

**A SIMPLIFIED ONLINE SOLUTION FOR SIMULATION-BASED OPTIMIZATION OF
EARTHMOVING OPERATIONS**

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ABSTRACT

Daily field management of earthmoving operations requires quick and regular decisions for allocating available equipment to different jobs on a project. A general foreman's day starts with matching several activities with a suitable set of available equipment to achieve the highest productivity and lowest unit cost. Usually, this decision-making process needs to be quick, and depends to a great extent on the foreman's experience, which varies from one individual to another. Many analytical solutions with various degrees of sophistication and optimization exist to address such decisions. However, adopting any of these solutions is contingent on how accessible and easy-to-use the solution is. This paper discusses the development process of a web-accessible solution for evaluating earthmoving fleet composition and allocation scenarios. The solution relies on discrete event simulation and an optimization back-end engine, but introduces the user with a simplified and easy-to-use interface that is accessible from any mobile device, and is customized to specific user's needs. The developed system gathers most equipment and site-related input data from a company's information systems to minimize user input. The user mainly needs to formulate equipment and job combinations and allocation scenarios (e.g. soil type, quantity, and hauling distance), according to equipment availability each day. Then the system will evaluate the productivity and unit cost estimates for each scenario, allowing the user to choose the most suitable one. It may also be used to automatically recommend the optimum solution given an available list of equipment. The paper presents the process followed in prototyping the proposed system in collaboration with a major Canadian earthmoving contractor, and customizing it to the user needs within the company. It also describes the overall structure of the developed system and its core simulation model.

KEYWORDS

Earthmoving, Resource Allocation, Simulation, Optimization

LITERATURE REVIEW

Earthmoving operations have been tackled by many researchers; one example is implementing queuing theory (Halpin & Woodhead, 1976). Hajjar & AbouRizk

(1996) developed a special purpose simulation tool for earth moving operations. Special purpose simulation tools aid users with no experience to easily gain simulation advantages. Alkass, El-Moslmani and Al-Hussein (2003) developed a computer model "FLSELECTOR" for equipment fleet selection for earthmoving operations; they found that only queuing theory and simulation are suitable for modeling earthmoving operations because they capture the uncertainty associated with equipment cycle time. Marzouk & Moselhi (2003) used Object Oriented Programming (OOP) technique to develop a simulation system (SimEarth) which simulates earthmoving operations and selects "a near-optimum fleet configuration."

Smith, Osborne and Forde (1995) studied the effect of different variables on the production rate of earthmoving operations; they showed that the production rate is sensitive to six factors: number of trucks, passes per load, load passes time, spot time, travel time, and dump time.

Kannan, Schmitz and Larsen (2000) tried to address the gap between academia and industry in simulation; they showed that the success of the simulation model in industry depends on answering the question "who is going to use what, why and how often."

OBJECTIVES

General foremen dealing with earth moving operations make decisions on a daily basis regarding tasks and equipment, i.e. which task to start with, which task is most suited to the available fleet, dealing with having many trucks but a limited number of excavators or vice versa, etc. For example, in a typical situation, the general foreman may have to choose to move dirt either from A to B (hauling distance = 3 km), or from C to D (hauling distance = 20 km); this clearly will depend on the trucks to excavators ratio and on his personal past experience. This experience varies from one general foreman to another, and because of their daily nature, these decisions may affect the project total float.

The objective of this paper is to illustrate the development of a tool that supports and enhances daily decisions by simulating different tasks and calculating productivity and unit cost for each case. This will aid general foremen in choosing the most suitable task (highest productivity in case of schedule-driven projects or least unit cost in case of budget-driven projects) for the available fleet. Since the target users are general foremen, we tried to make the tool as simple as possible, and also accessible from anywhere, so, unlike many other models, we decided to build a computer simulation model with a web component that can be accessed from any smart phone or web browser. In addition, an optimization component has been developed and illustrated in this paper.

DEVELOPMENT PHASE

To develop the tool, we started the investigation phase, in which we captured our partner company's traditional solutions through contact with their estimators; then, in the modeling phase, we started development of the model and adjusted it in

cooperation with the estimators; after that, we moved to the deployment phase, testing the tool in remote construction sites. Finally, we are currently building a validation model to compare our model's output with real data.

INVESTIGATION PHASE

We worked with estimators in our partner company to capture the traditional methods they use to estimate productivity and resource allocations. We created an IDEF0 (Integration Definition for Function Modeling) diagram (Figure 1) which describes the current process; estimators use Microsoft Excel® to calculate productivity and Hard Dollar® to calculate unit cost during the bidding process. According to the estimators, 1) quantity of soil, 2) soil type, 3) hauling distance, 4) excavator type, 5) number of excavators, 6) truck type, and 7) number of trucks are the variables that affect productivity.

Scenarios

A scenario can be defined as a specific case in solving an earthmoving problem; each scenario has known items, available options, and output. Depending on the seven variables above, we extracted the different scenarios that face estimators or general foremen. Table 1 shows these scenarios. In scenario one, all variables are known and it is only calculation of productivity and unit cost are required, while in the second scenario, determination of the number of trucks that match the available excavators is also required. Estimators might also have another scenario when quantity of soil, soil type, and hauling distance are known, while there are available options for truck and excavator type and numbers (Scenario 3, 4).

MODELING PHASE

After capturing the traditional solution used by our partner company, we started to develop a state-of-the-art solution to this process. This tool has two components: the first one targets estimators, and the second one, general foremen. While developing the general foremen component we complied with two basic concepts, simplicity and accessibility. Regarding simplicity, we tried to develop an intuitive and simple interface and reduce the required inputs; at the same time, this tool had to be easy to access through any handheld device.

We believed that the best way to achieve simplicity and accessibility is through a web-based solution (Figure 2) because websites can be accessed from any smart phone and usually have a very simplified interface. The website is connected to a simulation engine in a server. When a user fires a request, the simulation engine simulates the problem, calculates productivity for the operation and sends the result back to the interface. ASP.NET® was used to develop the web interface while the simulation model is developed in Symphony (Hajjar & AbouRizk, 1999).

Table 1 – Different scenarios for earthmoving operations

	Known variables	Available options	Output
Scenario 1	1, 2, 3, 4, 5, 6, 7	-----	Duration/Productivity, Unit cost
Scenario 2	1, 2, 3, 4, 5, 6	-----	№ of trucks, Duration/Productivity, Unit cost
Scenario 3	1, 2, 3	4, 5, 6	№ of trucks, Duration/Productivity, Unit cost
Scenario 4	1, 2, 3	4, 5, 6, 7	Duration/Productivity, Unit cost

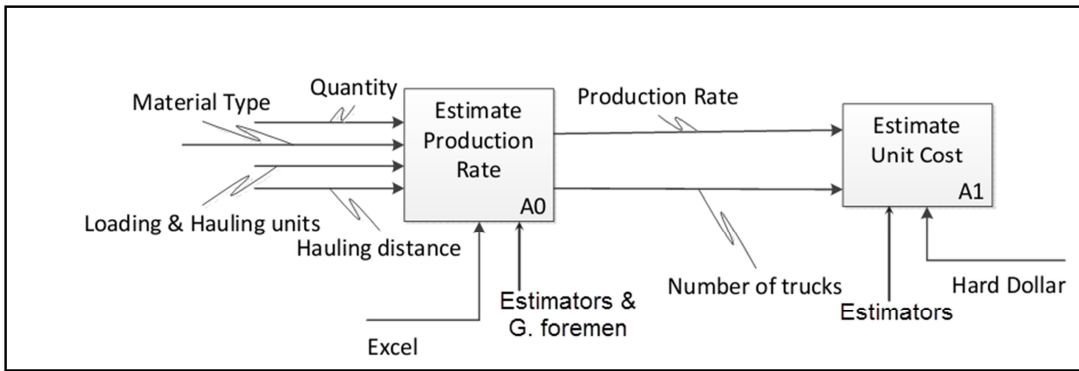


Figure 1 – IDEF0 diagram for current process in our partner company

Figure 2 – Web user interface for comparing two different scenarios

Simulation Pseudo Code

Behind the scenes, the website interface uses Symphony simulation engine (Hajjar & AbouRizk, 1999) to simulate the whole operation and calculate productivity; this simulation model does not have a graphical interface, instead Symphony core services were used to develop a model through code. This will enable us to adjust the model easily depending on user input. In this model, entities represent trucks and excavators are represented as resources, while loading, hauling, dumping, returning and fueling are represented as activities. A pseudo code for the model has been introduced and the Symphony engine automatically calculates the resource utilization, idling time, and the mean waiting time for the trucks.

List 1 – Pseudo code for the simulation model

```
Take user inputs (required quantity to move, trucks, excavators...etc.)  
Generate entities (equal to number of trucks)  
Generate resources (equal to number of excavators)  
For each entity:  
    Try to capture a resource  
    Calculate loading time (based on truck capacity and excavator production  
rate)  
    Wait till elapsing loading time then release the resource  
    Wait till elapsing hauling time then start dumping event  
    After dumping time elapsed, increase dumped quantity  
    Calculate production rate  
    If dumped quantity >= required quantity, exit for  
    Wait till elapsing return time, and go next  
Display results for the user
```

Attribute Values

To keep the interface simple, and because general foremen are interested in the relative productivity between two tasks rather than the absolute values, we considered that some attributes are constant, like fueling time, truck speed ..etc. Table 2 shows these attributes and their values; these values were agreed upon with estimators based on previous projects. Although general foremen cannot change these values, estimators can change them by accessing the server.

Table 2 – Pre-assumed values in the model

Attribute	Value	Attribute	Value
Efficiency factor	85%	Truck speed	20 km/hr
Spot time	60 seconds	Dump time	30 seconds
Fuel time	30 seconds	Exc. swing time	30 seconds

Optimization Component

To extend the power of our model, we added an optimization component that aids in configuring an optimum solution for the required task. To use this component, the user has to define a list of available excavators and define the comparison base (whether time, cost, or both with different weight). Then the component will configure

all possible combinations, simulate each scenario and get the optimum solution, as shown in Figure 3. We found that it takes about one minute to simulate 1575 iterations on Core i5® processor (**Error! Reference source not found.**).

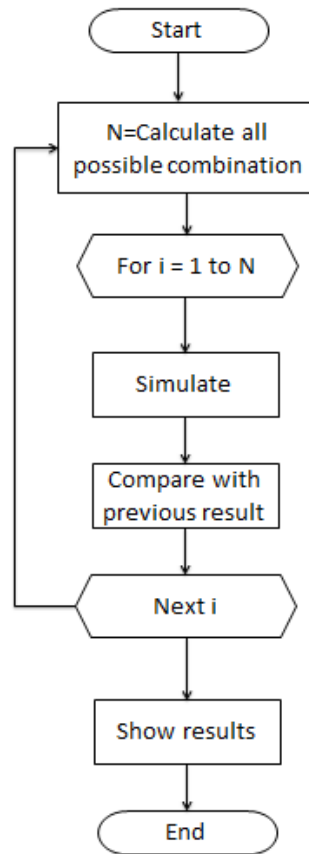


Figure 3 – Algorithm for optimization component

Possible Combinations

In order to ensure that every possible combination is taken into account, we used bitwise operations. Here, we will illustrate a small-scale problem: getting all possible combinations of three trucks, namely, T_1 , T_2 , and T_3 , as in **Error! Reference source not found.** We assign a number to each truck in the form of:

$$2^n \text{ where } n = 0, 1, 2, \dots$$

In our case, this will be 1, 2, 4 for T_1 , T_2 , and T_3 respectively. Next, we create a numerical series from 1 to $(2^{\# \text{ of trucks}} - 1)$. This series, 1, 2, 3,...7 in our case, includes every possible truck combination, e.g. 4 means T_3 while 5 (4+1) means T_1 and T_3 . **Error! Reference source not found.** shows every possible combination in our case.

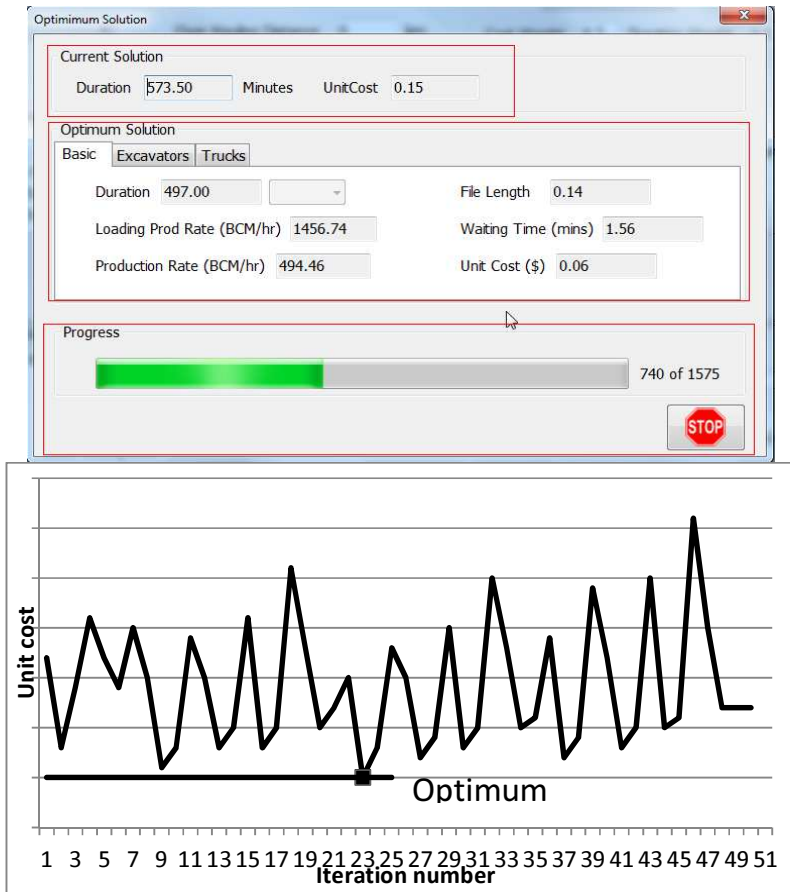
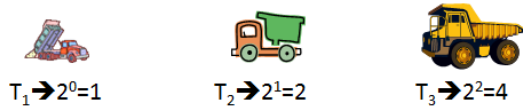


Figure 4 – It took 1 minute to get optimum solution from 1575 iterations

First we assign a number in form of 2^n for each truck



Then generate number from 1 to $(2^{\# \text{ of trucks }} - 1)$ and associate with the related combination

Generate number	Related combination
1	T_1
2	T_2
3	T_1 and T_2
4	T_3
5	T_1 and T_3
6	T_2 and T_3
7	$T_1, T_2,$ and T_3

Figure 5 –Use bitwise operations to find every possible combination

DEPLOYMENT PHASE

The model can be accessed through a URL. We tested access of the model from smart phones in remote locations, like in Fort McMurray; it works as expected in comparing scenarios. We asked general foremen to use the tool, without background knowledge of simulation, they found it intuitive and easy to use; however, they required additional features from the original component (like the ability to add different types of excavators). Also, currently, the optimization component is only available for estimators; we will look into adding it to the web-based application.

CONCLUSION

This paper discussed the development of an earthmoving simulation model that can be accessed as a web page. The main purpose of this model is to help estimators and general foremen allocate resources efficiently. It can be used during project execution to make quick decisions on-site by comparing two different tasks. This model can also suggest the optimum number of trucks to balance the excavators, or even the optimum combination of available equipment.

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