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A PRACTICAL SIMULATION APPROACH FOR AN EFFECTIVE TRUCK DISPATCHING SYSTEM OF OPEN PIT MINES USING VBA

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ABSTRACT

Material handling is one of the most important operations carried out in open pit mines. According to previous studies, it accounts for approximately 50% of total operating costs. As a means of reducing the operating cost, it is important to allocate and dispatch the trucks efficiently. Although optimizing the necessary number of trucks assigned to transportation and hauling is an important issue in the operation of open pit mines, in practice, creating a reasonable truck dispatching control table is more beneficial. In this paper, we propose a practical simulation modeling approach enhanced by VBA programing to achieve an effective truck dispatching system in an open pit mine. We present a case study in an open pit mine, where we implement an algorithm with VBA to determine the best allocation of trucks to meet a particular grade and achieve stable production.

1 INTRODUCTION

There are two general approaches to mining, open pit (i.e., surface) mining and underground mining. Truck haulage is the most common means of transporting ore/waste in open pit mining operations, but the diesel consumption of haul trucks is considered the largest part of the operating costs. As previously demonstrated by many other studies, the transportation costs represent approximately 50% of the operating costs in an open pit mine (Alarie and Gamache 2002; Ercelebi and Bascetin 2009). In this context, as a means of reducing the operating costs, it is important to allocate and dispatch the trucks efficiently.

An efficient truck dispatching system represents a traditional approach to improving production equipment utilization in open pit mining operations. Truck dispatching systems in the mining industry have been studied and have garnered much attention since the mid-1980s. Nenonen *et al.* (1981) studied an interactive computer model of truck/shovel operations in an open pit copper mine. Yun (1982) studied a computer simulation program of drill rigs and shovel operations in open pit mines. In some previous studies, optimization methodologies such as integer programming and dynamic programming were used to determine the fleet size and truck/shovel allocation. Ercelebi and Bascetin (2009) studied shovel and truck operation models and optimization approaches for the allocation and dispatching of trucks under various operating conditions. They used closed queuing network theory for the allocation of trucks and linear programming (LP) for dispatching trucks to shovels. Boland *et al.* (2009) proposed LP-based disaggregation approaches to solve a production scheduling problem for open pit mining. To use linear programming to solve the problem of dispatch planning, there are some problems and prerequisites such as the requirements that the objective function and constraints must be linear and that the data must be deterministic. However, in actual mining operations, uncertainties are rather common. Other studies focused on stochastic behavior and took into account the ambiguities of the uncertain conditions. Oraee and Asi (2004) proposed a model incorporating fuzzy theory in a goal-planning model. Although these studies determined the optimal number of trucks for transport and provided a better truck/shovel allocation, they still could not present a detailed dispatching table to achieve the transport target and production goals.

In actual mine operations, when considering how to dispatch a truck, such questions as when and where to dispatch the truck and how much ore/waste should be transported in this trip need to be answered in a timely fashion. Furthermore, open pit mine planning must consider the amount of production in the refinery factory. It is difficult to determine the best mining positions by considering the required percentages of target minerals required to meet the operations planning of a successful refinery. These are very important issues at a practical level, but they have not been studied in detail in previous studies. To compensate for the above-mentioned problems, this paper applies computer simulation techniques to support operations management in open pit mining. After a brief review describing how simulation has been used in the mining field, a case study utilizing simulation techniques to solve a problem of truck dispatching in an open pit mine is illustrated. Simulation models are constructed and applied to evaluate the current state of operations for an open pit mining company by utilizing global positioning system (GPS) tracking data. Then, the simulation model is enhanced with Excel and VBA (Visual Basic for Application) programming, which provide the capability to test and create a truck dispatching control table for meeting a stable mining plan.

2 TRUCK DISPATCHING PROBLEMS IN OPEN PIT MINING OPERATIONS

In the open pit mining operation, a material handling system is composed of loading, hauling, dumping, returning, and various other auxiliary subsystems, as shown in Figure 1. In the open pit, there are usually several loading points and dumping points. Each loading point is always a pile of loosened ore or waste rocks (to be collectively referred to as material). At each loading point, there is typically one and only one shovel to load the material into dump trucks. When the trucks reach the dumping point, the trucks dump the material into the dumping port (only one, as well).

With the enhanced calculation capacity of computers, it is possible to simulate complex operations in open pit mines. Simulation involves designing a model of a real system and then conducting experiments with the model for the purpose of understanding the behavior of the system and/or evaluating various strategies for the operation of the system (Tan *et al*. 2012). Simulation-based optimization has been performed in various cases in the mining industry. Simulation models of a material handling system for an underground coal mine have been proposed to identify the bottleneck of a conveyance system to identify more efficient mining and conveyance methods (Miwa and Takakuwa 2011). Simulation-based optimization was performed by Chinbat and Takakuwa (2008) in an open pit mine Six Sigma project to define, measure, analyze, and improve the mining and enrichment processes. Another case study was performed to determine suitable numbers of drilling engineers and workers based on the open pit mine

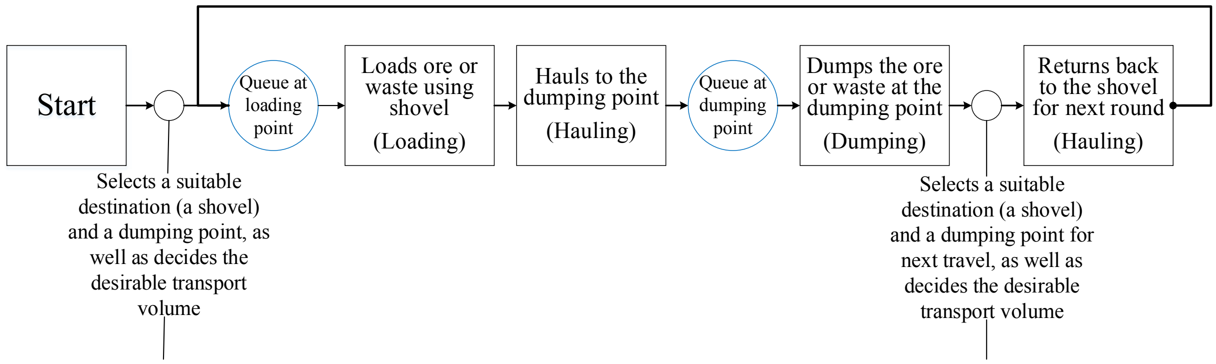


Figure 1: A typical loading and haulage cycle in an open pit mining operation.

process (Chinbat and Takakuwa 2009). Fioroni *et al.* (2008) proposed concurrent simulation and optimization models to achieve a feasible, reliable and accurate solution to the analysis and generation of a short-term planning schedule. Subtil *et al.* (2011) proposed a multistage approach for dynamic truck dispatching in real open pit mine environments; the implementation was achieved with a commercial software package. Optimizing the necessary number of trucks per shovel in the transportation and hauling of material in open pit mines is an important issue to be resolved. Tan *et al.* (2012) proposed a procedure to determine the optimal number of trucks and to estimate the maximum mining capacity at an open copper pit by using the simulation approach.

The problem of dispatching trucks to shovels is quite difficult. An effective dispatching system can not only optimize the loading and haulage cycle, but it also enables mines to maximize productivity across the entire mine operations. Two goals have been targeted in solving the dispatching problem: increasing productivity and reducing operating costs (Alarie and Gamache 2002). As Subtil *et al.* (2011) states, “In the specific context of the mining industry, the truck dispatch problem in open pit mining is dynamic and consist of answering the following question: ‘Where should this truck go when it leaves this place?’”. For example, after ore is transported to the refining plant, the ore will be fed to large mills to be triturated and then will be sent to a froth flotation process. At the froth flotation process, some blended chemicals are added to generate froth to separate valuable minerals from worthless materials. The amounts of these chemicals added to the ore should be adjusted prudently according to the target mineral content contained in the ore. In this context, to keep the production in the enrichment plant continuous, the content of ore fed to the plant must be kept approximately constant over time.

The dispatch approaches in open pit mining can be broadly divided into two types of rules: single stage and multistage systems. Table 1 summarizes the main dispatching methods that have been proposed in the literature (Alarie and Gamache 2002). The single-stage methods are heuristic methods based on human experience, dispatching the trucks without taking into account certain calculations using mathematical programming. On the other hand, multistage methods are plan-driven dispatching methods, which are divided into a number of steps. Usually, the “upper” stage produces the production plan for every shovel using mathematical programming methods, and the “lower” stage then assigns trucks to the shovels to minimize the deviation from the production plan suggested by the upper stage. Furthermore, because the focus is on trucks or shovels, the multistage dispatching methods can be subdivided

Table 1: Main dispatching methods for open pit mines.

Single Stage	Multistage	
Systems using a single-stage approach simply dispatch trucks to shovels according to one or several criteria without taking into account any specific production targets or constraints.	Systems using the multistage approach divide the dispatching problem into subproblems or stages. These systems usually can be reduced to two components: an "upper" stage that consists of setting production targets for every shovel and a "lower" stage that assigns trucks to shovels to minimize the deviation from the production targets suggested by the "upper" stage.	
Method 1: Manual Dispaching	**Method 2: 1-truck-for-n-shovels**	**Method 3: m-trucks-for-1-shovel**
Dispaching methods that are often heuristic methods based on rules of thumb.	When a truck operator asks for a new assignment, he considers the n shovels where the truck can be dispatched, and the system evaluates the cost or the benefits of assigning the truck at each of these shovels according to the chosen dispatching criterion shown as follows: ・Fixed Truck Assignment (FTA) ・Minimising Truck Waiting Time (MTWT) ・Maximise Trucks ・Minimising Shovel Waiting Time (MSWT) ・Maxmising Truck Momentary Productivity ・Minimising Shovel Saturation (MSC)	Truck-dispatching decisions will be made by taking into account the next trucks to dispatch in the near future but only considering one shovel at the time. Specifically, the shovels are first ordered according to a measure indicating by how much they are behind schedule on their production. Next, considering each shovel in that order, one assigns to the current shovel the truck that will reduce the particular measure.

into several approaches such as 1-Truck-for-n-Shovels and m-Trucks-for-1-Shovel, as shown in Table 1. Although the multistage dispatching methods take into account the completion status and progress of the production plan, which can reduce the deviation of the progress of production (excavation) plan between shovels, the above-mentioned problems of determining “when and where should this truck go next?” and “to satisfy the production requirements, how much should the transport amount be set to?” must be addressed. In this study, in consideration of the multistage dispatching method described in Table 1, a new dispatch approach that can solve the above-mentioned problems is proposed.

3 DYNAMIC DISPATCHING APPROCH USING SIMULATION AND VBA

Considering that these problems have not been adequately studied in the literature so far, we propose a dynamic dispatch approach that incorporates the VBA programming with simulation techniques (Figure 2). The dynamic dispatch approach described in this study can be classified as a multistage dispatch approach, as shown in Table 1. Most of the previously proposed dispatch methods have focused on the calculation of the optimal number of trucks to ensure that the production plan is completed within a certain fixed period of time. These methods can be said to be "short-sighted" because they dispatch the current truck without considering its effect on subsequent requests (Subtil *et al*. 2011). In this context, the dispatch approach proposed in this study introduces a dynamic dispatching algorithm after the production plan is assigned in the first stage. Through capturing the dynamic effects brought about by every single

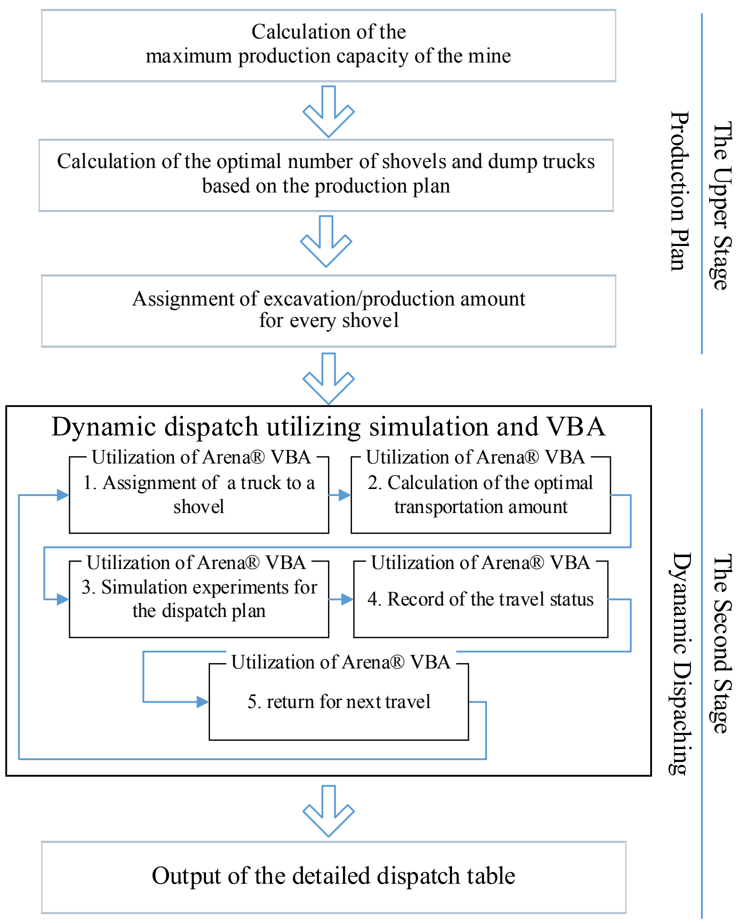
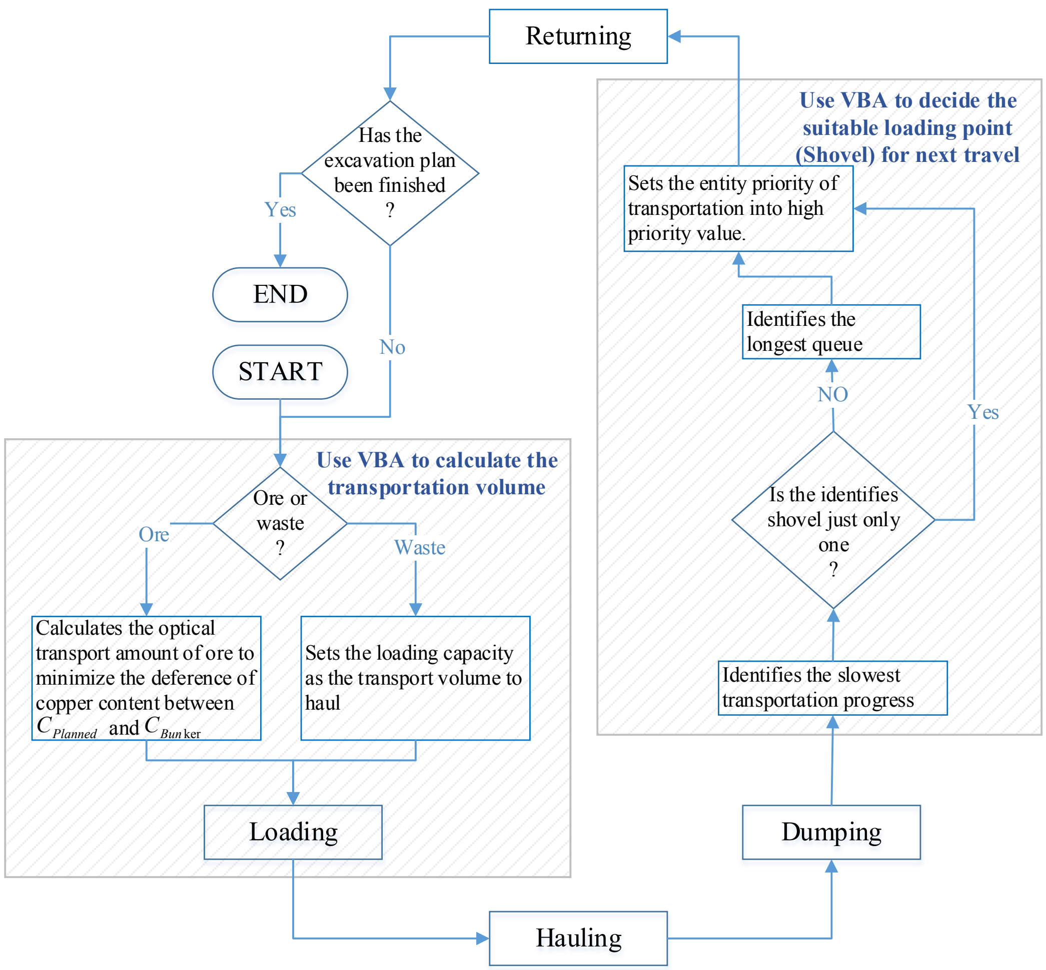


Figure 2: A dynamic dispatch approach incorporating VBA programming with simulation techniques.

transportation by a dump truck, the optimal transportation amount in each trip is dynamically calculated to achieve partial optimization in real time.

In this study, to achieve the above-mentioned research objectives, a simulation technique is adopted. In order to achieve a dynamic dispatching algorithm as shown in Figure 2, Arena VBA is utilized. Microsoft VBA represents a powerful development in technology that rapidly customizes software applications and integrates them with existing data and systems (Miwa and Takakuwa, 2005). Arena permits the model developer to use VBA as the model file is loaded, executed, or terminated or as entities flow through the Arena model modules (Seppanen, 2000). In addition, by using Arena VBA, the simulation model can communicate with other applications such as Microsoft Excel and Access. By combining the simulation capabilities of Arena and VBA, we can construct a customized integrated simulation model that is both dynamic and flexible. The overall structure and the flow of the simulation model are shown in Figure 3.



Note: C_{Bunker} refers to the content of copper contained in the mixed ore in the bunkers;
$C_{Planned}$ refers to the content of copper of ore that had been pre-planned in order to achieve the production plan of the plant;
C_{Ore} refers to the content of copper contained in the primary ore.

Figure 3: The overall structure and flow of the simulation model.

4 CASE STUDY: DISPACHING OPERATIONS IN A MONGOLIAN OPEN PIT MINING COMPANY

4.1 System Description of a Mongolian Open Pit Mining Company

Company "A" is one of the largest ore mining and ore processing companies in Asia. Similar to most mining plants, the production process of company "A" consists of two major components, an open pit mine and a copper ore enrichment plant. The mine and factory are located in Mongolia and have been in continuous operation since 1978. Both the open pit and the enrichment plant are running and producing continuously 24 hours a day throughout the year. At present, company "A" processes 25 million tons of ore per year and produces over 530 thousand tons of copper concentrate and about three thousand tons of molybdenum concentrate annually. The following case study is part of a wider joint research project with company "A," with the goal of improving the efficiency of the operations of mining and transportation in an open pit mine and in an ore enrichment plant.

Over the course of years of mining, the contents of copper and molybdenum have gradually decreased. Additionally, in this open pit mine, the contents of copper and molybdenum vary according to the altitude of the specific mining location. Specifically, the content of copper at low-altitude mining points, at which there has been deep digging, is lower. However, those ores that have a content of copper of less than 0.25% are unable to be processed under the current technical conditions at the enrichment plant. Therefore, from the perspective of operational management, to preserve the product quality as well as to maintain a stable throughput, it is desirable that the content of copper contained in the ore fed to the enrichment be keep approximately stable. Therefore, before feeding the ore into the enrichment process, it is necessary to mix ores with initially high and low contents of copper.

4.2 Transportation and Truck Dispatching

The stage of mining planning is very important in any type of mining because it seeks cost reduction while maximize production plans and focusing on quality and operation requirements, as well as asset utilization and restraints, such as shovels, trucks, and tractors (Fioroni *et al*. 2008). A simplified process map of the open pit mine operation in company "A" is shown in Figure 1. When creating a mining plan in accordance with a production plan, it is necessary to plan for both ores containing a low copper content and those containing a higher copper content. In company "A", a plan for the mining site is developed by the geologist group section. The open pit mining plan is based on the annual plan, which states how much volume to excavate from the current altitude of the open pit, to be distributed evenly to the different altitudes of the mine. In planning, the following are also considered: the ore volume, concentrate and oxide levels, and primary ore percentage. The geological plan and strategy, ore processing standards and normative technology of the enrichment plant and excavation site are also considered. Table 2 shows an example of a completed mining plan from a certain week.

Table 2: An example of a completed mining plan from a certain week.

Elevation of the No. of Mining Points	No. of Excavators	Ore (tons)	Disposal Soil (tons)	Content of Cu in Ore (%)
1355	16	-	-	-
1355	17	126	163,281	-
1355	12	85,067	-	0.54
1325	14	146,917	7,681	0.52
1310	15	7,651	108,919	0.57
1310	16	61,564	48,889	0.44
1295	18	113,964	9,809	0.42
1295	20	87,966	47,635	0.49
1280	19	90,415	36,398	0.68
Total		593,670	422,612	-
Planned Average Content of Ore (%)				0.53

Table 3: Technical data on the transport resources of Company "A".

Drillers				
	Number of units held	5	units	
	Operation shifts	2	shifts	
Bulldozers				
	Number of units held	2	units	
	Operation shifts	3	shifts	
Excavators				
	Number of units held	8	units	
	Average productivity per hour	331.4	m^3/h	1)
	Operation shifts	3	shifts	
	Operators	30		
Dump Trucks				
	Number of units held	24	units	
	Capacity	130	tons	
	Amount per transportation	TRIA(90,130,147)	tons	2)
	Average distance in a one-way transportation	3.26	km	1)
	Average velocity when loading	24	km/h	1)
	Average velocity when unloading	40	km/h	1)
	Operation shifts	3	shifts	
	Operators	80		
Shifts				
	Shift No.1	8:00 -16: 00		
	Shift No.2	16: 00 - 24: 00		
	Shift No.2	24: 00 - 8: 00		

Note: 1) Actually these measures have some variation.
2) TRIA indicates a triangular distribution.

4.3 Transportation and Truck Dispatching

As mentioned earlier, the transportation of material (both ore and waste soil) in an open pit corresponds to approximately 50 percent of the total operating costs. In this context, to allocate and dispatch the trucks efficiently provides considerable savings of resources.

The transportation resources held by company "A" and technical data on the transport resources are summarized in Table 3. In company "A", there are 24 dump trucks, all of which can be used to transport either ore or soil from the mining points to the enrichment plant or the disposal hills, respectively, in accordance with the instructions provided by the operation center. There are 13 soil disposal locations (hills) around the location of the open pit mine. At the soil disposal locations, the soil is spread over the ground using a bulldozer to recover the environment. In the enrichment plant, there are two ore feeding entrances. When the ore is transported to the enrichment plant, the ore will then be fed to an ore feeding entrance (bunker A or B) according to the size (diameter) of the ore; concentrating processes are then performed inside the plant. In Table 3, the parameters of some measures are briefly indicated as average values.

A few years ago, company "A" introduced a mining transportation control system that utilizes GPS technology. This transportation control system helps company "A" to control the loading and transportation processes technically and economically. Although use of the GPS technology in the transportation control information system plays a very important role in controlling the fuel consumption, weight capacity and speed of the dump trucks, dispatching a truck to an excavator has not been automated yet. This is due to the complex logic of dispatching trucks. As described above, to keep the production in the enrichment plant continuous, the content of ore fed to the plant must be kept approximately constant at an average content. However, it is quite difficult to do this. As shown in Table 1, different mining points with different locations have different contents of copper. When considering dispatching a truck to an excavator, the dispatchers have to decide where or which excavator is the best destination to send the truck to satisfy the production requirements, as well as to direct the transportation amount to the truck. At the same time, the dispatchers should also consider the progress of transportation at each mining point because the entire specified mining plan, both the transportation of ore and waste soil, must be completed on schedule. Currently, the truck dispatch is directed by the transport control staff manually via wireless walkie-talkies based on the data and information obtained from the GPS transportation control information system that are displayed on the computer monitor in real time.

In this study, to facilitate the fleet management in open pit mining, we try to embed the logic of dispatching a truck and automate the truck dispatching systems by utilizing simulation and VBA. Thus, after the mining plan has been made, when we run the model, as an output of the program, the truck dispatching control table is generated automatically.

4.4 Construction of Simulation Models Enhanced by VBA Programming

Computer-aided simulation is a powerful tool for modeling nonlinear dynamic systems, providing a method for including random and structural variation in the models. Simulation can help mining project managers to understand the behavior of the system and to optimize the system through various strategies by providing a visual and dynamic description (Tan *et al.* 2012). To support operations management in company "A," the computer simulation technique is applied. The simulation model is programmed in Arena (Kelton, *et al*. 2010) and is then overlaid on a scaled mine layout. To achieve the dynamic dispatch approach, Microsoft VBA language programs are incorporated into Arena simulation models.

An algorithm for the problem of the dynamic dispatch of trucks in open pit mining has been proposed (Subtil *et al.* 2011). The proposed algorithm includes two main phases: allocation planning and dynamic allocation. Allocation planning is to find the maximum mining capacity of the mine in the current scenario and the optimal size of the fleet of trucks needed to meet this maximum capacity. Because the maximum mining capacity and the optimal size of the trucks for company "A" have already been discussed and determined (Tan *et al.* 2012), in this study, we continue the study from the dynamic allocation.

As shown in Figure 2, in the second phase, dynamic allocation finds the best allocation scheduler for a dispatch requisition to comply with the allocation planning, using a dynamic dispatch heuristic. The algorithm for calculating the transport amount when dispatching trucks to shovels is shown in Figure 4. To illustrate this algorithm, for convenience, we try to consider this based on a simple example. At the mining point of "Z", the content of copper contained in the ore is 0.60%. To maintain stable production in the enrichment plant, it is necessary to provide ore with a 0.53% average content stably and continuously. 100 tons of ore have been transported to the bunker so far, and the average copper content in the bunker is

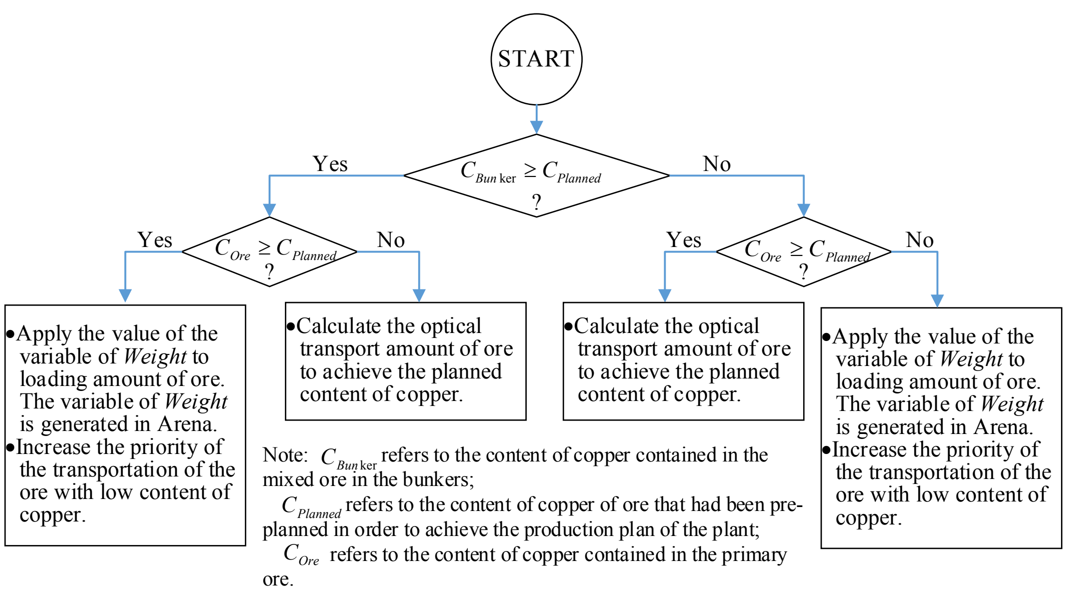


Figure 4: Algorithm for calculating the transport amount when dispatching trucks to shovels.

presently 0.48%. Now the question is how much of the ore with a 0.6% copper content should be transported to the bunker? Here, the maximum load capacity of the truck is restricted to 130 tons.

To seek out the solution of the optical amount of transportation (referred to below as "Q"), we generate a loop for Q from one ton to 130 tons by steps of one ton. While Q is looping, we calculate and estimate the copper content (referred to below as "Cu%") after Q tons of ore with 0.6% content being fed to the bunker, as well as to calculate the error between 0.53% and Cut%. Then, when Q makes the value of this error become the smallest, Q is a solution to this problem.

To facilitate verifying the effectiveness of the proposed dynamic dispatching method, we revised the As-Is model to another experimental model by adopting Arena VBA programming. Partial views of the simulation model and VBA procedures are shown in Figure 5.

4.5 Simulation Experiment and Results

After the simulation model is built, validation of the model is accomplished through an interactive process between the company staff and the modeler; this interactive process compares the model's output with the real GPS tracking data. After confirming the reliability of the model, the simulation models are run, and the results are analyzed. Table 4 shows a comparison between the results of the manual and proposed VBA-utilizing dynamic dispatching methods. The values in Table 4 are average execution results at the 95% confidence interval. The simulation is executed for a total of 30 replications. A portion of the truck dispatching control table output from the VBA-enhanced simulation model used to achieve the mining plan is shown in Figure 6.

As shown in Table 4, the values of the performance indicators are improved when adopting the VBA-utilizing dynamic dispatch. First, the length of time of the simulation, as well as the time taken to complete the expected mining plan, is significantly reduced from 11,502 minutes to 7,422 minutes. Thus, company "A" can then expand its production using the time saved. In addition, the total number of transportation rounds and the total transportation distances of ore and waste decrease. Because the trucks

Table 4: Comparison between results of manual dispatching and the VBA-utilizing dynamic dispatching methods.

Obervation Intervals — Min, Avg, Max, 95%CL

Performance Indicators	Dynamic Dispached Method with VBA	Manual Dispatching (Historic Value)
Expected Excavation Plan of Ore (tons)	593,670	
Expected Excavation Plan of Waste (tons)	422,612	
The Length of Simulation / Total Time Taken to Complete the Expected Excavation Plan (min.)	7,422; 7,398; 7,438; 7415; 7,429	11,502
Number of Transportations (round trips)	8,351; 8,331; 8,360; 8,346; 8,356	8,347
Total Weight of the Transported Ore (tons)	593670; 593670; 593670; 593670; 593670	593,670
Total Weight of the Transported Waste (tons)	422,612; 422,612; 422,612; 422,612; 422,612	422,612
Average Weight of Loading per Transportation (tons)	121.4; 90.1; 146.9; 122.1; 121.6	122
Average Transportation Time Spent in a Single Trip (min.)	9.67; 4.50; 21.56; 9.61; 9.74	11.8
Total Transportation Distance of Ore (km)	12,640; 12,610; 12,659; 12,631; 12,648	13,332
Total Transportation Distance of Waste (km)	8,524; 8542; 8628; 8,520; 8,563	11,423
Average Copper Content in Bunkers (%)	0.5242; 0.42; 0.68; 0.5239; 0.5245	N/A
Average Truck Scheduled Utilization (%)	99.85; 99.8; 100; 99.85; 99.85	71.2

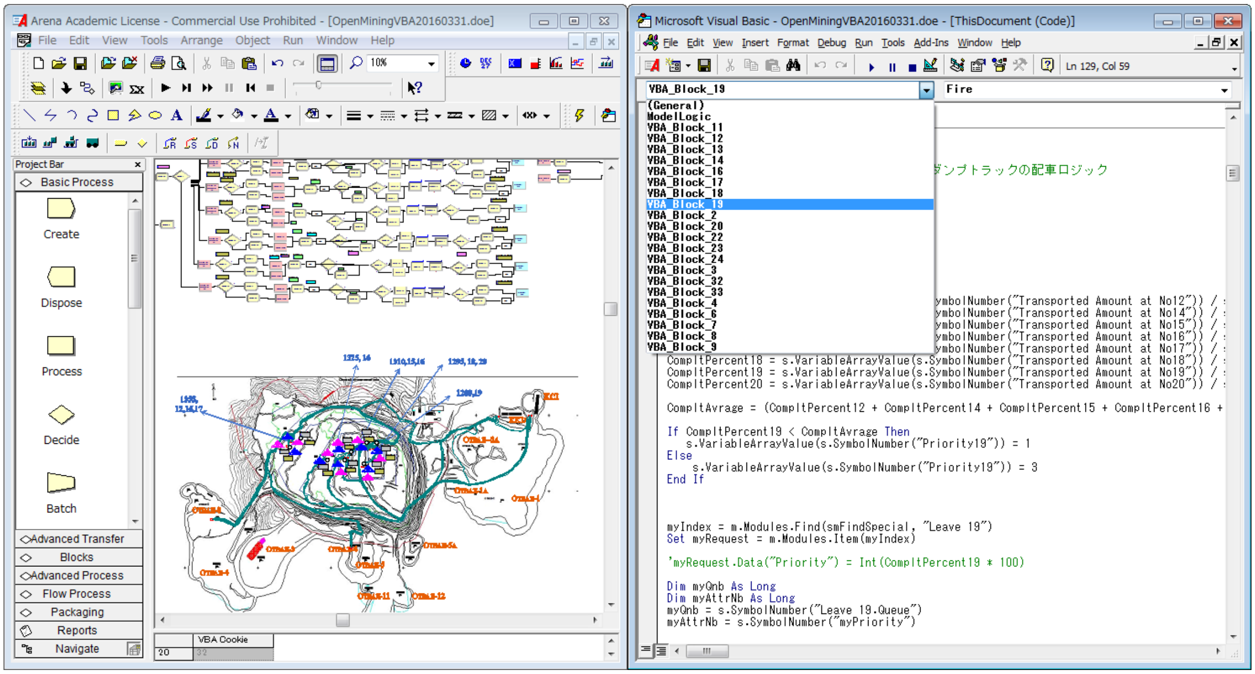
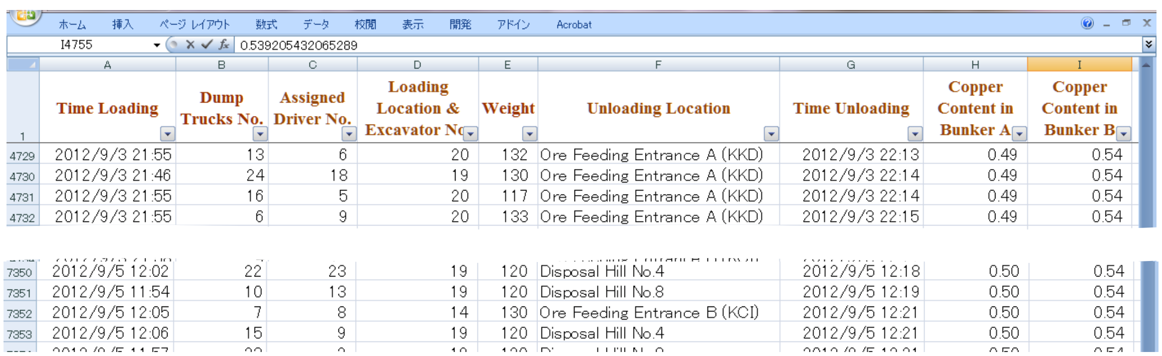


Figure 5: Partial views of simulation model and VBA procedures.



	Time Loading	Dump Trucks No.	Assigned Driver No.	Loading Location & Excavator No.	Weight	Unloading Location	Time Unloading	Copper Content in Bunker A	Copper Content in Bunker B
4729	2012/9/3 21:55	13	6	20	132	Ore Feeding Entrance A (KKD)	2012/9/3 22:13	0.49	0.54
4730	2012/9/3 21:46	24	18	19	130	Ore Feeding Entrance A (KKD)	2012/9/3 22:14	0.49	0.54
4731	2012/9/3 21:55	16	5	20	117	Ore Feeding Entrance A (KKD)	2012/9/3 22:14	0.49	0.54
4732	2012/9/3 21:55	6	9	20	133	Ore Feeding Entrance A (KKD)	2012/9/3 22:15	0.49	0.54
7350	2012/9/5 12:02	22	23	19	120	Disposal Hill No.4	2012/9/5 12:18	0.50	0.54
7351	2012/9/5 11:54	10	13	19	120	Disposal Hill No.8	2012/9/5 12:19	0.50	0.54
7352	2012/9/5 12:05	7	8	14	130	Ore Feeding Entrance B (KCI)	2012/9/5 12:21	0.50	0.54
7353	2012/9/5 12:06	15	9	19	120	Disposal Hill No.4	2012/9/5 12:21	0.50	0.54

Figure 6: Partial view of the truck dispatching table output generated by the VBA-enhanced simulation model.

consume a large amount of gasoline, these reductions of transportation needs will directly lead to a reduction in transportation costs.

5 CONCLUSIONS

In this paper, simulation models were constructed and enhanced with VBA programming to create and test a dynamic dispatching control table to meet a mining plan in an open pit mine. It was found that by combining simulation with VBA programming, the transportation performance of the trucks could be significantly improved, leading to a reduction in transportation costs. Simulations can help mining project managers understand the behavior of their systems by providing visual and dynamic descriptions to allow for the optimization of a system through various strategies.

REFERENCES

Alarie S. and M. Gamache. 2002. "Overview of Solution Strategies Used in Truck Dispatching Systems for Open Pit Mines." *International Journal of Surface Mining, Reclamation and Environment* 16(1):59-76.

Boland, N., I. Dumitrescu, G. Froyland, and A. M. Gleixner. 2009. "LP-based Disaggregation Approaches to Solving the Open Pit Mining Production Scheduling Problem with Block Processing Selectivity." *Computers & Operations Research* 36: 1064-1089.

Burt, C., L. Caccetta, S. Hill, and P. Welgama. 2005. "Models for Mining Equipment Selection." In *Proceedings of MODSIM 2005 International Congress on Modelling and Simulation*, edited by A. Zerger and R. M. Argent, 170-176.

Chinbat, U. and S. Takakuwa. 2009. "Using Simulation Analysis for Mining Project Risk Management." In *Proceedings of the 2009 Winter Simulation Conference*, edited by M. D. Rossetti, R. R. Hill, B. Johansson, A. Dunkin and R. G. Ingalls, 2612-2623. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Ercelebi, S. G. and A. Bascetin. 2009. "Optimization of Shovel-truck System for Surface Mining." *Journal of the Southern African Institute of Mining and Metallurgy* 109:433-439.

Fioroni, M. M., L. A. G. Franzese, T. J. Bianchi, L. Ezawa, L. R. Pinto, de Miranda, and J. Gilberto. 2008. "Concurrent Simulation and Optimization Models for Mining Planning." In *Proceedings of the 2008 on Winter Simulation Conference*, edited by S. J. Mason, R. R. Hill, L. Moench, O. Rose, 759-767. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Kelton, D., R. Sadowski, and N. B. Swets. 2010. *Simulation with Arena*. 5th Edition. New York: McGraw-Hill, Inc.

Kolojna, B., D. R. Kalasky, and J. M. Mutmansky. 1993. "Optimization of Dispatching Criteria for Open Pit Truck Haulage System Design using Multiple Comparisons with the Best and Common Random Numbers." In *Proceedings of the 1993 Winter Simulation Conference*, edited by G. W. Evans, M. Mollaghasemi,. E. C. Russell, W. E. Biles, 393-401. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Miwa, K. and S. Takakuwa. 2005. "Flexible Module-based Modeling and Analysis for Large-scale Transportation-inventory Systems." In *Proceedings of the 2005 Winter Simulation Conference*, edited by M. E. Kuhl, N. M. Steiger, F. B. Armstrong, and J. A. Joines, 1749-1758. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Neonen, L. K., P. W. U. Graefe, and A. W. Chan. 1981. "Interactive Computer Model for Truck/Shovel Operations in an Open Pit Mine." In *Proceedings of the 1981 Winter Simulation Conference*, edited by T. I. Oren, C. M. Delfosse, C. M. Shub, 133-139. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Yun, Q. 1982. "Computer Simulation of Drill-rig/Shovel Operations in Open Pit Mines." In *Proceedings of the 1982 Winter Simulation Conference*, edited by H. J. Highland, Y. W. Chao, and O. S. Madrigal, 463-468. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Seppanen, M.S. 2000. "Developing Industrial Strength Simulation Models Using Visual Basic for Applications (VBA)." In *Proceedings of the 2000 Winter Simulation Conference*, edited by J. A. Joines, R. R. Barton, K. Kang, and P. A. Fishwick, 77-82. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Subtil, R. F., D. M., Silva, and J. C., Alves. 2011. "A Practical Approach to Truck Dispatch for Open Pit Mines." *35Th APCOM Symposium*, 765-777.

Tan, Y., U. Chinbat, K. Miwa and S. Takakuwa. 2012. "Operations Modeling and Analysis of Open Pit Copper Mining Using GPS Tracking Data." In *Proceedings of the 2012 Winter Simulation Conference*, edited by C. Laroque, J. Himmelspach, R. Pasupathy, O. Rose, and A. M. Uhrmacher, 1309-1320. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

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