequency of the progress report as shown in Figure 6-25.

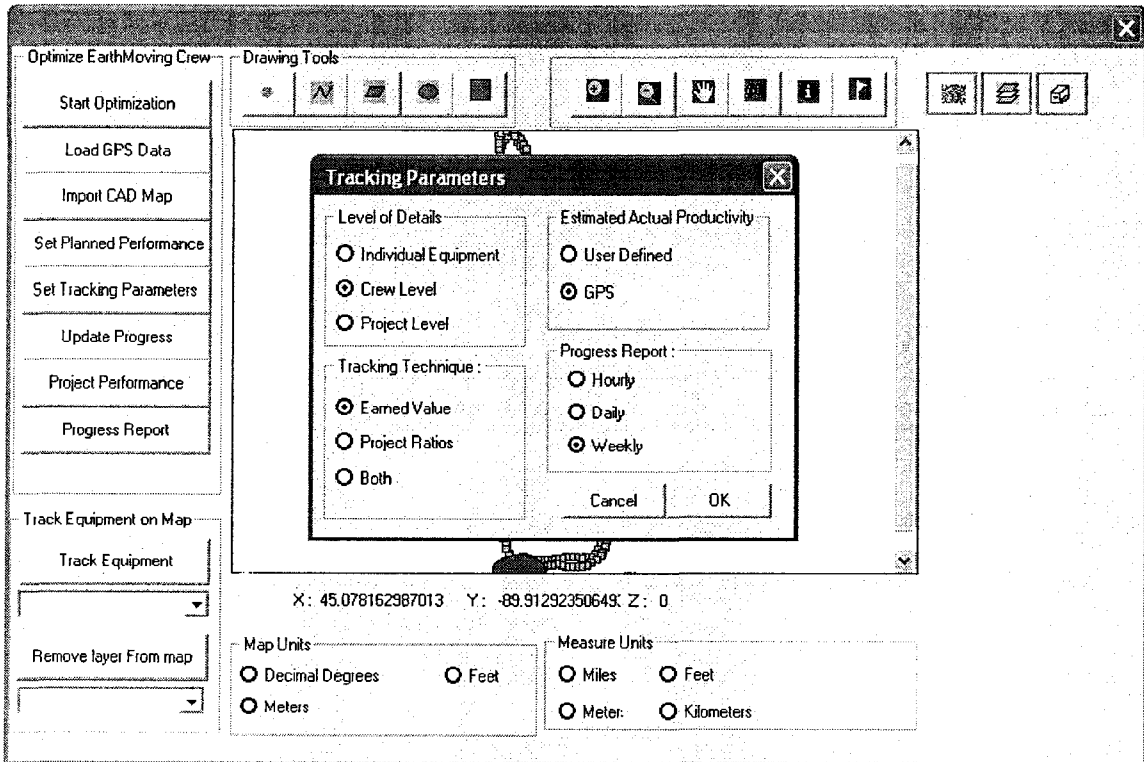


Figure 6-25: Setting-tracking options

Step 5:

At this stage, the user is required to enter the actual quantities of earth moved and the actual cost occurred for reporting period and up to date as shown in Figure 6-26.

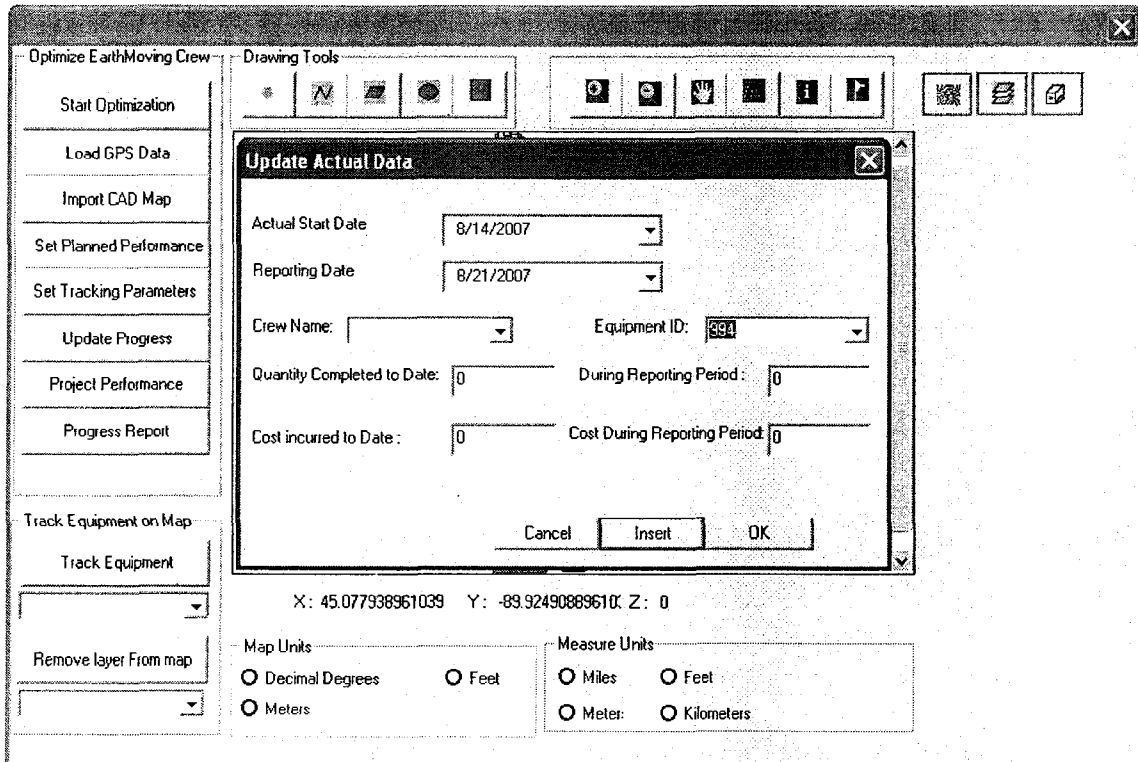


Figure 6-26: Entering actual data

Step 6:

Upon completing the data entry, the user activates the module by pressing "Project performance" push button. Soon after, the module generates tabular and graphical reports showing the progress report. Figure 6-27 represents the module output for the first report taken a week after the actual start date. As shown in the same figure, 10 % of total work has been completed in this period. The property page of the performance indices shows that the project is experiencing cost under-run and slightly behind schedule status. Note that the unacceptable cost performance of the graders does not affect the overall project performance since the graders represent a small portion of the crew cost. As shown in forecast graph, the project will finish with cost saving of \$ 290966.57.

Performance Measurement						
As Planned Performance			Performance Indices		To Date Performance	
Reporting Period Performance					Performance Forecasting	
No	EQ Model	%	CPI	SPI	PPI	Que
1	932G	10.00	1.02	0.91	0.9126	
2	725	10.00	1.10	0.91	0.9126	
3	CAT CS-583C	10.00	9.20	0.91	0.9126	
4	24H(Global)	10.00	0.93	0.91	0.9126	

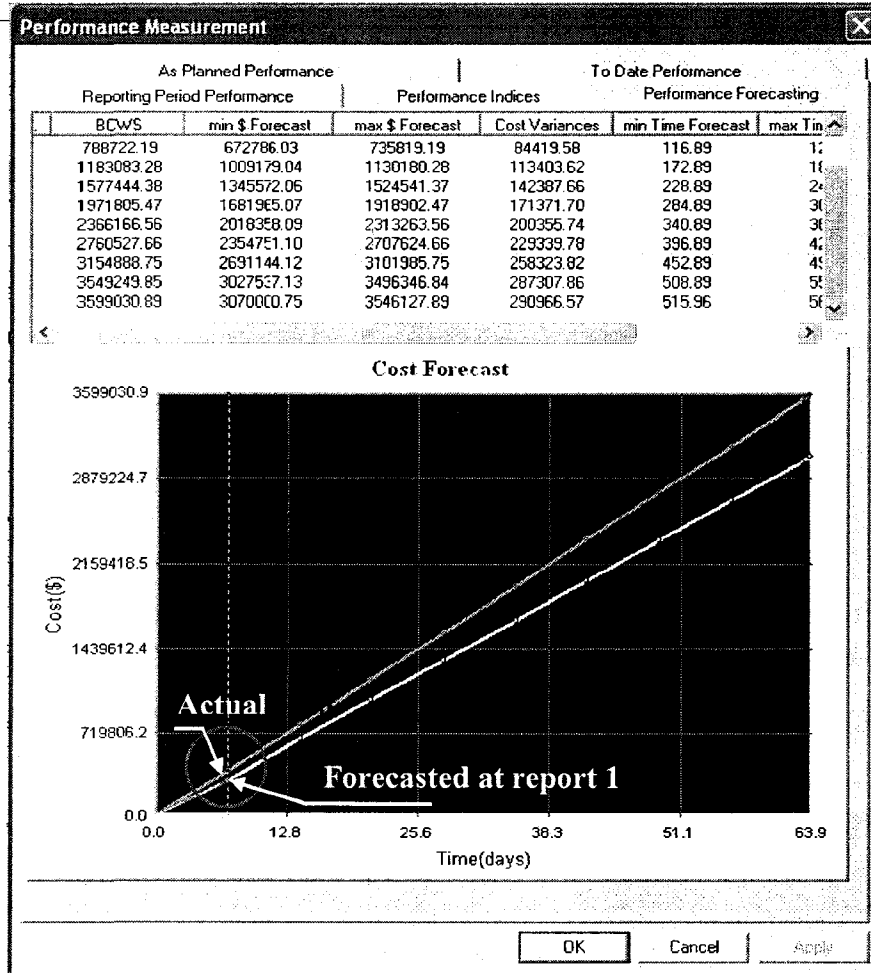


Figure 6-27: Progress report (Report 1)

Two weeks after the actual starting date, a second progress report was taken. During this period, 120,000 m³ of earth has been moved, and 220,000 m³ completed to date. The completed quantities represent 22% of the scope of work. As it depicted in Figure 6-28, although the cost performance index of the loader

is less than one (acceptable range set by the user), the project is still under-run. This is because the loader cost does not represent the biggest portion of the total cost. Additionally, despite the improvement of productivity index this period, the project is still slightly behind schedule. Before forecasting project cost and time of the remaining work, the module determines the cost and time adaptive factors from the previous period by comparing the actual cost occurred with that forecasted as presented in red circle in Figure 6-27. The module slightly underestimated the cost forecast at report one. Those factors are then used to forecast the remaining work. Despite the improvement in the productivity rate during this period, the project will finish with 27 days delay and with saving cost of \$ 140335.85.

Performance Measurement						
As Planned Performance			To Date Performance			
Reporting Period Performance			Performance Indices		Performance Forecasting	
No	EQ Model	%	CPI	SPI	PPI	Quer
1	992G	22.00	0.99	1.00	1.0039	
2	725	22.00	1.04	1.00	1.0039	
3	CAT CS-583C	22.00	1.72	1.00	1.0039	
4	24H(Global)	22.00	0.98	1.00	1.0039	

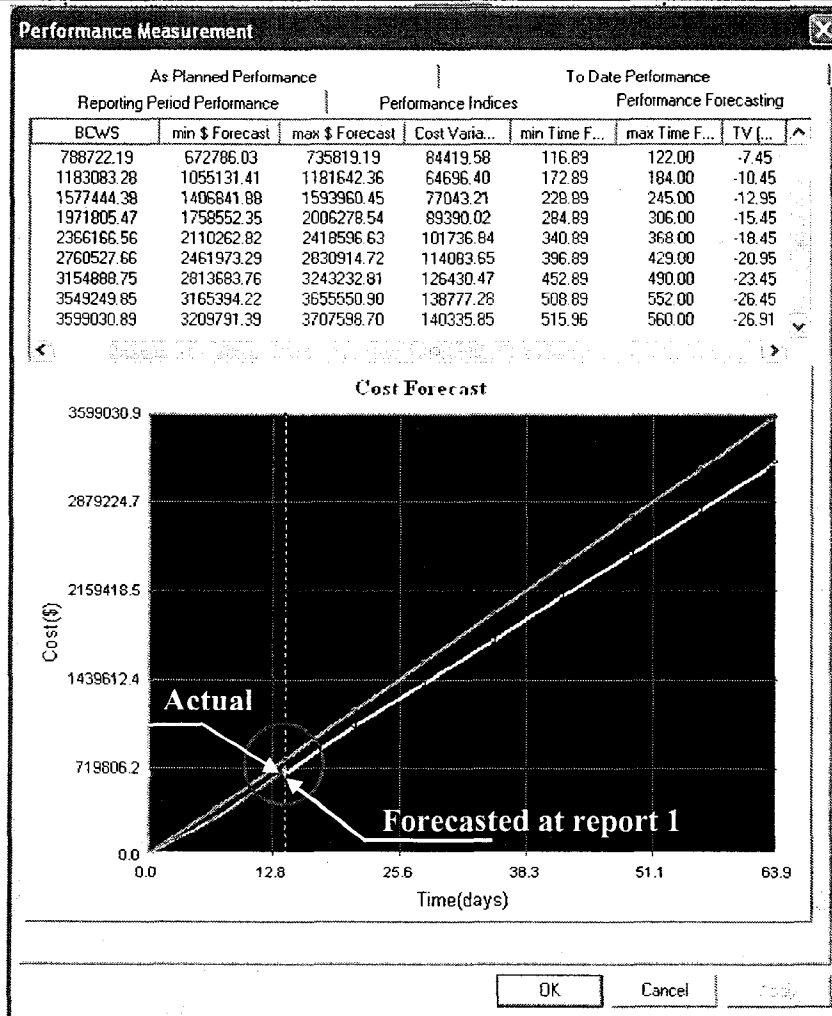


Figure 6-28: Progress report (Report 2)

The report was taken three weeks after the actual starting date. Figure 6-29 depicts that 40% of the project has been completed with slightly overrun and behind schedule status. The property page of reporting period performance

shows that the loader cost performance index is good but the truck performance is slightly under acceptable range. The PPI is still under acceptable range of productivity rate. Under this condition, the project may finish with cost overrun of \$ 404719.78 and 26 days delay at completion. The forecasting screen shows how the project status has switched from under run to overrun status.

Performance Measurement							
As Planned Performance				To Date Performance			
Reporting Period Performance		Performance Indices		Performance Forecasting			
EQ Model	(Q)b	(Q)tp	(\$/Q)b	(\$/Q)tp	(W/hr/Q)b	(W/hr/Q)tp	PPI
992G	1000000.24	180000.00	0.46	0.46	0.0015	0.0028	0.5476
725	1000000.24	180000.00	2.75	2.77	0.0128	0.0233	0.5476
CAT CS-583C	1000000.24	180000.00	0.09	0.08	0.0010	0.0019	0.5476
24H(Global)	1000000.24	180000.00	0.10	0.10	0.0010	0.0019	0.5476

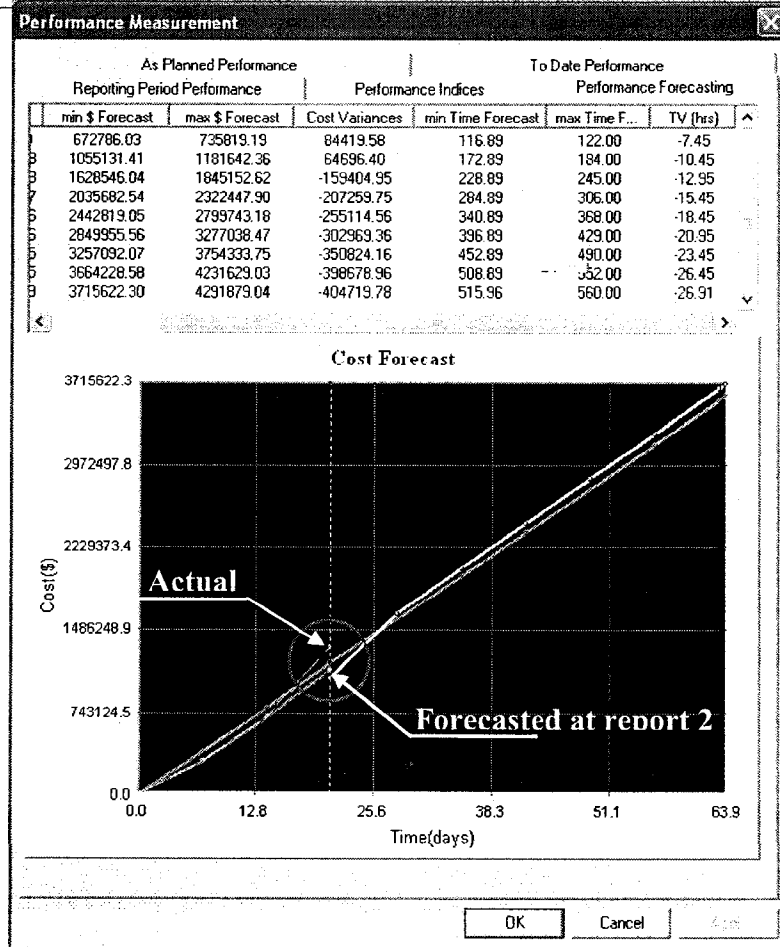


Figure 6-29: Progress report (Report 3)

6.9 Model Limitations

The main limitations of the developed model can be summarized as:

1. The developed model applies in general to heavy civil engineering with except of some mining and damp construction operations, where the use

of GIS map could be replaced with 3D modeling using other technologies such as laser scanner (Moselhi and El-Omari 2006), because GIS provides data in two dimensions.

2. The model does not account for uncertainty associated with cycle time duration in earthmoving operations.
3. The model cannot be applied in urban area where an open sky cannot be reached.
4. The model cannot be applied in tracking and control in close mining projects.
5. The model tracks crew onsite by attaching GPS to only one hauling unit
6. The model cannot recognize broken equipment time outside the loading and the dumping areas.

6.10 Summary

This chapter presented the implementation of the proposed methodology in prototype software. Object-oriented programming is employed to implement the developed system. The system modules are coded in Visual C++ utilizing Microsoft foundation classes. The user interfaces incorporates menus, toolbars, a status bar and dialog windows. Microsoft Access 2003 is employed as database management system. The Pathfinder algorithm is implemented in GIS environment using map objects 3.2 in addition to visual C++ V.6. To illustrate its essential features in optimizing and controlling earthmoving operation in massive earthwork projects, a case study of an actual project also presented.

Chapter 7: Summary and Conclusions

7.1 Summary

This thesis presented a new methodology for optimizing, tracking and controlling earthmoving operations using genetic algorithms, linear programming, and spatial technologies embracing Global Positioning Systems (GPS) and Geographic Information Systems (GIS). The proposed methodology has been implemented in prototype software utilizing visual C++, V.6, and Microsoft Foundation Classes (MFC). The system consists of four main modules in addition to the Pathfinder algorithm, which has been developed in GIS environment. They are: (1) database module; (2) crew optimization module; (3) tracking and control module; and (4) reporting module.

The database module is designed using Microsoft Access Database Management System. The module designed to allow all modules and the developed Path Finder algorithm to be integrated easily. It is based on that developed by Hassanien (2002). The database module provides the proposed system with access to the data needed for computations. The module is composed of three separate databases. They are: (1) resources, (2) project, and (3) Soil databases.

The resources data consists of available equipment to contractor. It also contains some other relevant information such as equipment model, capacity, hourly fuel consumption, ownership, and operating cost. The project data consists of: (1) installed quantities; (2) planned and actual cost, and (3) data collected by GPS.

The soil data stores properties of different types of soil such as shrinkage and swell factors.

The crew optimization module utilizes genetic algorithms and linear programming as optimization tools supported by the Pathfinder algorithm, which has been developed in GIS environment. The module accounts for factors that impact optimization of earthmoving operations. These factors are: (1) resources that are available to contractors; (2) construction site conditions; (3) travel roads topography; (4) quantity of earth to be moved; (5) type of equipment required in these operations; (6) different borrow pits and landfill sites and their respective capacities and setup costs; and (7) project indirect cost.

The tracking and control module use spatial technologies to: (1) automate onsite data collection and acquisition; (2) calculate onsite crew productivity; (3) measuring project's performance at report date and forecast its status at any future set date; (4) detecting possible causes behind unacceptable performance; and (5) generating a progress reports. The module relies on the use of data collected by GPS for estimating crew actual productivity, measuring project performance, and forecasting project cost and time.

The developed Pathfinder algorithm is responsible for feeding the optimization and tracking modules with the data pertinent to travel roads. It also selects the optimal path that suits crew being considered and offers the shortest travel and returns time. The Pathfinder algorithm has been developed using VC++, and map-objects library developed by ESRI.

The reporting module provides project management team with tabular and graphical reports in the planning stage and during construction. Tabular format has been used in presenting the crew formation in planning stage and presenting progress report during construction. The graphical format provides several charts such as project cost breakdown, cost and time forecasting to display information at varying degree of detail. The module also provides project baseline chart. In addition, the module graphically represents the hauling unit path in GIS map, depicting positioning data of different traveled roads, landfill, and borrow pit sites. The application of spatial technologies in optimizing, tracking and controlling of earthmoving operations has proved to be useful to rectify some limitations in current practice.

7.2 Research Contributions

The contributions made by this research were in three fronts; spatial technologies; optimization; and tracking and control:

1. A study the application of spatial technologies (GIS, GPS) in optimizing, tracking, and controlling earthmoving operations;
2. The employment of GIS to acquire and analyze spatial data collected by GPS receivers during construction;
3. The employment of GPS for onsite data collection
4. The development of optimization methodology using genetic algorithms, linear programming, and spatial technologies to select near optimum crew configurations that minimizes construction time, direct cost, or project total cost. The methodology accounts for the availability

of equipment to contractor, construction site conditions, travel roads topography, setup cost, and quantities of earth to be moved from different borrow pits and landfill sites; Combining genetic algorithm with linear programming as new method in optimizing earthmoving operations;

5. Optimizing earthmoving operations not only in planning stage but also during construction as form of corrective actions;
6. The development of waiting time rules to speed up the optimization process and to avoid selecting and evaluating unrealistic crew formations.
7. The development of a methodology to track and control earthmoving operation in near real-time;
8. Automating onsite data collection using GPS receivers
9. The development of a methodology to forecast project cost and time at any future set date;
10. The development of a methodology for estimating onsite productivity based on data collected by GPS;
11. Implementation of the developed tracking methodology in an automated system as a proof of concept

7.3 Recommendations for Future Research

Below is a list of issues, which can be considered for future work to enhance the developments made in this thesis:

1. The optimization module can be extended to account for resource sharing among projects.
2. GPS can be utilized in updating work progress in the GIS sub-module.
3. Simulation can be embedded in the developed model to account for uncertainty in cycle time duration.
4. The system's database can be extended to include historical data of similar projects. This can support the development of a module that provides advice on recommended corrective actions based on the reported project status.
5. The optimization module can be extended for schedule optimization using multi crew formations to accelerate construction time.

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Appendix A

Sample of Dialog Windows of the Developed System

1. Optimization

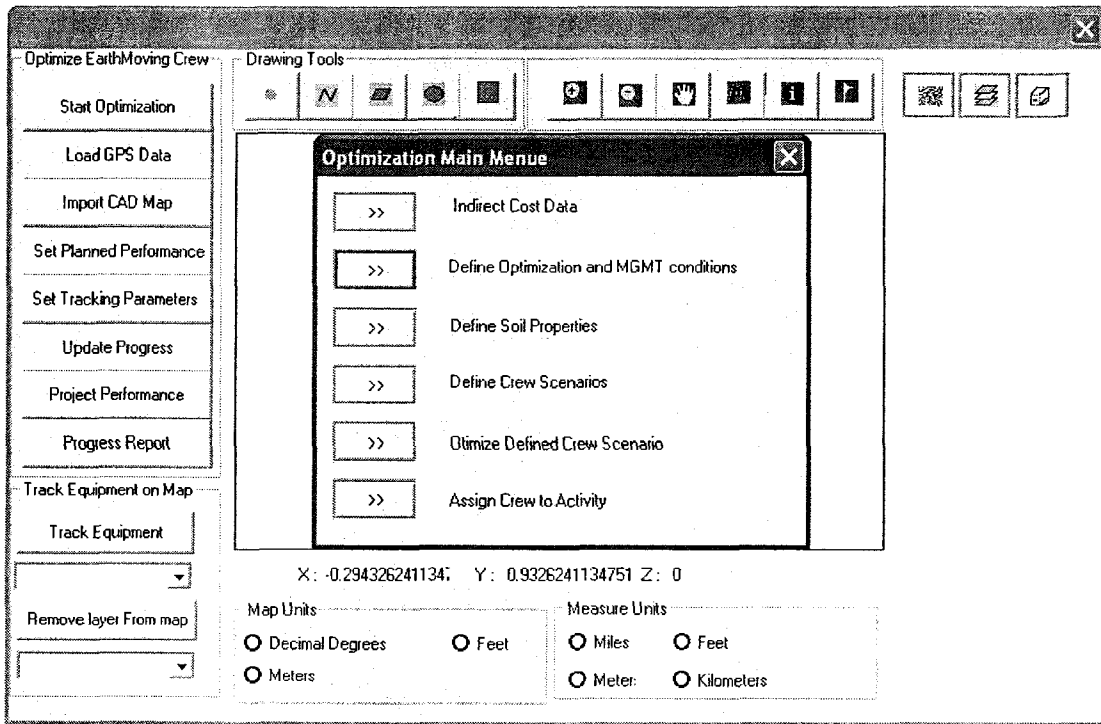


Figure A 1: Main dialog of optimization module

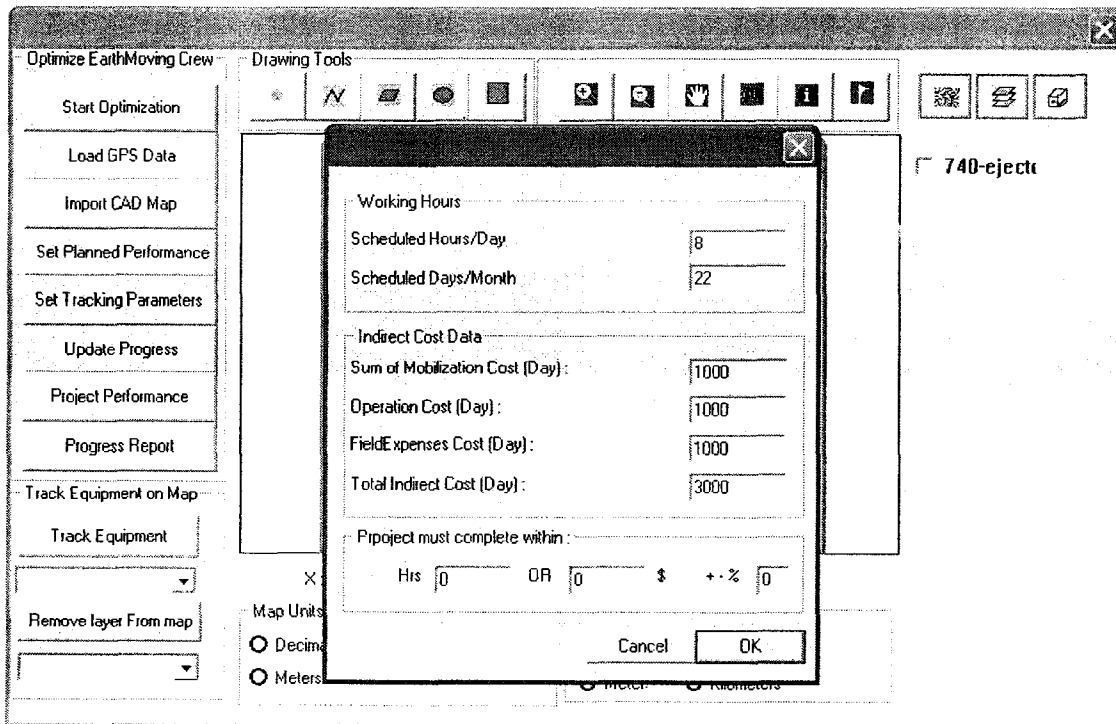


Figure A 2: Dialog window of project's indirect cost

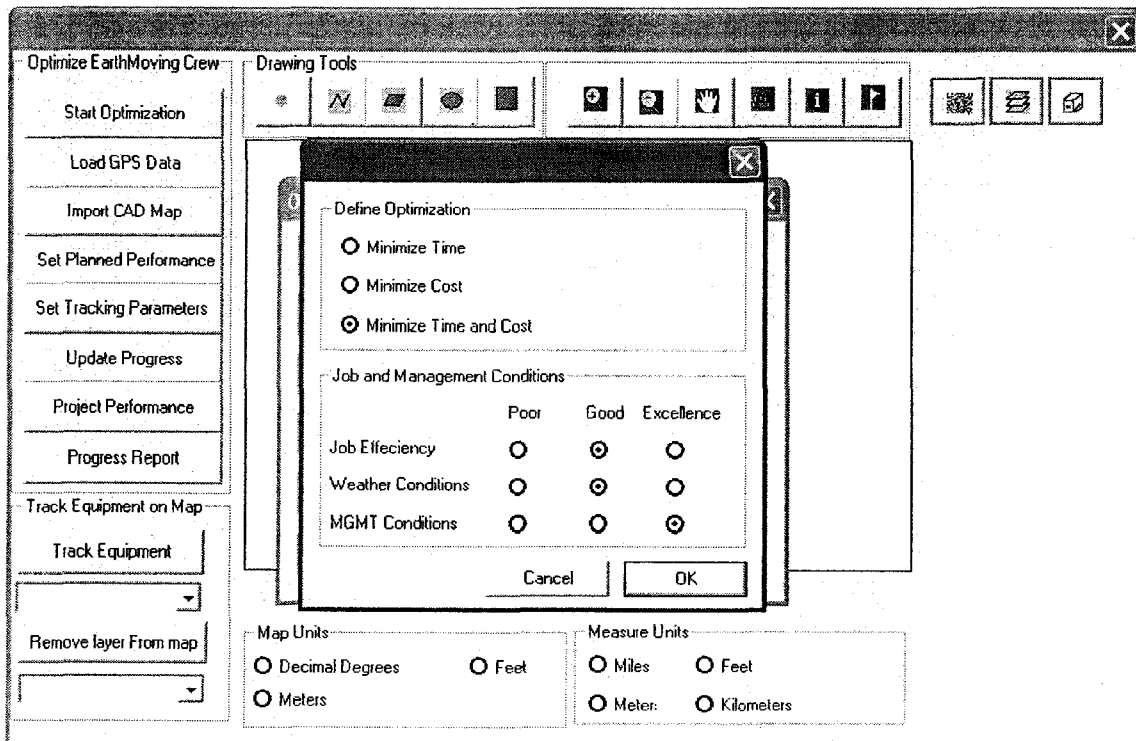


Figure A 3: Dialog window of management and Job conditions

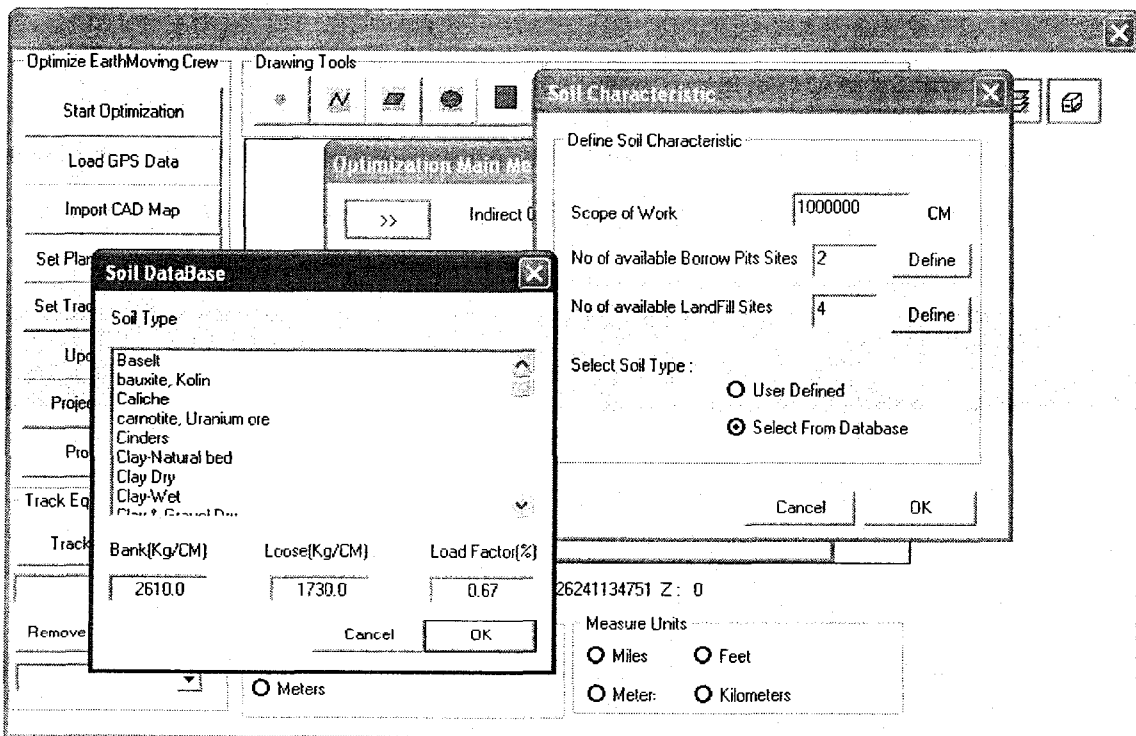


Figure A 4: Dialog window of soil database

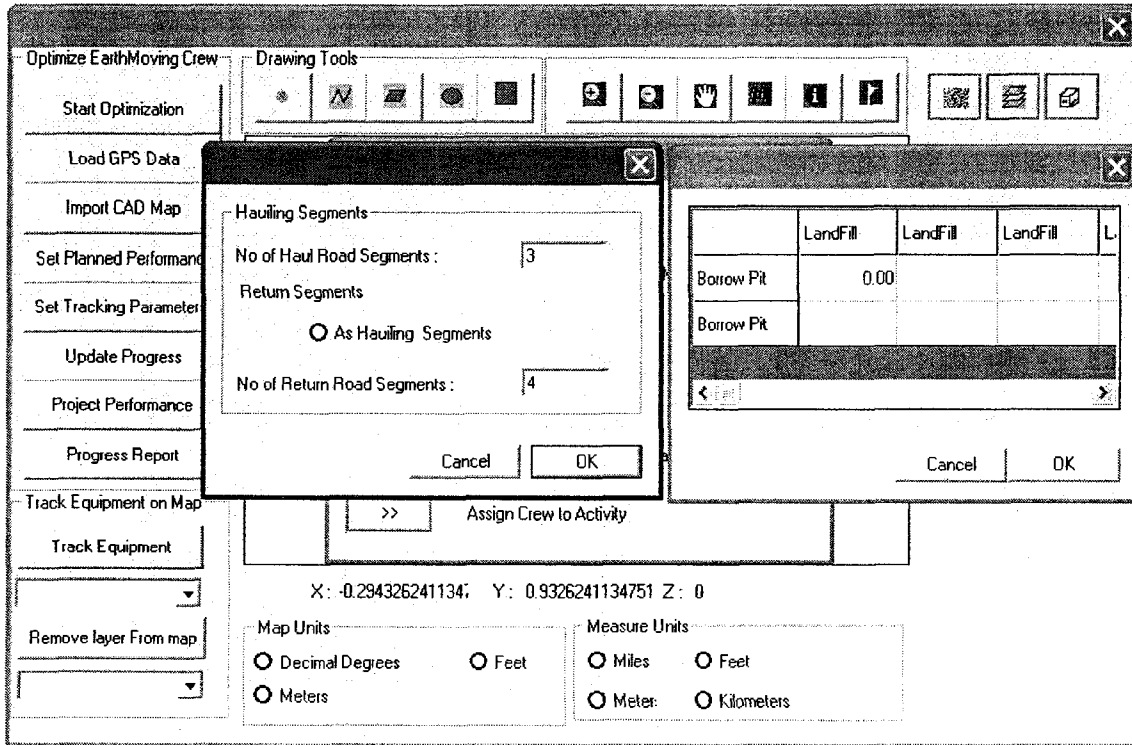


Figure A 5: Dialog window of defining hauling segments

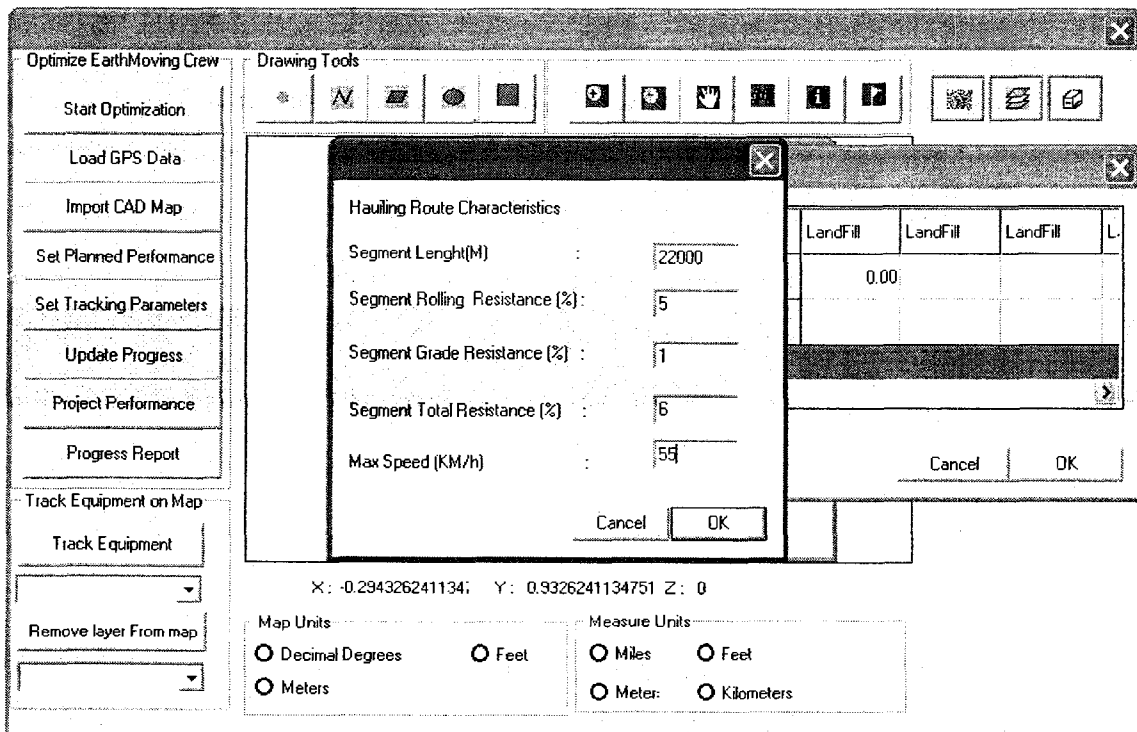


Figure A 6: Dialog window of hauling route characteristics

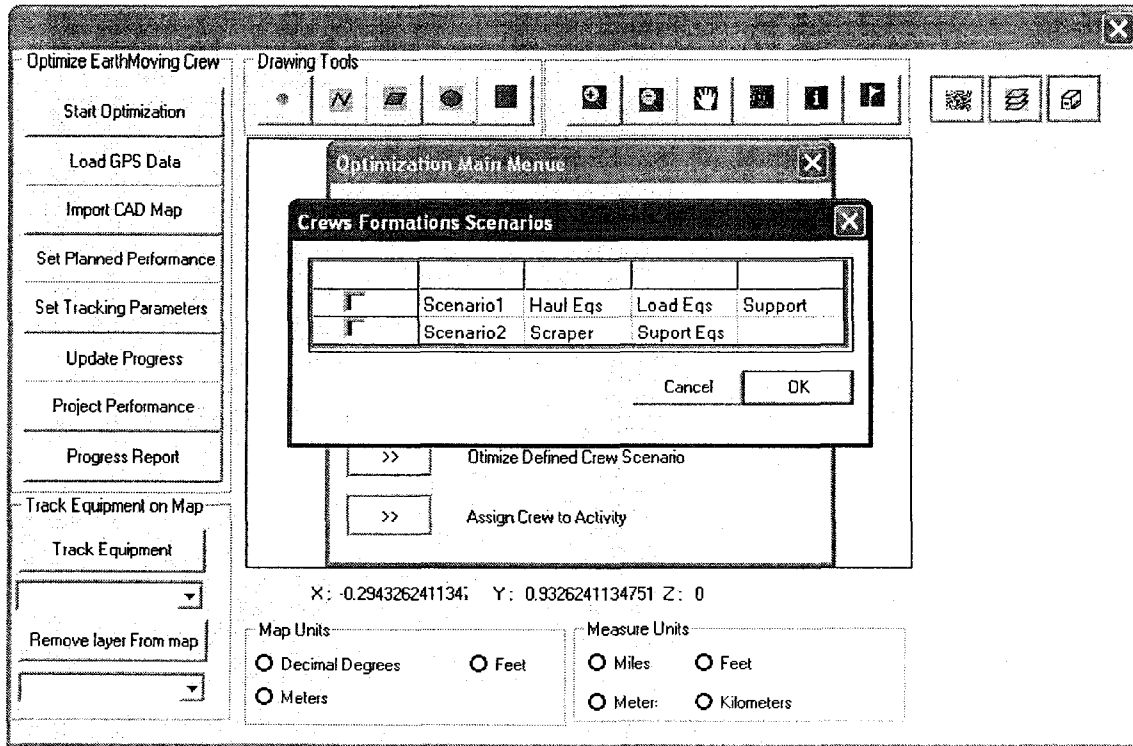


Figure A 7: Dialog window of predefined crews

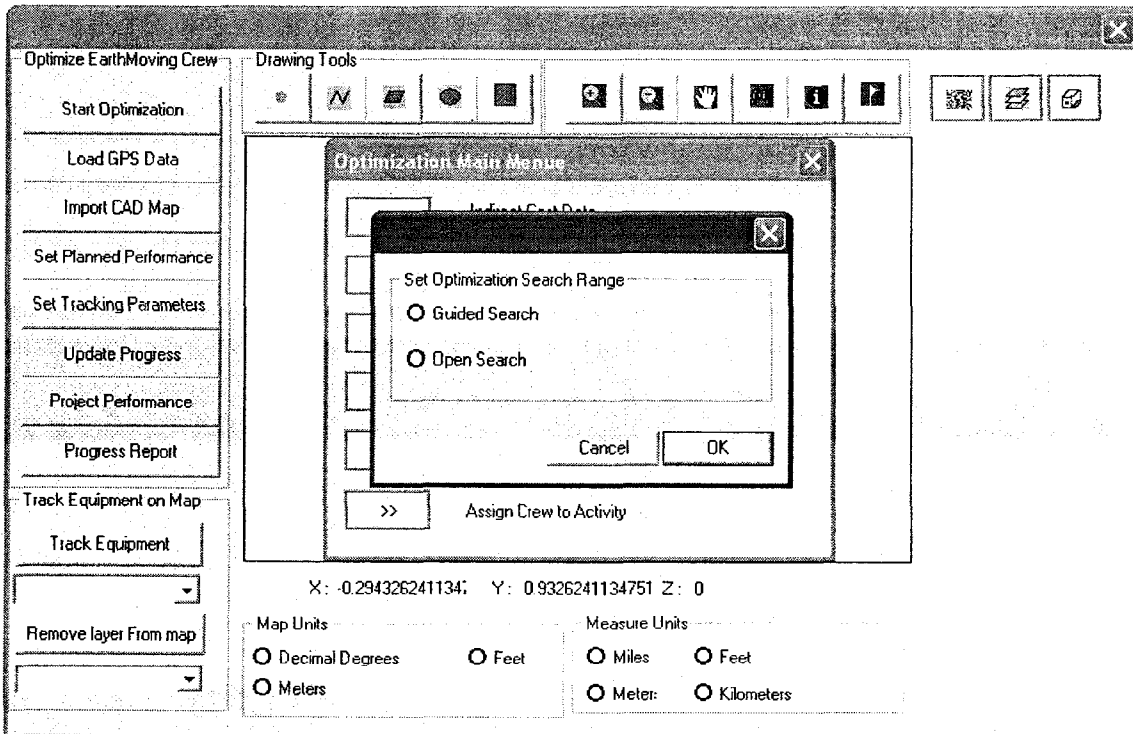


Figure A 8: Dialog window of optimization search range

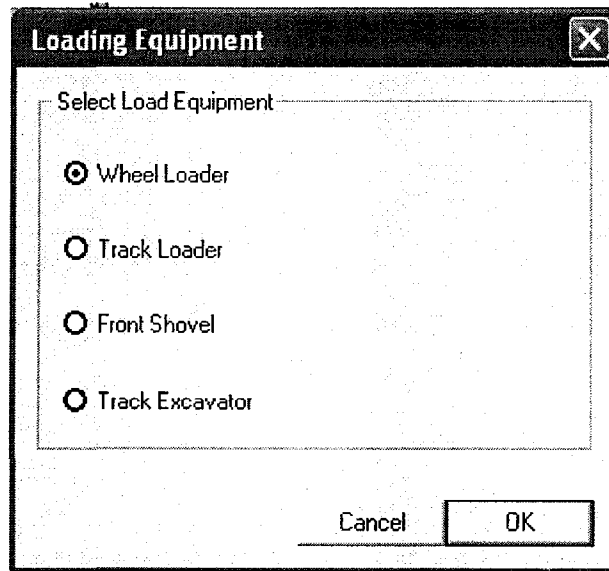


Figure A 9: Dialog window of loading equipment

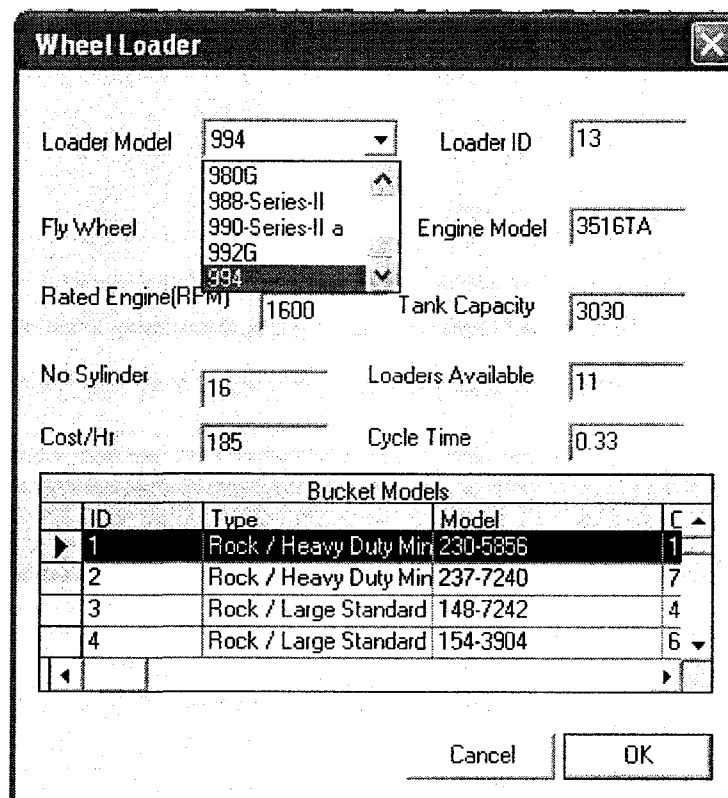


Figure A 10: Dialog window of wheel loaders

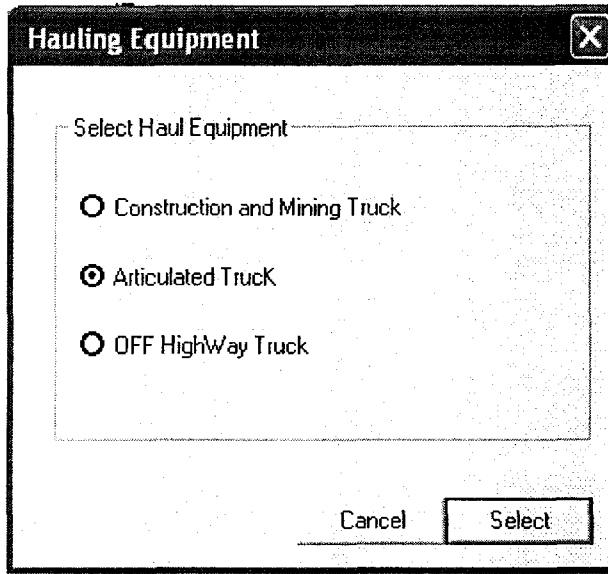


Figure A 11: Dialog window of hauling equipment

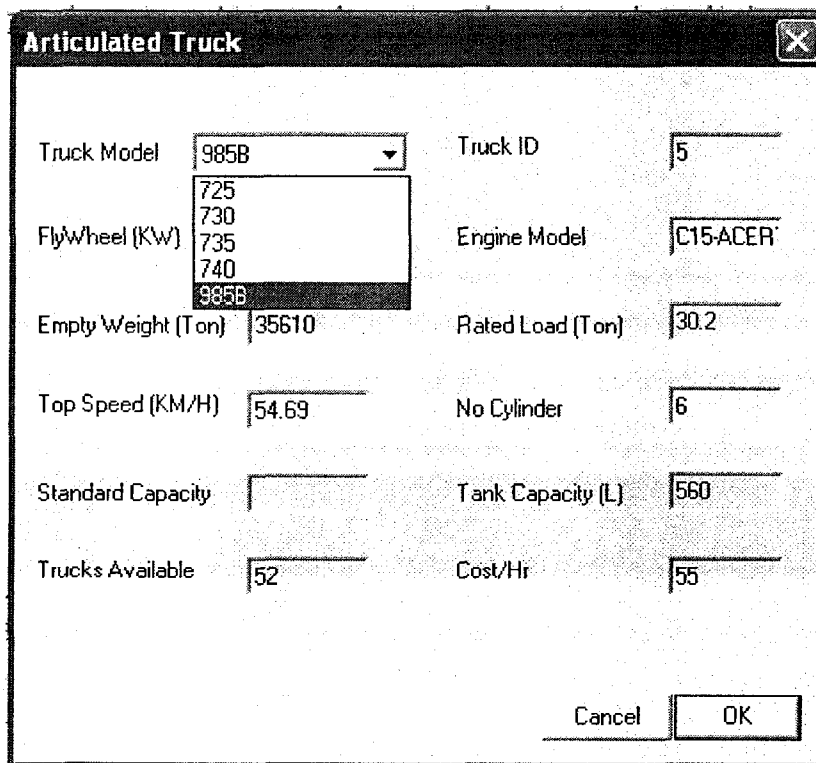


Figure A 12: Dialog window of mining trucks

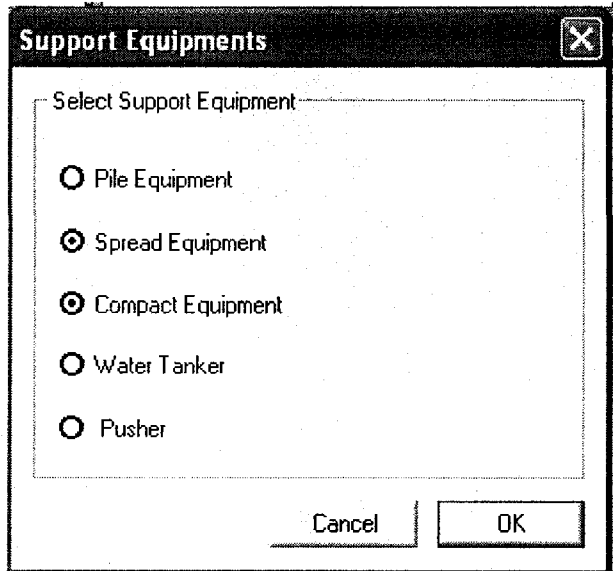


Figure A 13: Dialog window of support equipment

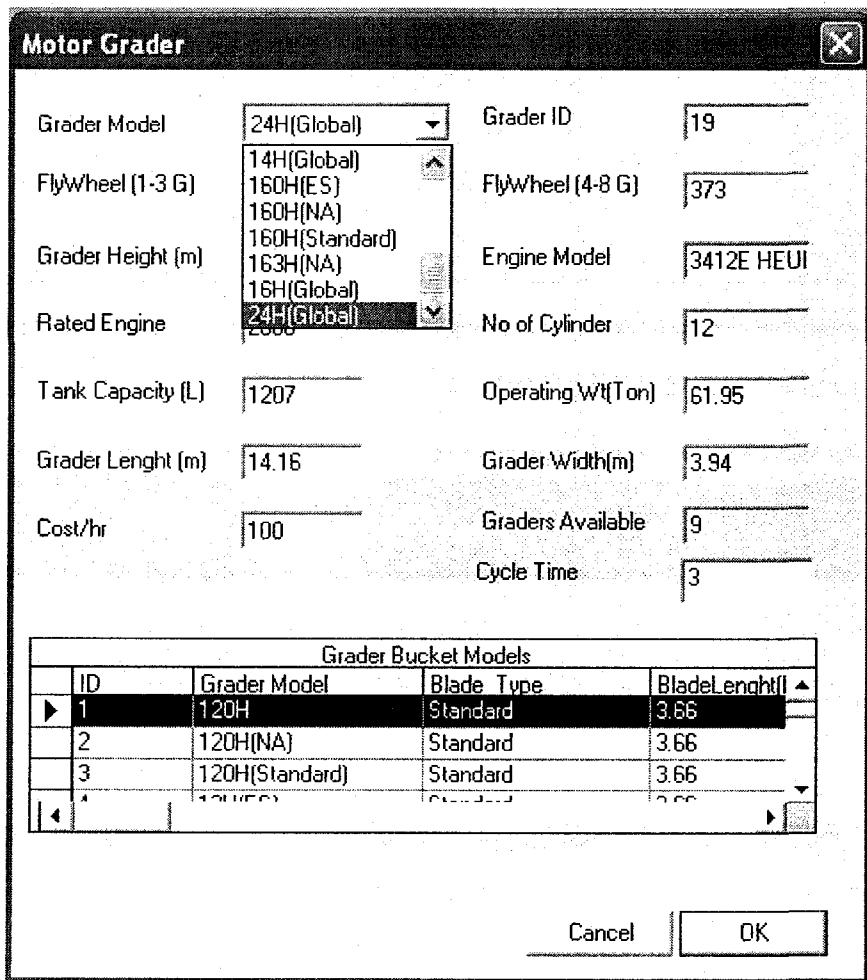


Figure A 14: Dialog window of graders

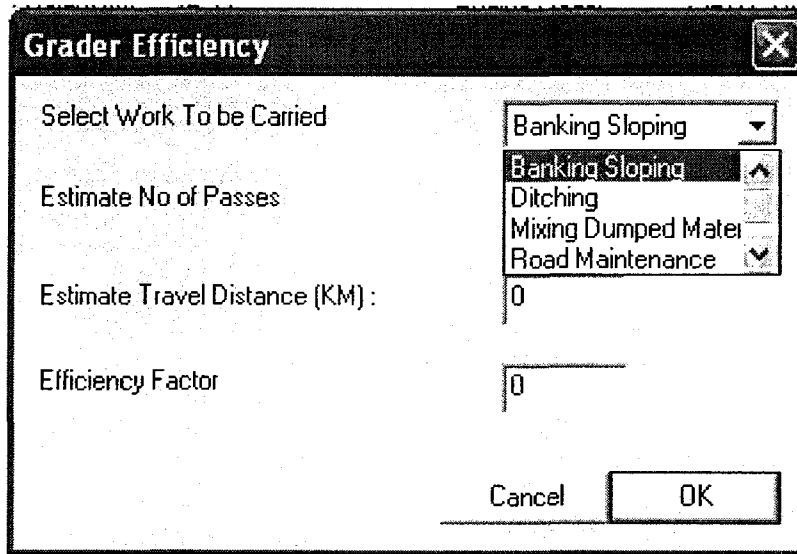


Figure A 15: Dialog window of grader efficiency

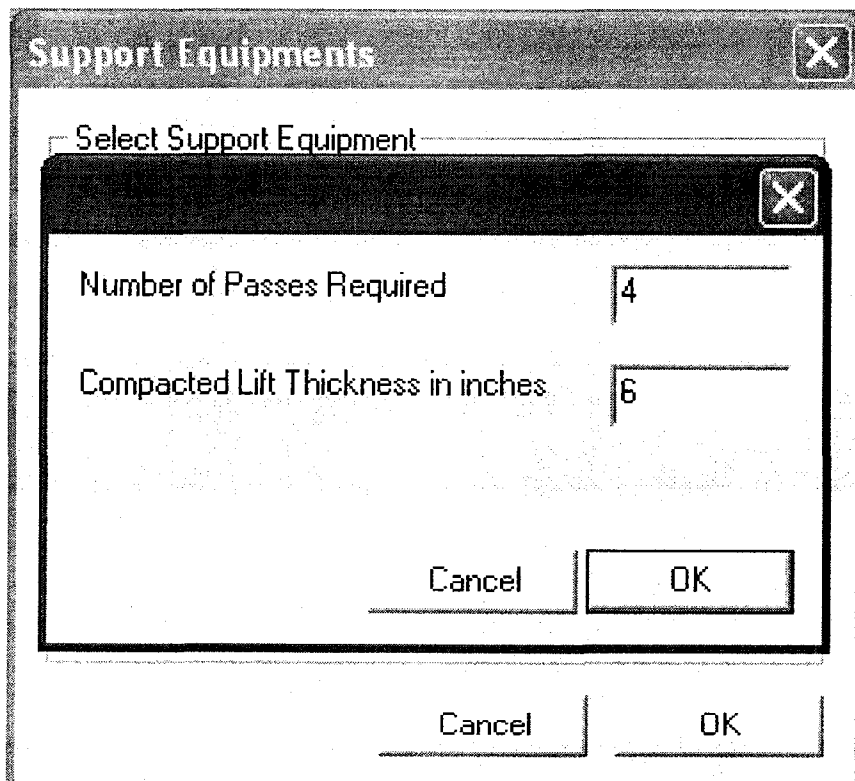


Figure A 16: Dialog window of rollers passes features

Soil Compactor [X]

Compactor Model	CAT CS-583C	Compactor ID	6
FlyWheel (KW)	825H 826H 836H CAT CS-583C	Engine Model	3054CT
Front Axle	Fixed	Blade Type	Vibratory S
Drum Width(m)	18	Gross Power(KW)	75
Rear Axle	±7	Number Available	10
Cost/Hr	90	Cycle Time	3

Cancel OK

Figure A 17: Dialog window of compactors

Water Tanker [X]

Tanker Model	651E	Tanker ID	9
Tanker Type	651E 657E 769D	Tanker Size	45000
Water Pump(CM)	5680	No of Spray Group	2
Cost/Hr	0	Tankers Available	3

Cancel OK

Figure A 18: Dialog window of water tankers

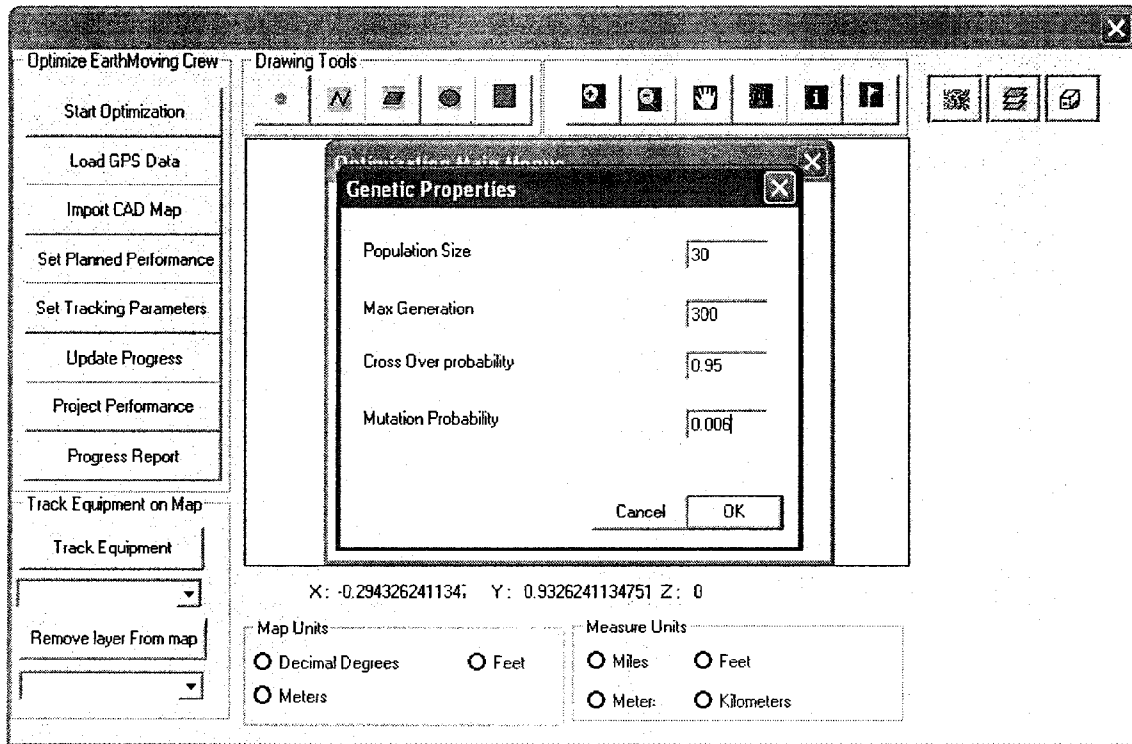


Figure A 19: Dialog window of GA parameters

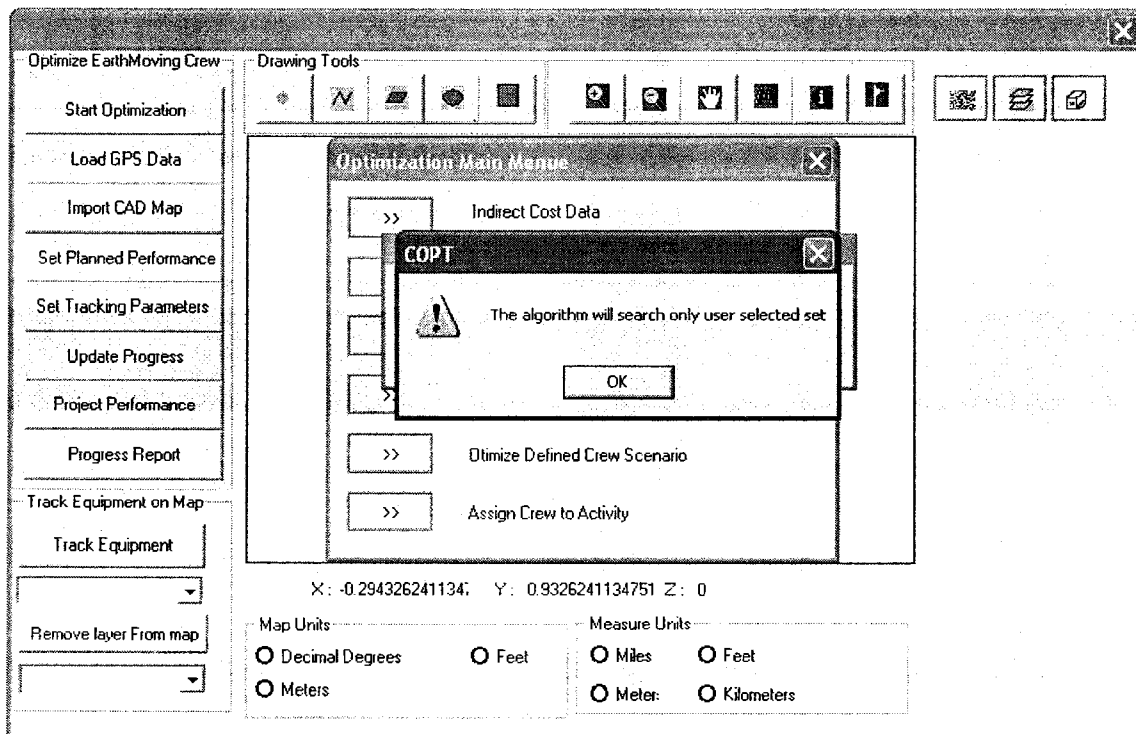


Figure A 20: Dialog window of message box

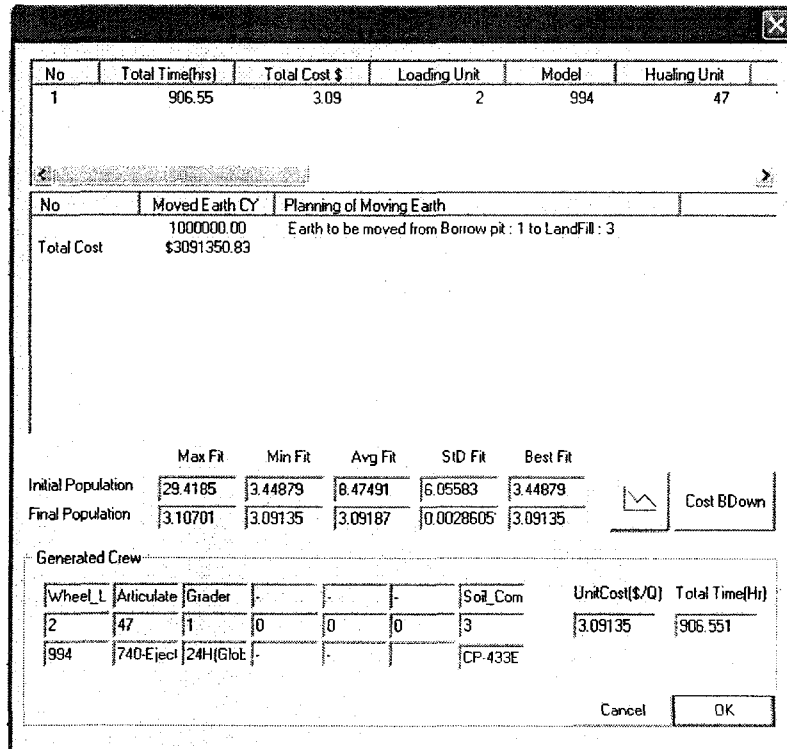


Figure A 21: Dialog window of optimization output

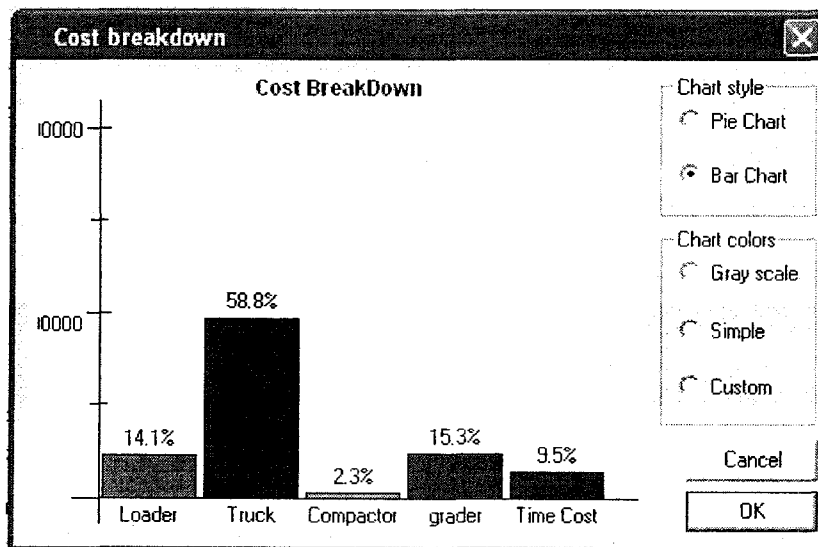


Figure A 22: Dialog window of cost break down

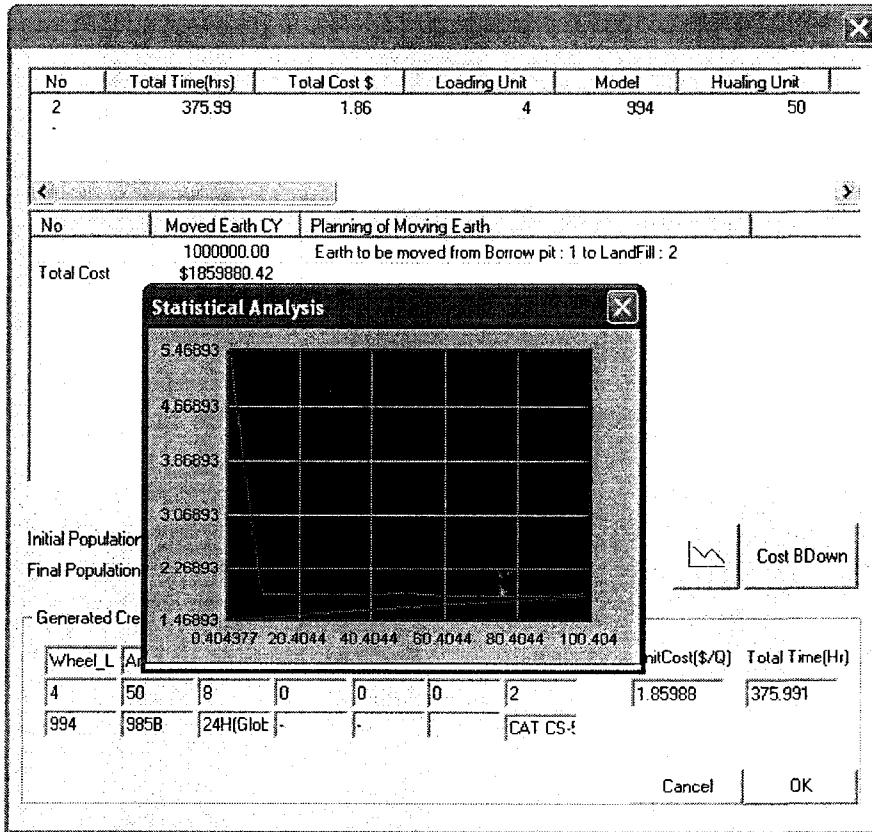


Figure A 23: Dialog window of statistical analysis

2. Tracking and Control

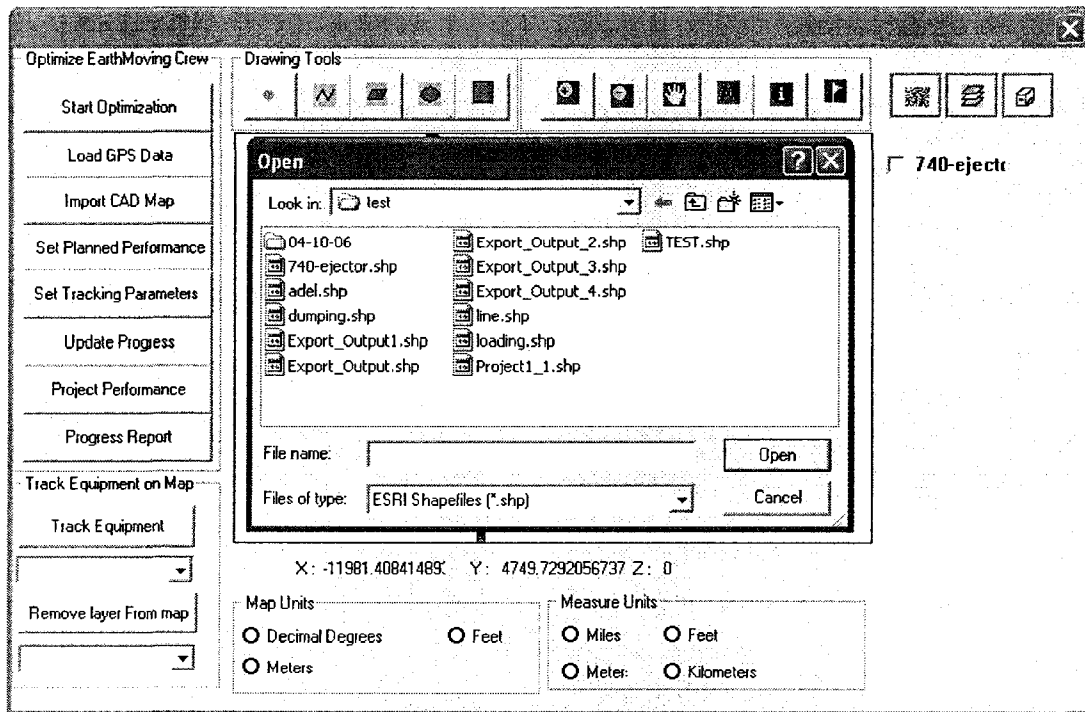


Figure A 24: Dialog window of loading GPS data

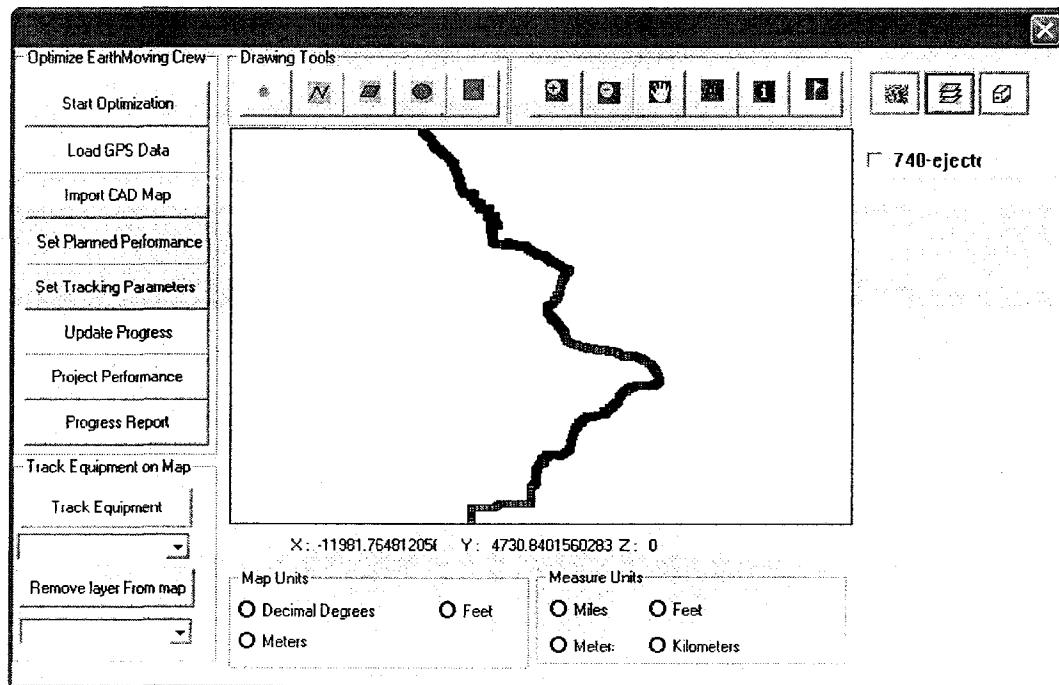


Figure A 25: Dialog window of tracking and control

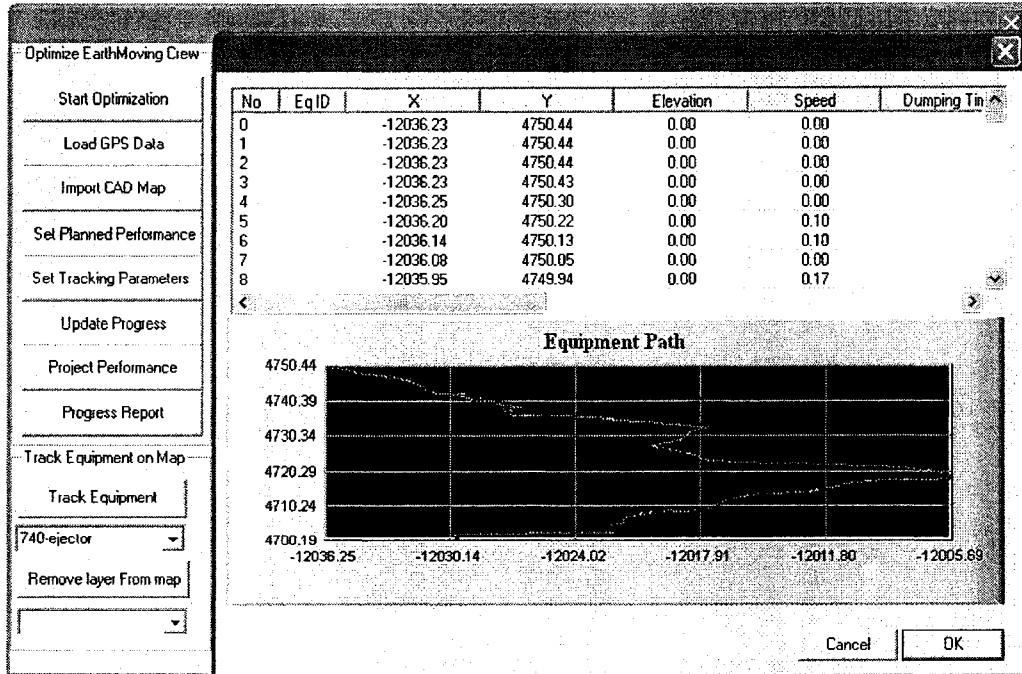


Figure A 26: Dialog window of equipment path

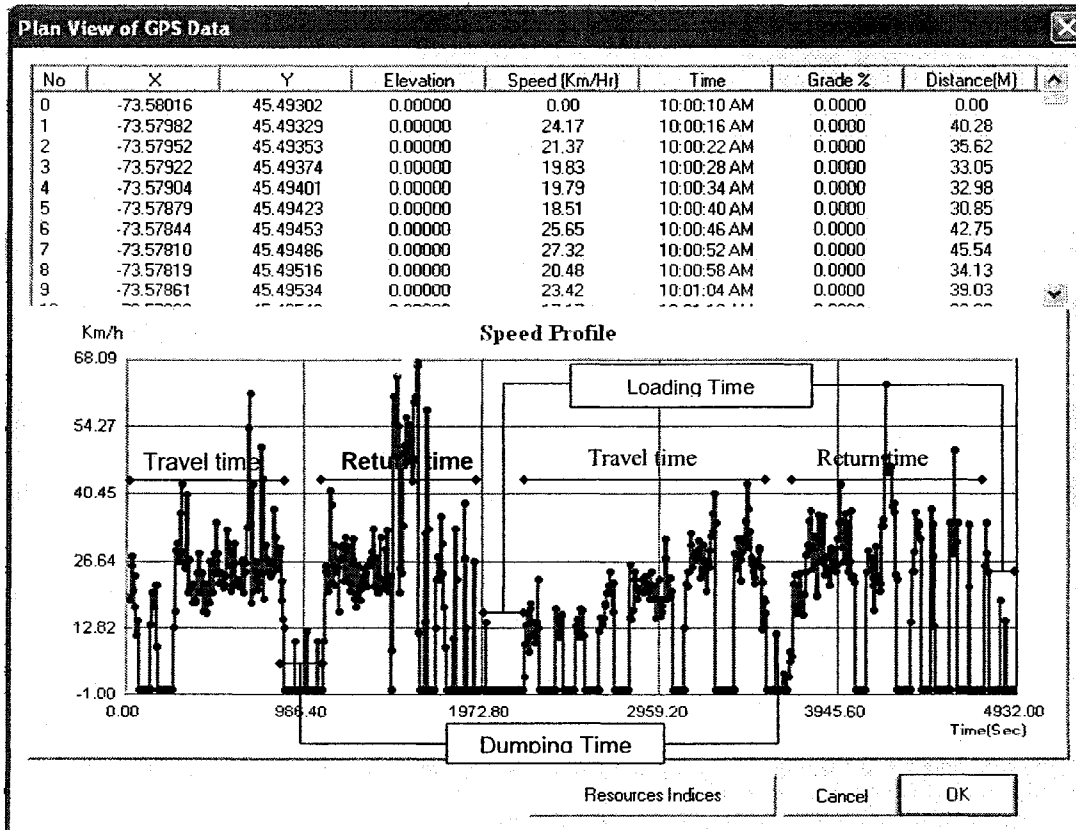


Figure A 27: Dialog window of speed profile

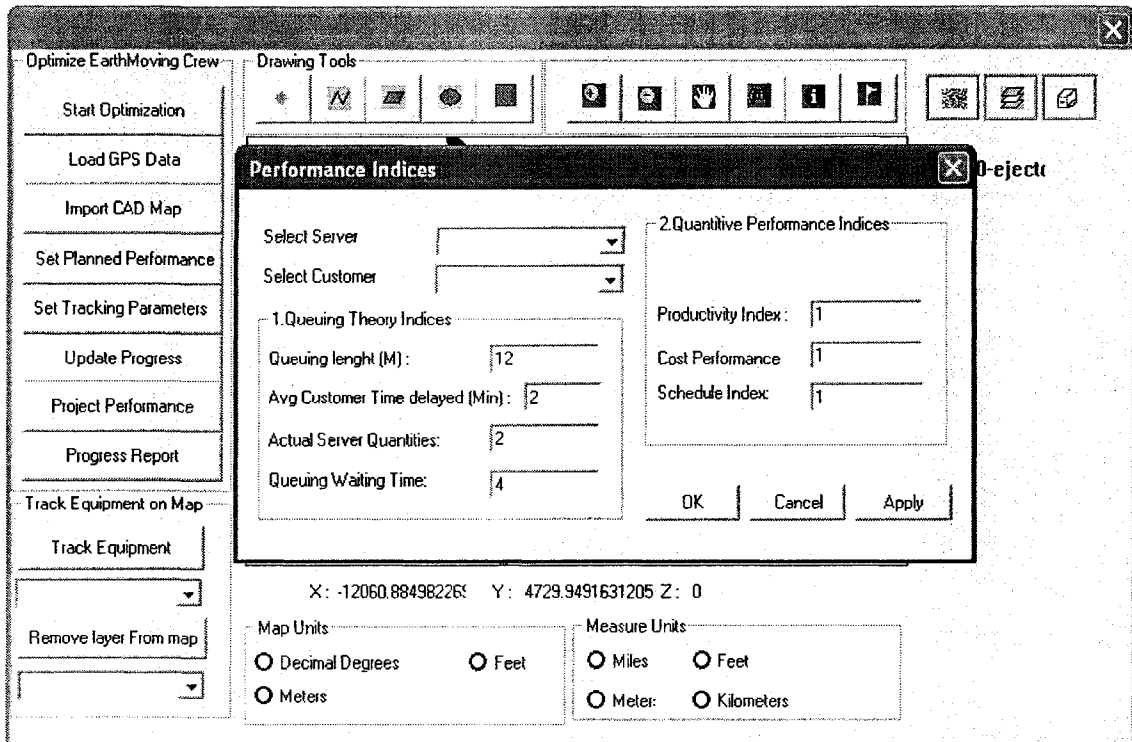


Figure A 28: Dialog window of setting acceptable indices

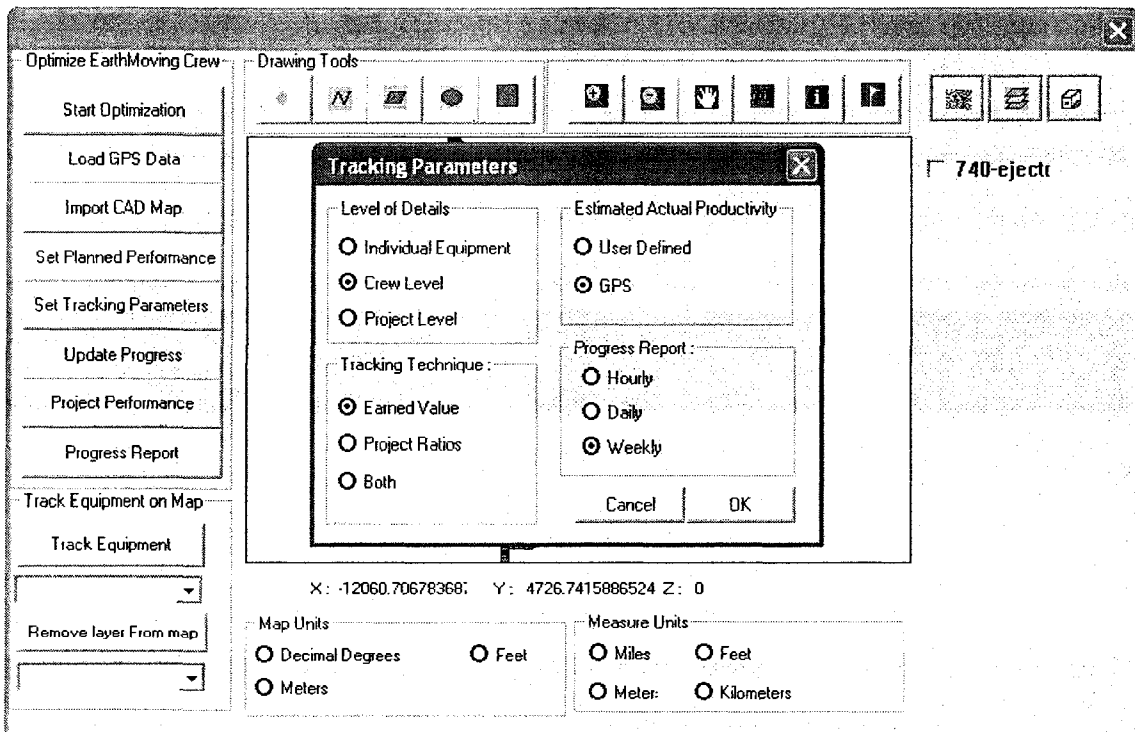


Figure A 29: Dialog window of setting tracking parameters

Update Actual Data

Actual Start Date: 6/ 4/2007

Reporting Date: 6/11/2007

Crew Name: Equipment ID: 985B

Quantity Completed to Date: 0 During Reporting Period: 985B

Cost incurred to Date: 0 Cost During Reporting Period: 0

994
985B
CAT CS-583C
24H(Global)

Cancel Insert OK

Figure A 30: Dialog window of updating actual data

Performance Measurement

Reporting Period Performance As Planned Performance		Performance Indices	Performance Forecasting To Date Performance		
No	EQ Model	No of EQ	EQ(\$/whr)b	Time(whrs)	EQ(T\$)
1	994	4	185.00	376.00	278240
2	985B	50	55.00	376.00	103400
3	CAT CS-583C	2	90.00	376.00	67680
4	24H(Global)	8	100.00	376.00	300800
Total direct \$					171888
Total indirect \$					141000
Total \$					185988
(Q/whr)b					2659.64

Figure A 31: Dialog window of as planned performance

Performance Measurement

Reporting Period Performance		Performance Indices			Performance Forecasting	
As Planned Performance					To Date Performance	
No	EQ Model	(Q)b	(Q)td	(\$/Q)b	(\$/Q)td	(whr/Q)b
1	994	1000000.24	60000.00	0.28	10.00	0.0015
2	725	1000000.24	60000.00	2.75	10.00	0.0128
3	CAT CS-583C	1000000.24	60000.00	0.05	1.00	0.0005
4	24H(Global)	1000000.24	60000.00	0.10	2.67	0.0010

Figure A 32: Dialog window of to date performance

Performance Measurement

As Planned Performance		Performance Indices			To Date Performance	
Reporting Period Performance					Performance Forecasting	
No	EQ Model	%	CPI	SPI	PPI	Que
1	994	6.00	0.03	0.27	0.2738	
2	725	6.00	0.27	0.27	0.2738	
3	CAT CS-583C	6.00	0.05	0.27	0.2738	
4	24H(Global)	6.00	0.04	0.27	0.2738	

Figure A 33: Dialog window of actual performance indices

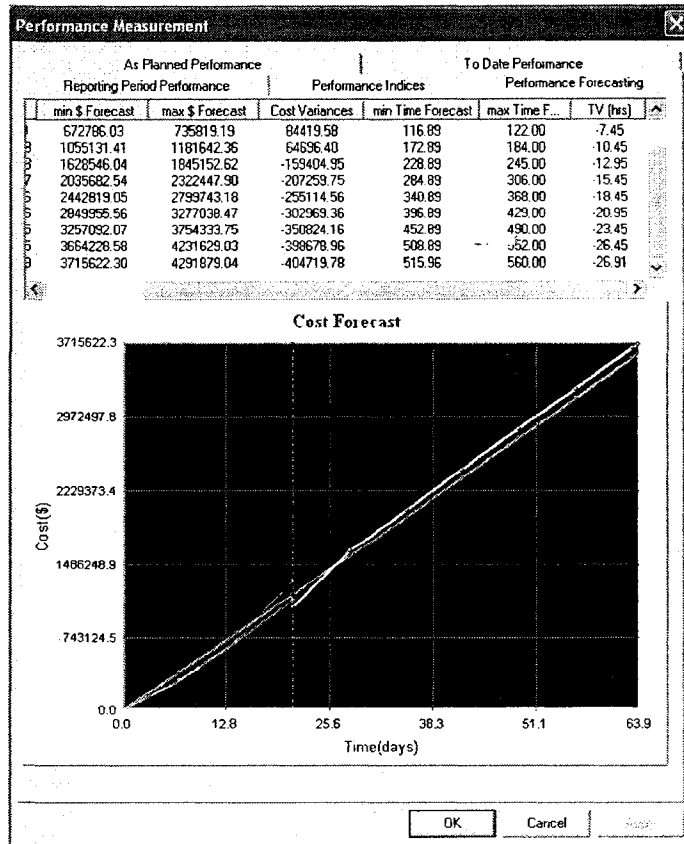


Figure A 34: Dialog window of performance forecasting

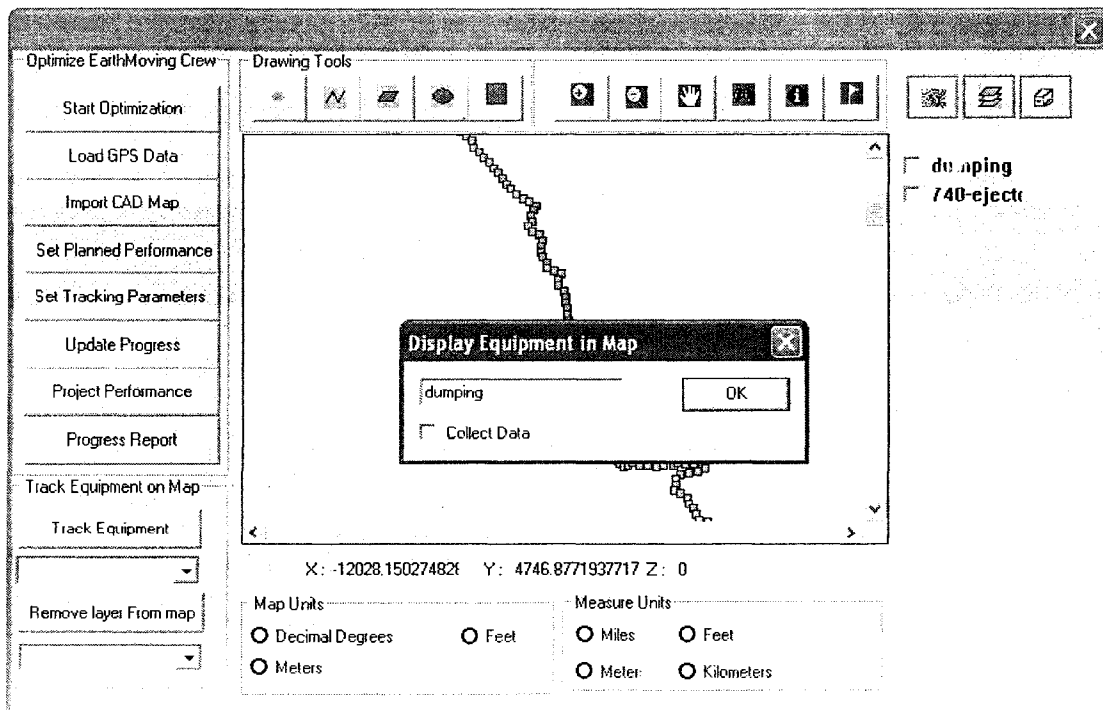


Figure A 35: Dialog window of find function