Dynamic Risk Modelling for Optimizing Earthmoving Operations

Adel Alshibani[1], Osama Moselhi[2]

Department of Building, Civil, Environmental Engineering, Concordia University

[1]adelshib@encs.concordia.ca

[2]Moselhi@ encs.concordia.ca

***Abstract*-Scheduling and cost estimating of the construction project are interdependent management functions despite the fact that different teams may be responsible for their respective development. Realistic project schedules and accurate cost estimates depend largely on the measures taken to account for uncertainties inherent in their development. This paper aims to present a newly developed methodology; and is designed to integrate the two functions and dynamically accounts for uncertainties associated with each function. The paper focuses primarily on earthmoving operations. The research methodology utilizes simulation based optimization to generate near-optimum fleets and estimate project total cost, while considering the uncertainties associated with project duration, direct and indirect cost dynamically over the project duration. The developed methodology is expected to provide contractors with a better understanding of the dynamic nature of uncertainties on large construction projects and their impacts on generated project schedules and cost estimates. To validate the proposed methodology and to illustrate its capabilities, it was applied to two example projects.**

Keywords-Cost Estimate; Dynamic Uncertainties; Earthmoving Fleet Equipment-selection; Simulation Optimization; Schedule

I. INTRODUCTION

Literature reviews reveal that considerable effort has been made to developed models and systems for equipment selection of earth-moving operation and to estimate its cost using different techniques, including: (1) queuing theory (e.g. [1]); (2) knowledge-based expert systems (e.g. [2], [3], [4]); (3) discrete event simulation (e.g. [5]); (4) simulation optimization (e.g. [6], [7], [8]); and (5) commercial software systems (e.g. [9]), (6) linear programming (e.g. [10], [11], [12]), (7) genetic algorithm with linear programming (e.g. [13]), and (8) genetic algorithm (e.g. [14]). These 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 ([9]); (2) evaluate, concurrently, different fleet scenarios as in [12], (3) dynamically reconfigure crew formations while site operations are in progress except that in [13], and (4) consider the probability distribution of the model output.

Of the previous stated models, only simulation and queuing theory consider the uncertainty that is associated with the cycle time of the equipment involved in earthmoving operations making them more suitable for modeling these operations. However, these models do not account for all the previously stated factors. In addition, the use of computer simulation based methods requires dedicated simulation professionals ([15]) and expert opinions in absence of numeric data ([16]). In estimating the cost of these operations, the previously stated models consider uncertainties associated with the project time and cost statically, i.e. without a change over the project duration. This is fine for projects that do not require long duration to complete. However, in large earthmoving operations that require relatively long duration for completion, i.e. more than two years, uncertainties associated with project cost are better expressed as a function of time over the project duration.

Fig. 1 illustrates the likely variation of uncertainty in the planning stage and during construction. As presented in the figure, the level of uncertainty is much higher at the planning stage than during construction. This is attributed to the lack of accurate cost information at planning stage. But as earthmoving operations progress, more accurate information become available, and consequently, the level of uncertainties decreases.

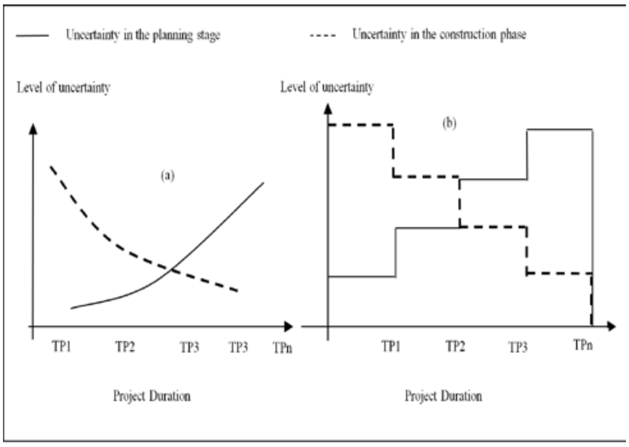

Fig. 1 Modelling uncertainties in the developed model

Most of the simulation-optimization models assume that known environment so that all relevant parameters (simulation inputs) are to be known ([17]). Reference [17] states that : (1) ignoring the uncertainty associated with simulation parameters (inputs) in developing simulation models may lead to a suboptimal solution; (2) the integration of simulation with optimization considering the uncertainties associated with the simulation model provides more flexibility in exploring many values per input and many scenarios (combinations of these values). The main purpose of simulation optimization is to find the best sets of the model parameters (variables and assumptions) that produce the optimal performance ([18]). Combining optimization with simulation benefits from the advantages of the two techniques and eliminates their disadvantages when are they used separately.

Having said that it is clear simulation optimization that offers new opportunities for developing more effective applications that involve risk and uncertainty ([19]). This paper describes a new model developed to overcome the previous stated limitations. The model uses optimization based simulation and considers the uncertainties associated with project time and cost dynamically over the project duration. The model offers the contractor a flexible tool that (s) he can use to integrate schedule and cost estimate of earthmoving operation while assess the risk of being associated with them.

II. PROPOSED MODEL

A. Model Description

Unlike the models referred above, the proposed model integrates these functions and considers the uncertainties associated with project cost, loading, hauling, dumping, and returning operations times. As shown in Fig. 2; the model integrates two commercial software systems: (1) Fleet Production & Cost Analysis (FPC), and (2) Risk analysis system (Oracle *Crystal Ball EPM*).

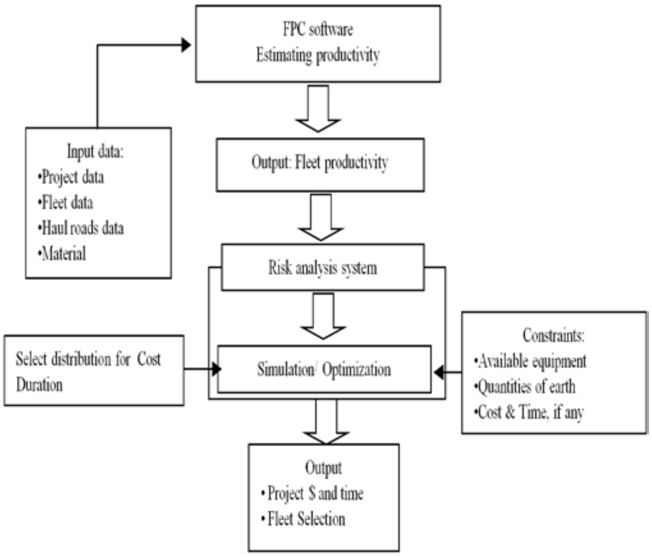

Fig. 2 Main components of the developed model

FPC is utilized to estimate the productivity of equipment of fleet under consideration. In this software, the user needs to enter: (1) project data including project name, daily working hours, scheduled hours per year, operator efficiency factor, etc; (2) fleet input data including the numbers of loaders and trucks, etc.; availability to the contractor (defined later as decision variables), speed correction factor, loader availability, truck availability, etc.; (3) haul roads data including road distance, its rolling and grade resistances, and allowed maximum speed and stop time, if applicable; and (4) material type. Upon entering the required data, FPC estimates the hourly production rate of loaders, trucks, and support equipment, if any, for the fleet under consideration. The risk analysis software is then used subsequently to build a probabilistic model that considers the uncertainties associated with the operations involved. The variables associated with the uncertainties considered in this paper are: (1) hourly loader cost; (2) hourly truck cost; (3) hourly support equipment if any; (4) hourly indirect cost; and (5) durations of load, haul, dump, and return activities. These variables are referred to as assumptions. The risk analysis software uses Monte Carlo simulation to model the selected fleet configuration.

The simulation optimization is used to search for the best combination of decision variables that yields the configuration that best meets the optimization objective set by the user and satisfies project constraints. The constraints considered are: (1) project duration, (2) project cost; (3) scope of work; and (4) available equipment to contractors. The first two constraints may not be possible to satisfy all cases. In such events, the model configures fleets are closer to satisfy the constraints within specified ranges.

B. Computation Process

As shown in Fig. 3, the application of the proposed model involves the execution of the following computational steps:

Step 1: entry of project data into FPC

The user here needs to define the project data. The user is guided through a set of interface dialog windows to input this data. The project data includes scope of work, daily working hours, haul roads, and characteristic type of excavated material, and loaders/ truck fleet, and support equipment, and job conditions.

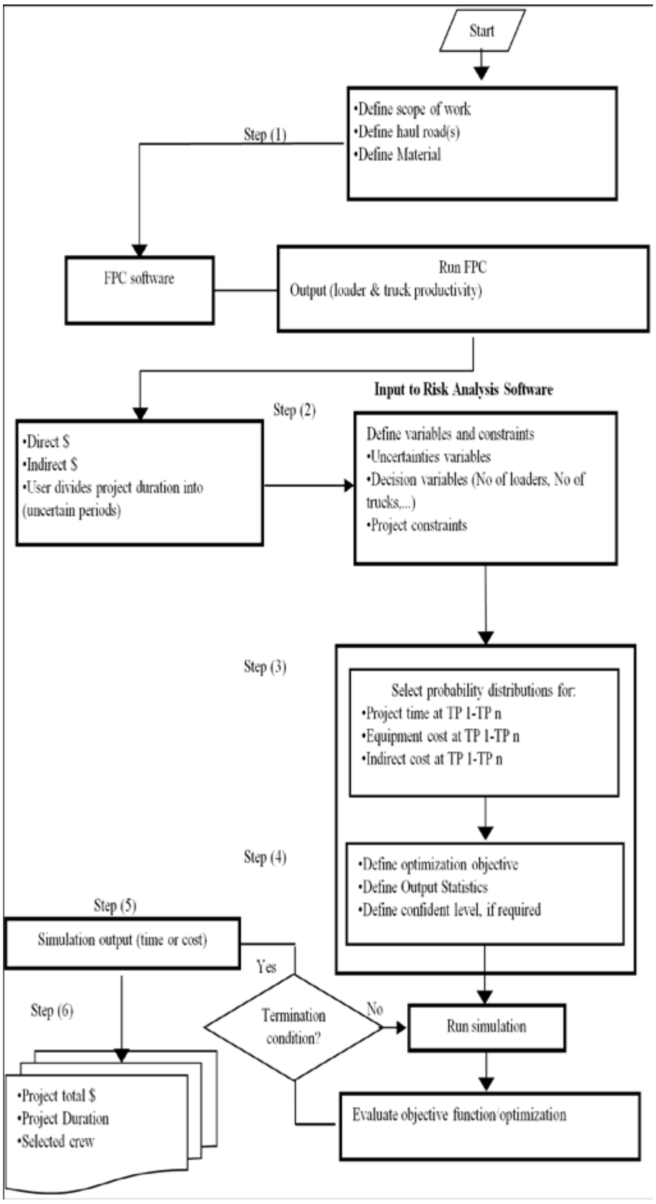

Fig. 3 Flowchart of the computational process

Step 2: Identification of project variables and constraints

Having estimated the fleet productivity in FPC, the user is then required to define the project variables (referred to as assumptions), decision variables and the project constraints. The assumptions are the variables with uncertainties including trucks, loaders, and support equipment hourly cost, daily indirect cost, equipment cycle time; and project time elements. The decision variables are variables that under the contractor control including the numbers of loaders, trucks, and support equipment, if any. The user then defines the upper and lower limits for these variables. The user also has to define variable types (discrete, continuous, binary, etc). The project constraints considered are: (1) project duration, (2) project cost; and (3) available equipment to contractors.

Step 3: select probability distribution

Having the user defined project variables, constraints, and the project time elements as (s) he sees fit based on the fleet estimated productivity and the project scope of work; the user then is required to select the probability distributions that best represent the data involved for project variables stated above.

Step 4: define project outputs

Prior to running the simulation, the user needs to define: (1) optimization objective, (2) output statistics, (3) confident level, if required, and (4) project's output (project total cost, project time, crew configuration). The project output is defined according to the optimization objective, e.g. If the objective is to minimize the project total cost, the total cost will be defined as project output (referred to in the risk analysis software as forecasting cells).

Step 5: run simulation

Having entered the required data; the simulation optimization is then run.

Step 6: analyzing the result

Upon completion of the simulation, the model generates the project outputs. The user can evaluate and analyze the output considering the impact of the level of confidence. The user also can use other analysis tools using scatter charts and sensitivity analysis (Figures 4 and 6) to evaluate the effect of different variables on the model output.

C. Cost Representation

Both direct and indirect costs are considered. The project direct cost includes: (1) equipment mobilization and demobilization costs; (2) cost arising from executing the work at hand; and (3) setup cost of borrowing pits and landfill sites. Mobilization and demobilization costs are those required for mobilizing the equipment fleet from contractor's storage area to the project site and back. The mobilization cost has a sizeable effect on project cost and directly impact the optimization process ([20]). It includes float cost if any, assembly and disassembly cost of equipment if any, and cost incurred due to idle time of equipment during the mobilization process. The cost incurred in mobilizing a fleet is given by summing float and assembly and disassembly costs for mobilization to and from the project site. The cost arising from executing the work at hand is the operating cost of equipment during the executing of the work at hand. The duration, required for any fleet to carry out the work, is first estimated based on the productivity of that fleet. The cost of that fleet can then be calculated by multiplying the equipment hourly cost in the fleet by the duration. The setup cost depends on: (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. The indirect cost is considered as a per-day cost ($/day).

D. Objective Function

In order to search for a near-optimum fleet that meets the objective set by the user, the simulation optimization process evaluates fleet configuration every time a new fleet is generated by that process (Fig. 3). The system evaluates the generated fleet configuration by calculating the project duration and accordingly the project's total cost. The project duration is calculated knowing the scope of work and the fleet productivity.

The developed simulation optimization uses an objective function to evaluate the fitness of each generated fleet according to the optimization objective set by the user. If the optimization objective is set to minimize project total cost, Equation 1 is used:

$$\text{Total Cost} = \left(\sum_{i=1}^{t} EHC_i \times NE_i \times \text{Project Time} + \text{Project Time} \times \frac{DIC}{DH} \right) \quad (1)$$

Where:

NE : Number of pieces of equipment associated with each type.

DH : Scheduled working hour per day (defined by the user).

EHC : Equipment hourly ownership and operating cost.

DIC : Daily indirect cost (defined by the user).

Project time:Time required to move earth from borrowing pit to landfill sites in working hour;

The first term in Eq. (1) represents the project direct cost, whereas the second term represents the project indirect cost. The total cost is calculated by knowing the numbers of loaders, haulers, support equipment, if any, the time required to move the required earth from the borrowing pit to landfill and the project indirect cost.

E. Project Examples

Project I

This example is adopted from a training project example used at Concordia University, 2010. The project involves excavating and moving approximately 100,000 m^3 (bank cubic meters) of earth from one location, referred to as borrowing pit and hauled to designated area, referred to as a landfill site. The material is crushed stone. The landfill site is located at a distance of approximately 3 km from the borrowing pit location. The fleet considered consists of 988F II loaders and 730D DMP trucks, all in good operating condition. Table 1 represents the project data. It is required to optimize and estimate the cost of the earthmoving operations while considering the uncertainties associated with the project direct and indirect cost. The data pertinent to the haul-road that connects borrow pit and landfill site is summarized in Table 2.

The developed model calculates first productivities of loaders and trucks using the FPC software. The probabilistic model is then formulated and processed using the risk analysis software. The project duration is divided into four time elements. In each time element, uncertainties associated with the hourly cost of loaders, trucks, and indirect costs are defined, and 300 simulations are performed. The output of the developed model is presented in Fig. 4. The result shows that the project's total cost falls between $180,000.00 to $190,000.00 with confidence level of 50 %. The model selects a fleet that consists of 3 loaders and fourteen trucks.

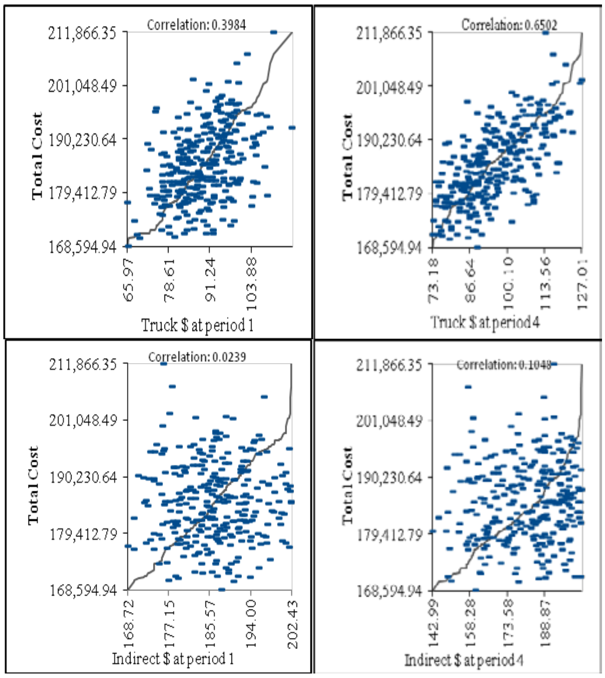

Fig. 4 Scatter plots

TABLE I
PROJECT DATA

Material	
• Earth-moving Volume (m^3)	100,000
• Bank Density (Kg/bm^3)	2,670
Loader (988F II)	
• Bucket capacity	6. 12 LCM
• Cycle time	0.60 min
• Availability	80%
• Loading conditions	Average (BFF = 1.0)
• Fill factor	1.1
• First bucket dump	0.10 min
• Hauler exchange time	0.7 min
• Hourly cost	$ 120
• Available number	3
Truck (73D DMP)	
• Available number of trucks	20
• Dump Spot and manoeuvre Time	1.5 min
• Dump Time	0.5 min
• Availability	85%
• Hourly cost	$ 90
Fill factor	1.25
Haul road	
• Length of haul-road (m)	3000
• Daily working hours	8 hrs
• Hourly Indirect cost	$187
• Job conditions	Favourable

TABLE 2
HAUL ROAD PROFILE

Segment	Length (m)	Grade (%)	R.R (%)	Max speed
Around shovel	30	0	5	24
Along pit bench	470	0	3	55
Inpit ramp	200	10	3	40
Along dump	2270	0	4	55
Around dump	30	0	5	24
Total one way	3000			

The model output is compared to that obtained by using a deterministic optimization (Fig. 5), in which the uncertainties associated with the project duration and cost were not considered. The figure depicts the project's total cost of different fleet configurations of 988F II loaders and 73D DMP trucks. As it can be seen from the figure, near optimum fleet configuration consists of 14 trucks and 3 loaders. It is clear that increasing the number of trucks beyond 14 does not lead to the increase in fleet productivity.

As shown in Fig. 4, the truck hourly cost has positive correlation with project cost of 0.6502 at time element 4 and 0.3984 at the time interval 1, respectively. The correlation becomes stronger as the project duration increases. Although the truck hourly cost is less than the loader hourly cost, the truck cost has a greater positive correlation with the project cost than loader cost. The project indirect cost, on the other hand, has a weaker correlation with the project total cost. Fig. 6 indicates that the project cost is most sensitive to the trucks cost in comparison to the other parameters.

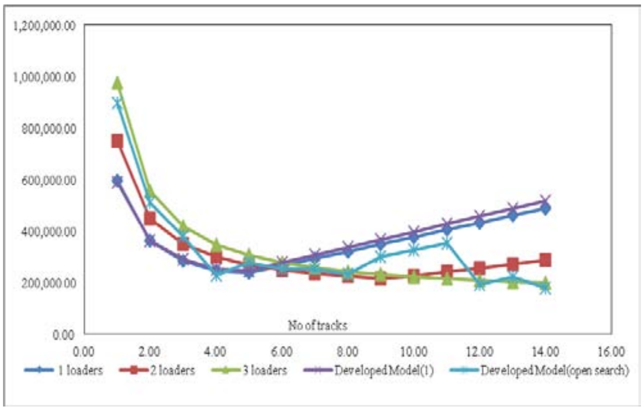

Fig. 5 The developed model Vs deterministic model

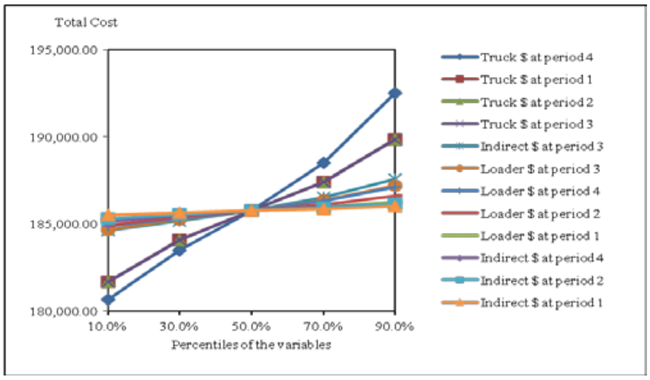

Fig. 6 Sensitivity analysis

Project II

This example project was originally analyzed using discrete simulation [8]. The project involved moving approximately 6,300,000 m^3 (bank volume) of several soil types with different amounts and compaction requirements for constructing a dam in Northern Quebec. In view of the relatively short construction season in the location of the project, the contractor targeted the completion of construction in three years. The number of working hours per year is 1400 hours, 8-hour-shift. Three soil types were used to construct the body of the dam: (1) compacted moraine ;(2) granular (sand and gravel); and (3) rock. In view of the targeted project duration, the project was phased in three stages, each spanning a construction season (Fig. 7). Tables 3 and 4 show the quantities and types of soils used to fill the body of the dam and their respective properties, respectively. A detailed description of the project can be found in [8].

The recommendation of equipment manufacturers was followed to ensure compatibility between haulers and loaders. These recommendations include not only suitable loaders to each hauler but also the number of loaders passed to fill the hauler. It is required to: (1) select fleet configuration using a set of equipment available to the contractor; (2) estimate the cost of the project to meet the contractor's plan of project completion in three years, and (3) evaluate the risk associated with the project cost. Table 5 provides the list of equipment available to the contractor and Tables 6 and 7 depict the probability distribution for equipment hourly cost and operation durations.

TABLE 3
SCOPE WORK FOR EARTH FILLS (BAMK/ M 3)

Soil Type	Stage (1)	Stage (2)	Stage (3)	Total
Moraine	29200	555900	269900	855000
Granular	14500	286500	139000	440000
Rock	192700	3209400	1602900	5005000
Total	236400	4051800	2011800	6300000

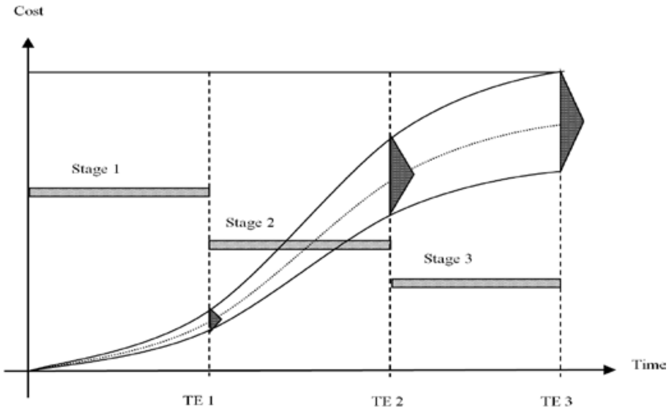

Fig. 7 Project stages and time elements

TABLE 4
SOIL PROPERTIES

Soil Type	Loose Density (t/cu m)	Bank Density (t/cu m)	Load Factor (%)
Moraine	1.66	2.02	100
Granular	1.72	1.93	90
Rock	1.66	2.73	80

TABLE 5
EQUIPMENT AVAILABLE TO CONTRACTOR [8]

Fleet Name	No of Loaders	No of Haulers	No of Spreaders	No of Compactors
F1_Mor	5	35	6	6
F2_Mor	5	40	6	6
F3_Mor	5	45	6	6
F1_Gran	5	35	6	6
F2_Gran	5	40	6	6
F3_Gran	5	45	6	6
F1_Rock	5	35	6	6
F2_Rock	5	40	6	6
F3_Rock	5	45	6	6

TABLE 6
PROBABILITY DISTRIBUTION OF EQUIPMENT HOURLY COST

Fleet Name	Time Element	Hauler H $	Loader H $	Spreader H $	Compactor H $
F1_Mor	Time 1	T(190,212.95,234.25)	T(260.00, 295.74,325.31)	T(130.00, 153.51,168.86)	T(80.66, 89.62, 98.58)
F1_Gra		T(190,212.95,234.25)	T(260.00, 295.74,325.31)	T(130.00, 153.51,168.86)	T(80.66, 89.62, 98.58)
F1_Roc		T(190,212.95,234.25)	T(260.00, 295.74,325.31)	T(130.00, 153.51,168.86)	T(80.66, 89.62, 98.58)
F2_Mor	Time 2	T(130.00, 161, 177.10)	T(200,243.35,267.69)	T(125,153.51,168.86)	T(75,89.62,98.58)
F2_Gra		T(130.00, 161, 177.10)	T(200,243.35,267.69)	T(125,153.51,168.86)	T(75,89.62,98.58)
F2_Roc		T(130.00, 161, 177.10)	T(200,243.35,267.69)	T(125,153.51,168.86)	T(75,89.62,98.58)
F3_Mor	Time 3	T(160,200,220)	T(135,174.21,191.63)	T(115,153.51,168.86)	T(65,89.62,98.58)
F3_Gra		T(160,200,220)	T(135,174.21,191.63)	T(115,153.51,168.86)	T(65,89.62,98.58)
F3_Roc		T(160,200,220)	T(135,174.21,191.63)	T(115,153.51,168.86)	T(65,89.62,98.58)

T: Triangle distribution

TABLE 7
PROBABILITY DISTRIBUTION FOR OPERATIONS DURATIONS [8]

Fleet Name	Load Dist	Haul Dist	Dump Dist	Return Dist	Spread Dist	Compact Dist
F1_Mor	T(2.43,2.56,2.82)	T(20.38,21.45,23.6)	U(1.9,2.2)	T(17.26, 18.17, 19.99)	T(2.47, 2.6,2.86)	T(1.80,1.9,2.09)
F2_Mor	T(1.82,1.92,2.11)	T(19.47,20.6,22.66)	U(1.6,1.9)	T(16.71, 17.59,19.35)	T(2.47, 2.6,2.86)	T(1.80,1.9,2.09)
F3_Mor	T(1.82,1.92,2.11)	T(19.10,20.11,22.12)	U(1.4,1.6)	T(16.76,17.64,19.4)	T(2.47, 2.6,2.86)	T(1.80,1.9,2.09)
F1_Gran	T(3.04,3.2,3.52)	T(29.75,31.32,34.45)	U(1.9,2.2)	T(22.75,23.95,26.35)	T(2.47, 2.6,2.86)	T(1.80,1.9,2.09)
F2_Gran	T(1.82,1.92,2.11)	T(26.80,28.23,31.05)	U(1.4,1.6)	T(22.07, 23.23,25.55)	T(2.47, 2.6,2.86)	T(1.80,1.9,2.09)
F3_Gran	T(1.82,1.92,2.11)	T(30.72,32.34,35.57)	U(1.3,1.5)	T(25.18,26.51,29.16)	T(2.47, 2.6,2.86)	T(1.80,1.9,2.09)
F1_Rock	T(3.94, 4.57, 5.03)	T(4.3,4.53,4.98)	U(1.9,2.2)	T(3.17,3.34,3.67)	T(2.47, 2.6,2.86)	T(1.80,1.9,2.09)
F2_Rock	T(3.15, 3.32,3.65)	T(4.17,4.39,4.83)	U(1.7,1.9)	T(3.10,3.26,3.59)	T(2.47, 2.6,2.86)	T(1.80,1.9,2.09)
F3_Rock	T(3.15, 3.32,3.65)	T(4.59,4.83,5.31)	U(1.6,1.9)	T(3.45,3.73,4.10)	T(2.47, 2.6,2.86)	T(1.80,1.9,2.09)

T: Triangle distribution,U: Uniform distribution

Three scenarios were considered (Table 8). The first scenario was used as baseline in which the developed simulation optimization model was used to search for near optimum fleet configuration and estimate the cost without consideration of any uncertainties and meet the objective set by the user. The second scenario was performed to search for near optimum fleet configuration and estimate the cost while considering uncertainties associated with project cost and the durations of the operations involved. The third scenario was applied to search for near optimum fleet configuration to minimize project total cost accounting for the uncertainties involved.

TABLE 8
CASE SCENARIOS

(1) Optimization Objective	Set project duration to 7578 hrs - No uncertainties considered
Constraints	Duration of stage 3 must be between 2,000 and 3,300 (hrs)
	Duration of Stage 2 must be between 2,900 and 3,400 (hrs)
	Duration of stage 1 must be between 1,200 and 1,300 (hrs)
(1) Optimization Objective	Set project duration to 7500 hrs – uncertainties are considered
Constraints	As above
(2) Optimization Objective	Minimize project $ - uncertainties considered
Constraints	As above

F. Analysis of the Results

Scenario (1): the user set the project duration to 7578 hrs and uncertainties associated with the project cost and time not considered. As shown in Table 9, the model selected fleets for the project's three stages. These fleets provide the most effective production rate to meet the project constraints. Using these fleets, the project can be completed in 6358.17 hours and with a total cost of $ 47,829,664.56. The durations of the three stages were 1192.63, 3121.34, and 2044.18 hrs, respectively. Stage 1 requires a single shift, while stages 2 and 3 require double shifts to meet the project constraints. The model selected fleets that satisfy the objective regardless of the project time. For example, for fleet F1_Rock, the model selected a hauler and three loaders. This is attributed to the facts that the borrow pit site is located near the dam site, and the scope of work for this stage is relatively small compared to that of stage three. Fig. 8 depicts the performance chart generated by of the developed model for this scenario. As it can be seen from the figure, the model found the best solution at 500 simulations run.

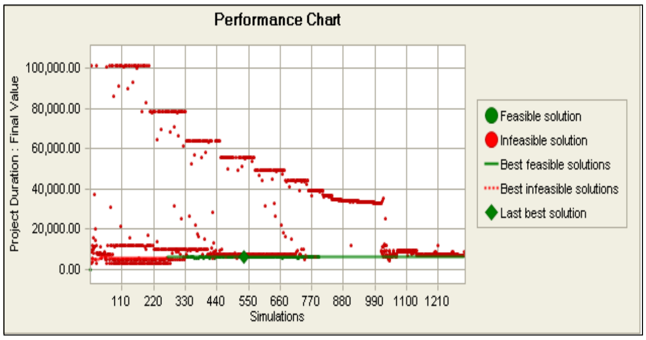

Fig. 8 Performance chart of the developed model (Scenario 1)

In scenario (2), the objective function of the model is set to project duration of 7500 hrs and uncertainties associated with the project cost and time are to be considered, while meeting the project constraints. Here, the uncertainties are considered dynamically on three time elements over the project duration. Triangular probability distribution was selected to represent the uncertainty associated with the duration of the load, haul, return, spread, and compact activities, while a uniform distribution was selected to represent the uncertainty associated with duration of dump activity. The triangular distribution was also selected to represent the uncertainty associated with the project direct and indirect cost.

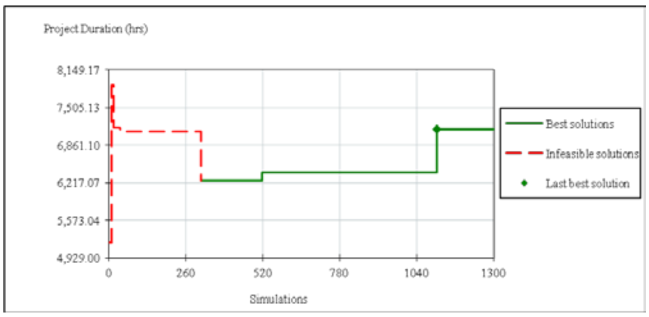

Fig. 9 Performance chart of the developed model (Scenario 2)

Fig. 9 depicts that the best solution that meets the project constraints set by the user found after 1100 simulations. Although the model did not find the solution that exactly match the project duration constraint, the model picked up the closest solution (7044 hrs) with a total cost of $ 53,106,212.21. Table 10 displays the model output of this scenario.

In the third scenario, the optimization objective is set to minimize project total cost, while meeting the same constraints set by the contractor as in the previous scenarios. The model also accounts for uncertainties associated with project operations and that associated with project cost. The same distributions were selected to represent the uncertainties associated with the project duration and the cost. Since the objective is to minimize the project cost, the model selected fleets configurations that are capable of completing the project with least cost. The selected fleets provide the most cost-effective production rate.

As shown in Table 11, using the selected fleets, the project can be completed in 4382.41 hours and with a total cost of 36,330,375 dollars. The result indicates an improvement over that provided by models in previous scenarios. As shown in Table 11, for fleet F1_Mor, the near optimum fleet configuration consists of 3 loaders, 35 haulers, 4 compactors, and 4 spreaders. Comparing with the fleet that generated in the first scenario, the number of haulers in F1_Mor in first scenario does not match the number of loaders. This is attributed to the fact that setting the project duration to targeted time value not necessary leads to minimizing in project cost. On contrary, minimizing the project time leads to minimizing the project total cost. This is attributed to the effect of the indirect cost. Comparing the output of the model in scenarios 1 and 3 shows that although in scenario 1 the number of equipment involved in the operations is smaller than that involved in the operations 3, the project total cost in scenario 3 is smaller than the project total cost of scenario 1.

TABLE 9
MODEL OUTPUT FOR SELECTING FLEETS CONFIGURATION FOR SCENARIO 1

Fleet Name	No of Loaders	No of Haulers	No of Spreaders	No of Compactors
F1_Mor	3	18	4	4
F2_Mor	3	21	4	1
F3_Mor	3	23	4	4
F1_Gran	3	18	4	1
F2_Gran	3	21	4	4
F3_Gran	3	23	4	4
F1_Rock	3	1	4	4
F2_Rock	3	21	4	4
F3_Rock	3	23	4	4
Project duration (hrs)	Stage 1(hrs)	Stage 2(hrs)	Stage 3(hrs)	Project duration
	1192.63	3121.34	2044.18	6358.17
	Direct $- stage 1	Direct $- stage 2	Direct $- stage 3	Total cost
Direct $	2,659,240.42	15,619,805.48	12,459,640.91	30,738,686.82
Indirect $	Time independent $	Time related $	Access road $	Total indirect $
	46,100,000	1,536,934.341	6,075,000	16,307,141.23
Total cost				47,829,664.56

TABLE 10
MODEL OUTPUT FOR SELECTING FLEETS CONFIGURATION FOR SCENARIO 2

Fleet Name	No of Loaders	No of Haulers	No of Spreaders	No of Compactors
F1_Mor	2	28	5	5
F2_Mor	1	29	2	4
F3_Mor	1	32	2	5
F1_Gran	2	29	4	4
F2_Gran	1	20	2	1
F3_Gran	4	33	5	5
F1_Rock	2	1	1	2
F2_Rock	3	33	6	3
F3_Rock	4	10	5	4
Project duration (hrs)	Stage 1(hrs)	Stage 2(hrs)	Stage 3(hrs)	Project duration(hrs)
	1168.74	3038.86	2836.96	7044.57
	Stage 1	Stage 2	Stage 3	Total Direct cost
Direct $	1,525,233.084	18,819,732.04	13,611,756.42	33,956,721.54
Indirect $	Time independent $	Time related $	Access road $	Total indirect $
	46,100,000	1,697,836.077	6,075,000	18,283,594.27
Total cost				53,106,212.21

TABLE 11
MODEL OUTPUT FOR SELECTING FLEETS CONFIGURATION FOR SCENARIO 3

Fleet name	No of Loaders	No of Haulers	No of Spreaders	No of Compactors
F1_Mor	3	35	4	4
F2_Mor	3	40	4	4
F3_Mor	3	45	4	4
F1_Gran	3	35	4	4
F2_Gran	3	40	4	4
F3_Gran	3	45	4	4
F1_Rock	1	1	1	1
F2_Rock	4	21	4	4
F3_Rock	5	34	4	4
Project duration (hrs)	Stage 1(hrs)	Stage 2(hrs)	Stage 3(hrs)	Project duration
	1163.12	2070.20	1149.09	4382.41
	Stage 1	Stage 2	Stage 3	Total cost
Direct $	1,079,965.186	13,100,837.58	10,756,532.68	24,937,335.44
Indirect $	Time independent $	Time related $	Access road $	Total indirect $
	1,246,866.772	6,075,000	10,757,138.48	46,100,000
Total cost				36,330,375.98

III. SUMMARY AND CONCLUDING REMARKS

This paper presents a new methodology for dynamic risk modeling of optimized schedules and cost estimates of earthmoving operations. The model considers the uncertainties associated with project time and cost as a function of time over the project duration. The model utilizes simulation optimization in its optimization process. Two project examples were analyzed to enable the comparison between the developed model and those developed by others and to demonstrate the capabilities of the developed model. The results indicate that the deterministic optimization model overestimates fleet project total cost. The main feature of the developed model is that the model selects near optimum fleet formations while considering uncertainties that impact project estimated cost. The results obtained from the 2nd example demonstrate the capabilities of the developed model considering large projects that require relatively long duration for completion.

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