PRODUCTIVITY ASSESSMENT OF ROCK TRANSPORTATION TRUCKS USING SIMULATION TECHNOLOGY

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Abstract: A new container terminal is currently constructed in South Korea in order to handle ever increasing goods transported. The proposed terminal site is partially occupied by a rock mountain that should be removed to provide necessary aggregates and eventually a flat land. A total of 23 million cubic meters of rocks are to be excavated from this mountain, and the port authority wants to get it done within 30 months. As many as 100 dump trucks are expected to be hired every day to transport rocks to be blasted at least 10 different locations on the mountain. Anticipating the congestion that might be caused by many trucks running on the mountain roads at the same time, the stochastic simulation technique was utilized to figure out whether it would affect the rock production. This paper shares lessons learned from the process of creating a simulation model and implementing it in the visual framework.

Keywords: Simulation, Visualization, Excavation

1. INTRODUCTION

A new container terminal is currently being constructed near Busan, the second largest city in South Korea, in order to handle ever increasing quantity of transporting goods. The new terminal is going be large enough to moor up to 30 container carriers at the same time. The construction project is expected to build a total of 9.95 km of quay walls and corresponding container handling facilities by 2011 through 8 phases of construction.

The first phase of construction was completed at the end of 2005 and 3 berths were opened. The quay wall was constructed using 18m high concrete caissons. Caissons were fabricated on nearby seashore, lifted and launched by 3,000 ton crane, and tugged to the proposed location. Aggregate needed for caisson fabrication was supplied from excavating a rock mountain located inside the proposed container terminal.

Currently the second phase of construction is in progress. The rock mountain located inside the proposed terminal needs to be removed to provide a space for the container yard. For this task, a total of 23 million cubic meters of rocks are expected to be excavated.

2. ROCK EXCAVATION

The port authority wants to open the entire container terminal as quickly as possible to secure the competitiveness of the terminal in the Far East, and therefore desires to remove the rock mountain in the second phase construction site within 30 months. In order to get the job done within time, 25,000m^3 of rocks are supposed to be blasted per day for the next 30 months. The blasted rocks are transported either to a dumping place or a barge wharf by dump trucks. Rocks loaded on the barge are to be transported to adjacent embankment construction sites.

If one 15-ton dump truck hauling 8.3m^3 of soil at once is employed to transport these rocks, 3,000 round trips would be required to transport all of them. If a truck can make one round trip in 20 minutes, and if the truck is running for 10 hours a day, one truck can make 30 round trips a day. Considering 3,000 round trips one truck has to make to transport all rocks blast, one needs to hire at least 100 dump trucks to get the job done on time.

If rocks are blasted at one location on the mountain, and if all 100 trucks are running at that blasting location, one may reasonably anticipate some congestion taking place at the blasting location or on the road from and to the dumping places. To avoid unnecessary congestion, the rock blasting needs to be arranged at multiple locations so the move of the dump trucks can be dispersed. If the rock blasting is taking place at 10 different locations on the mountain, for example, the number of trucks to be assigned to each blasting location could be reduced down to 10, and congestion at the blasting location would be reduced drastically.

However, this simple calculation may not predict a reasonably accurate rock production because:

- The speed of a truck is not consistent. It could take less or longer than 20 minutes to make a round trip.
- As more trucks are running on the mountain roads at the same time, more trucks may end up waiting for their turn at the 4-way stop intersection, which results in the truck's overall speed reduction.
- It is not clear how long a dump truck should wait at a blasting site until it gets loaded by the backhoe. The time needed for this activity may depend on the number of backhoes to be used. The dump truck's waiting time at the blasting site can be reduced by increasing number of backhoes. However, too many backhoes may result in having backhoes to wait for dump trucks, which is not

economically advantageous because the backhoe is more expensive to hire.

- It is unclear how long a dump truck would wait at the barge wharf. Obviously it depends on how quickly a truck can dump rocks on the barge. If too many trucks are waiting for their turns at the barge wharf, more barges may need to be hired. Then one may ask how many barges should be moored simultaneously to get the dump trucks moving seamlessly.

In order to take care of above-mentioned uncertainties and estimate the rock production reasonably, a stochastic method needs to be considered.

3. STOCHASTIC SIMULATION

One can estimate the time needed to get a certain task finished by taking historical data or other examples into consideration. However, the actual elapsed time of the task is seldom similar to the predicted one no matter what kind of resources is used. In practical situation, even the duration of the same task is hardly the same. The velocity of a truck running between the blasting location and the dumping place, for instance, is hardly consistent due to uncertainty involved in the process. The same truck would consume different time to make each round trip. If there is any succeeding activity that is controlled by the truck's round trip, its starting time tends to keep changing because of the variation of its predecessor. In addition, the elapsed time of the succeeding activity itself may keep changing due to its own uncertain situation. Considering the time variations of these tasks, one may find it difficult to predict the time needed to get the entire project done.

Attempts to solve stochastic problems in construction started in late 1960s as Au et al. [1] applied a random number technique to a construction bidding game. Their work was followed by the CONSTRUCTO project management game, where weather and labor productivity are integrated into project management [2]. With the advent of simulation methods in construction, a simple networking concept was introduced as a modeling framework for studying construction operations [3]. This concept was later used for the development of the CYCLONE [4] that became the basis for a number of construction simulation systems. The success of CYCLONE led to the development of diverse simulation applications such as MicroCYCLONE [5], INSIGHT [6], RESQUE [7], and PROSIDYC [8]. Although the construction industry has been reluctant to use construction simulation for resource optimization and productivity improvement, simulation technology has been gradually applied to actual construction projects. For instance, PROSIDYC has been used on over 30 projects including, tunnels, maritime projects, dams, highways, etc. and increased productivity by at least 20% [8].

Although CYCLONE successfully simulates the discrete events in construction, the authors found it somewhat difficult to predict truck's speed reduction due to traffic congestion by utilizing CYCLONE. It turned out that dummy activities were needed to consider the truck's speed reduction in the simulation model, which could be a cumbersome task. From the literature review, the authors found that Arena, developed with the SIMAN simulation language [9], may provide a better solution to handle the rock excavation project. Arena's general flowchart module, transporter flowchart module, and conveyer flowchart module seemed to be powerful means to take care of the truck's speed reduction. In addition, Arena provides a graphical means to build and check a simulation model. With Arena, users can build a simulation model by simply selecting appropriate icons from the panel, placing them in the workout sheet, and parameterize them. This process can be done without learning the SIMAN language. Icons representing entities in the workout sheet are moving as simulation time goes by, which is convenient way of checking whether the simulation model is working as intended. The authors therefore decided to use Arena to figure out the truck's potential speed reduction due to road congestion and estimate the amount of rocks to be excavated.

4. CREATING A SIMULATION MODEL

A simulation model was created to find out whether or not the given combination of backhoes, dump trucks, and barges could digest 25,000m^3 of rocks within 10 hours. Assumptions made for creating a simulation model are:

- The daily rock excavation target is 25,000m^3.
- The rock blasting is taking place simultaneously at 10 different locations on the mountain.
- Blasted rocks are transported either to a barge wharf or dumping place by 15-ton dump trucks.
- The loading capacity of a 15-ton dump truck is 8.3m^3.
- Dump trucks are working for 10 hours a day.
- Blasted rocks are loaded into dump trucks by 2m^3-bucket backhoes.
- Time needed to load blasted rocks into a dump truck is 3.81 minutes.
- Time needed to unload rocks at the barge wharf is 3 minutes.
- Time needed to unload rocks at the dumping place is 30 seconds.
- Dump trucks stop for 5 to 10 seconds at each intersection of on the road network.
- The truck's speed is 15km/hr.

5. APPLICATION OF THE SIMULATION MODEL

A total of 4 phases of excavations were planed according to topographic situation on the mountain. This paper presents the phase 1 excavation as an example. In the first phase of excavation, as sown in Figure 1, rocks blasted at 10 different locations. Rocks excavated at blasting location 1, 2, 7, 8, 9, and 10 were assumed to be transported to the barge wharf. Rocks from location 5 and 6 were to be transported to the dumping place A. Rocks from blasting locations 3 and 4 are supposed to be transported to the dumping place B.

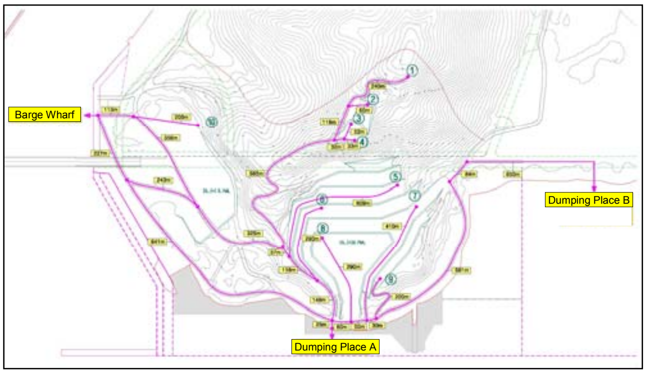

Figure 1: Rocks are blasted at 9 different locations on the mountain. A temporary road network is to be constructed to transport the blasted rocks to 3 different places. Dump trucks are designed in the model to stop for 5 to 10 seconds at each intersection to handle any speed reduction.

Figure 2 illustrates the road network through which dump trucks are traveling to transport blasted rocks, and distances between intersections in the network. Although different route could be selected by the driver in real situation, the authors designated a fixed route for each blasting location for the sake of efficient simulation modeling. For example, a route connecting the blasting location 1, intersection A, C, D, E, G, and the barge wharf in a row was designated for the route 1 although a different route could be taken by the driver.

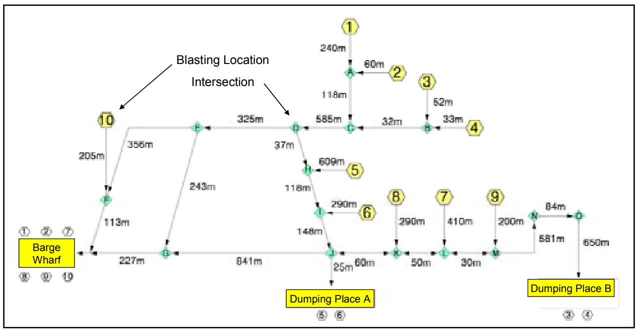

Figure 2: Temporary road network constructed on the mountain for rock transportation and distances between intersections

Figure 3 illustrates the portion of the Arena simulation model being created using the above-mentioned data. As mentioned above, the model can be created by simply selecting an adequate icon that may best represent the corresponding activity, and place it on the worksheet. As rules within the module and relationships between the modules are established, lines are created and connect them adequately. In order to handle the trucks movement in the road and simulate the truck' speed reduction at the intersection, the authors used a transporter flowchart module, which automatically control the speed of the trucks at each intersection.

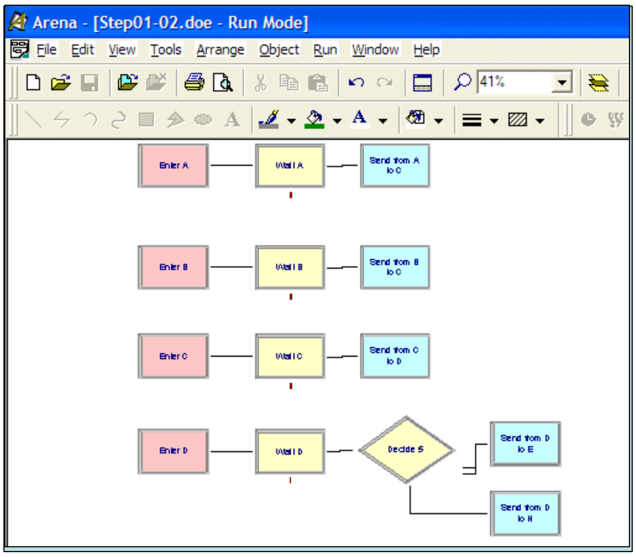

Figure 3: Snapshot of Arena screen displaying the presented simulation model

In order to check whether the simulation model was working as designed, a map representing the topography of the jobsite was integrated with the Arena simulation model as shown in Figure 4. Figure 5 illustrates dump trucks running on the jobsite. Especially Figure 5 shows a truck is waiting at the intersection B, which is near the blasting location 4, while another truck is passing through the same intersection. By looking at this graphic representation, the authors were able to make sure that the model was running as intended.

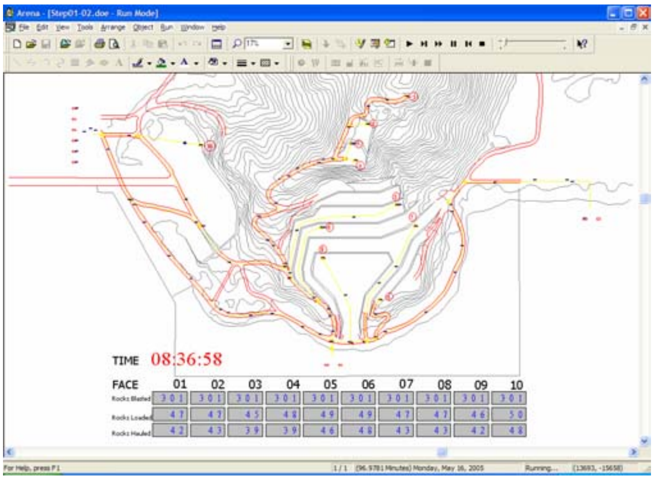

Figure 4: The snapshot of Arena running the presented simulation model. A map representing topography of the mountain was integrated with the simulation model.

After testing various machine combinations with the simulation model, the authors found that two backhoes should be utilized at each blasting location in order to seamlessly load 2,500m^3 of rocks into the dump truck. In addition, the simulation model determined that the wharf assigned to each blasting location should be large enough to moor at least two barges at the same time. The number of dump trucks needed for each blasting location varies according to the distance between the blasting location and the dumping place. Table 1 presents the number of dump trucks to be assigned to each blasting location.

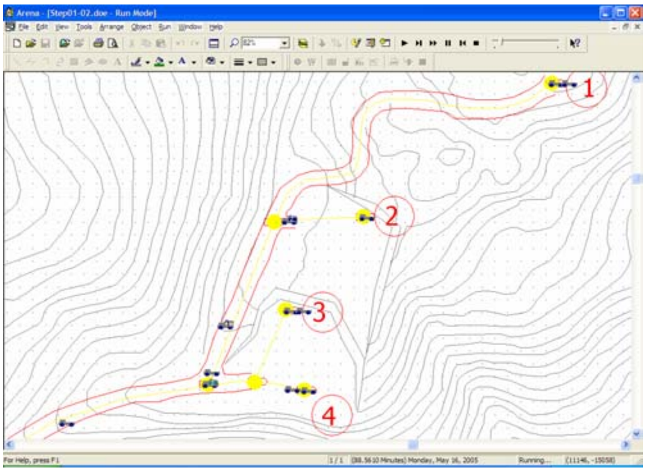

Figure 5: A snapshot of Arena showing dump trucks moving along the road network to transport blasted rocks.

Table 1: Summary of the simulation result

Blasting Location	No. of Dump Trucks	Dump Truck's Waiting Time
1	10	1.4 min.
2	9	0.9 min.
3	13	2.2 min.
4	12	0.5 min.
5	6	1.5 min.
6	4	1.3 min.
7	9	0.7 min.
8	8	0.3 min.
9	8	0.2 min.
10	4	1.6 min.
Total	83	

6. CONCLUSION

This paper briefly presents how the Arena simulation model was utilized to identify the optimum combination of construction equipment to excavate 25,000 m^3 of rocks a day on the mountain located in the proposed container terminal site in South Korea. The experimental application of the Arena to this project demonstrated that the Arena's transporter flowchart module was an effective tool to simulate the truck's speed reduction, which is often critical in construction planning. The authors believe that Arena's ability to represent the entities moving in the simulation model should facilitate the industry practitioners to validate the logic of the model and develop confidence in the result of simulation.

The presented simulation model however used fixed values for all activities except the time needed for the trucks to pass the 4-way stop intersections just to study the impact of traffic congestion on the rock production. For accurate results, the authors are adding more variables to the simulation model.

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