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Shovel-Truck Haulage Analysis Using Stochastic Discrete Event Simulation

Raymond Ninnang Tiile[1], Felix Adaania Kaba[2], Nassib Aouad[3], Francis Arthur[4]

[1]Department of Mining & Nuclear Engineering, Missouri University of Science and Technology, USA

[2]Newmont Limited, Akyem, Ghana

[3]Department of Mining & Nuclear Engineering, Missouri University of Science and Technology, USA

[4]Department of Mining & Nuclear Engineering, Missouri University of Science and Technology, USA

Abstract: ***Detailed weekly mining plans are prepared by the mine planning section of Perseus Mining Ghana Limited (PMGL) geared towards the accomplishment of monthly mining targets. Weekly and daily mining volumes are established primarily based on the excavator (shovel) dig rates and excavator availabilities and utilizations. A daily mining target of 15,000 BCM of material is expected to be mined by two (2) shovels and as many as twenty (20) dump trucks over a period of one (1) month. Given the size of the pit and the number of dump trucks, truck queuing and congestion in-pit and on roads with their downstream consequences is highly anticipated. This paper therefore seeks to address the above challenge by using an Arena-based stochastic discrete event simulation to derive an optimum shovel-truck combination that improves productivity, minimizes operation cost and maximizes overall profitability.***

Keywords: Mine planning, Arena® stochastic discrete simulation, Productivity, Optimization, Profitability

1. Introduction

Perseus Mining Ghana Limited (PMGL) is a gold producing company located in Ghana. The mine planning section of PMGL puts in place detailed weekly plans aimed at achieving the monthly production targets. The weekly mining volumes are generated taking into accounts the shovel dig rates, as well as, shovel availabilities and utilizations. The challenge during weekly mine planning is to find the optimum shovel-truck combination that delivers the production target.

Capital and operating costs associated with truck haulage contribute significantly to the overall surface mine expenditure. The costs of shovel-truck operations alone comprise 50 to 60 per cent of the total mining operation costs [1]. Thus, optimizing the shovel-truck combination in the load-haul operations increases productivity and minimizes capital and operating costs.

This paper aims at analyzing the truck haulage system in AG pit at PMGL using Arena-based stochastic discrete event simulation to derive an optimum shovel-truck match. Stochastic discrete simulation permits uncertainty and dynamic systems modeling, as well as, flexibility in modeling various levels of details and complexity [2]. The simulation model created incorporates the random behavior of shovels and trucks in the pit. The analysis in this paper considers truck cycle times, shovel dig rates, mining locations in-pit, dumps and haul routes.

1.1 Truck requirements prediction methods

The projection of truck requirements can be achieved through two basic methods: from the extrapolation of historical performance statistics such as tons per truck shift and ton-kilometres per truck shift, or from calculations of cycle times that require a basic mining simulation [3]. PMGL has been extrapolating truck requirements from historical performers of the shovel truck system and production projections. However, these projections unreliably account for planning and situational details that may significantly affect cycle time. Such details include the rate of advancement of faces both vertically and horizontally, ore reclassification, dumps expansions, and feed requirements.

Mining simulations have been conducted using computer software with high level programming languages to improve production in several ways [4]. There are many programming languages currently used in truck forecasting to predict truck cycle times. These languages utilize empirical or calculated data to formulate results. All these methods appear to provide results that are acceptable within the industry standards [1]. Arena® Simulation tool based on SIMAN Language, is one of such tools used to predict truck requirements. The software has been used to forecast long term truck requirements in surface mines and analyze shovel truck systems to improve cycle times [5-6]. Arena® Software has been employed in modeling other major mining systems such as shovel-truck systems, underground mining activities and metallurgical processes [7].

1.2 Shovel-Truck haulage system

The focus of this study was at AG pit, an active pit at PMGL. Loading is done using two Liebherr excavators. Two extra Liebherr excavators are put on standby for unscheduled and scheduled maintenance. Each excavator is matched to ten (10) caterpillar 777D dump trucks (100t) to move a daily target of 15,000 BCM over a two shift period with an average of 9hrs per shift. Trucks are strategically assigned to shovels in order to avoid undue congestion at the loading locations and on the roads. Trucks are loaded by shovels and ore hauled to crusher while waste is sent to the waste dump.

Trucks travel empty back to their respective shovels in the pit after dumping and the cycle continues. There is a 30-minute break in the middle of the shift and all trucks are parked at assigned spots for convenience. The loading and hauling process continues after the break and lasts the entire duration of the shift. Trucks and excavators are refueled and maintained after a mining shift in preparation for the next shift. Fig.1 represents a flow chart of the load and haul process.

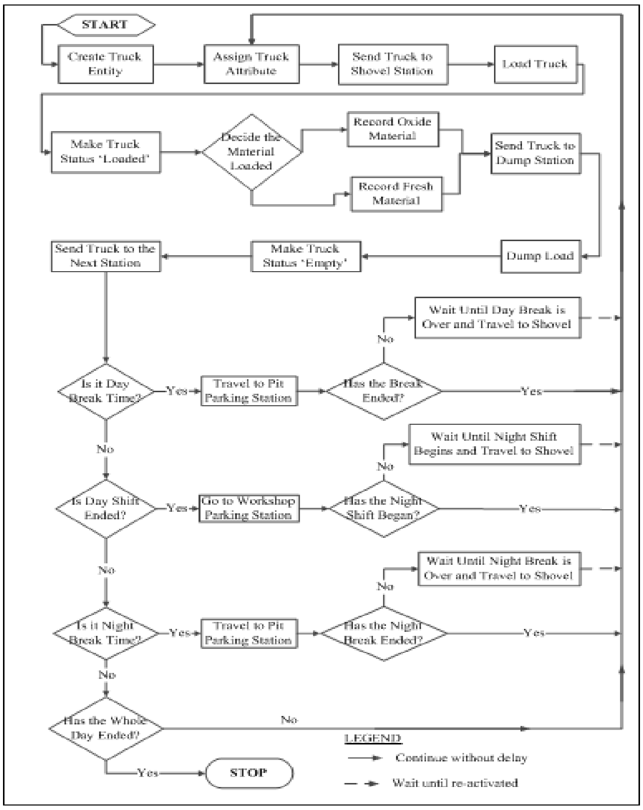

Figure 1: Conceptual model of shovel-truck system

2. Developing a Shovel-Truck System

The modeling process in Arena® involves the use of flow chart modules and data modules [8]. Flow chart modules define the processes to be simulated while data modules describe the characteristics of various process elements, such as variables, resources, and queues. During simulation, entities are created and are acted on by the modules as they navigate through the model [9].

In developing the Arena model for a shovel-truck system, trucks are considered as entities moving through the mine haulage system. Shovel and dumping areas are considered resources providing services to trucks. Additionally, roads and junctions are represented by routes and stations respectively. Truck cycle time comprising loading time, traveling loaded time, spotting and dumping time and traveling empty time have been gathered using time and motion studies over a two-week period. Other activities surrounding the shovel and trucks in-pit and at the dumps were carefully observed to assist in the shovel-truck modeling. Representative data was taken from 43 truck cycles and 39 truck cycles for Liebherr Excavator 9250 and Excavator 948 respectively.

The truck cycle times collected were analyzed with the Arena Input Analyzer to generate the appropriate expressions for the different Arena modules. The square errors between the theoretical distributions and the hypothesized distributions were also calculated. Chi- squares test and the Kolmogorov-Smirnov test were the goodness-of-fit tests employed by the Input Analyzer in the analysis. Tables 2.1 and 2.2 are summaries of the statistical distributions and the corresponding expressions used as Arena input parameters for the simulation.

Table 2.1: Distributions and Expressions for Cyclic Activities of Trucks Assigned to EX 36

Cyclic Activity	Distribution	Expression (mins)	Square Error	P-value α=5%
Loading Time	Gamma	2.54 + Gamm(0.113, 7.44)	0.004529	0.415
Hauling Time	Beta	6.63 + 2.28 × Beta(1.51, 1.24)	0.016383	0.320
Dumping Time	Triangular	Tria (0.55, 0.963, 1.1)	0.020682	0.198
Travelling Time	Beta	4.25 + 3.24 × Beta(1.84, 1.69)	0.011184	0.192
Travelling to Pit Park	User Defined	Continuous		
Travelling to Workshop	User Defined	Continuous		

Table 2.2: Distributions and Expressions for Cyclic Activities of Trucks Assigned to EX 40

Cyclic Activity	Distribution	Expression(mins)	Square Error	P-value α=5%
Loading Time	Beta	3 + 3.74 × Beta(1.45, 2.31)	0.001685	> 0.750
Hauling Time	Gamma	8.34 + Gamm(0.672, 5.15)	0.011478	0.078
Dumping Time	Beta	0.48 + 0.52 × Beta(2.11, 1.87)	0.014403	0.143
Travelling Time	Weibul	4 + Weib(4.37, 4.84)	0.004802	0.468
Travelling to Pit Park	User Defined	Continuous		
Travelling to Workshop	User Defined	Continuous		

2.1 Creating a simulation model

A simulation model was created to determine the optimal shovel-truck combination that improves productivity and maximizes profitability. Two different groups of trucks were assigned each to two shovels with one shovel mining ore and the other mining waste. Trucks were created using the create module in Arena® and the trucks pass through the Decider module to be assigned to the appropriate excavator (Resource). Traveling times were assigned to every truck travelling from the pit to dump and vice versa. A Route module was used to transfer the trucks from one station to another at specified times. Assumptions made were that all trucks have the same speed and double lane haul roads were used for the haulage.

A Process module was used to model shovel loading process and a Recorder applied to record load on trucks. The modeled shovel operation was such that a shovel seized a truck, delayed the truck for a random loading time and then released the truck for the truck load to be recorded before it proceeds to a dump. The shovel modeling was based on the assumption that there was adequate blasted stock to last the entire shift. The shovel loading time excludes all delays and the material mined could either be fresh (hard) or oxide (soft).

Dumps were also modeled as resources using a Process module and each dump seized a truck, delayed it for dumping and released the truck to travel back to a shovel or parking station. All dumps were assumed to have adequate dumping capacities and a dump can serve one truck at a time. The dumping time distributions were put into the delay time operand of the Process module.

A Batch module was used to batch all trucks at a particular parking station and then delayed for the duration of the break. A separate module was then engaged to separate the trucks to their respective shovel stations after an operational break. The simulation model is then created by simply selecting the appropriate icon that best corresponds to an activity and placing it on the worksheet. All required inputs are made to the various modules and lines created to connect the modules adequately. Figs. 2.1, 2.2 and 2.3 illustrate the portion of the Arena® simulation model generated using the above-mention information.

2.2 Animation of the shovel-truck system

Various activities of the shovel-truck system were animated to ensure visualization of the entire load and haul operation of AG pit at PMGL. A digital terrain model (DTM) of the AG pit was imported into Arena® to enable the addition of haul roads, dumps and parking stations. Trucks are seen traveling loaded from the pit and again noticed traveling empty from the dumps to shovels in-pit. Fig. 2.4 shows the animation of the system in Arena.

2.3 Model Validation

The truck entity movement was studied closely to make sure trucks followed the correct directions as specified and trucks stopped at the right stations. The model was also simulated for the entire day and the simulated number of loaded trucks was compared with the actual truck count of the shovel-truck system. Validation of results is shown in Table 2.3.

Table 2.3: Validation results

Number of Trucks	Actual	Simulated	Error(%)
Number of Trucks loaded by EX40	187	186	0.53
Number of Trucks loaded by EX36	185	184	0.54

2.4 Model execution

The various cycle time expressions generated are put into the appropriate modules. Thirty (30) replications of the model were run each day with the length of a replication being 19.5hrs. The length of a replication represents the effective daily shovel working hours.

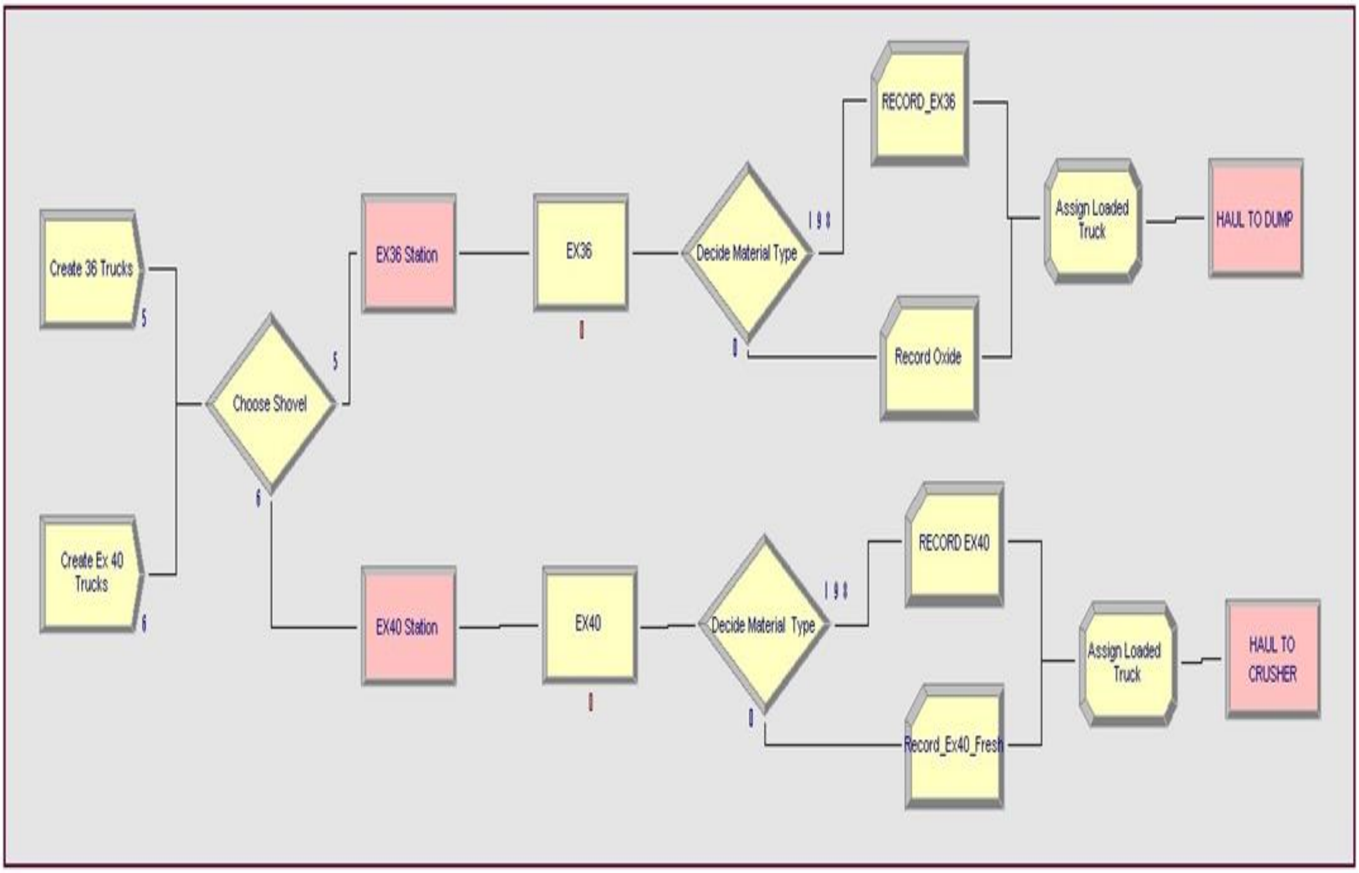

Figure 2.1: Trucks Entities creation and shovel Processes

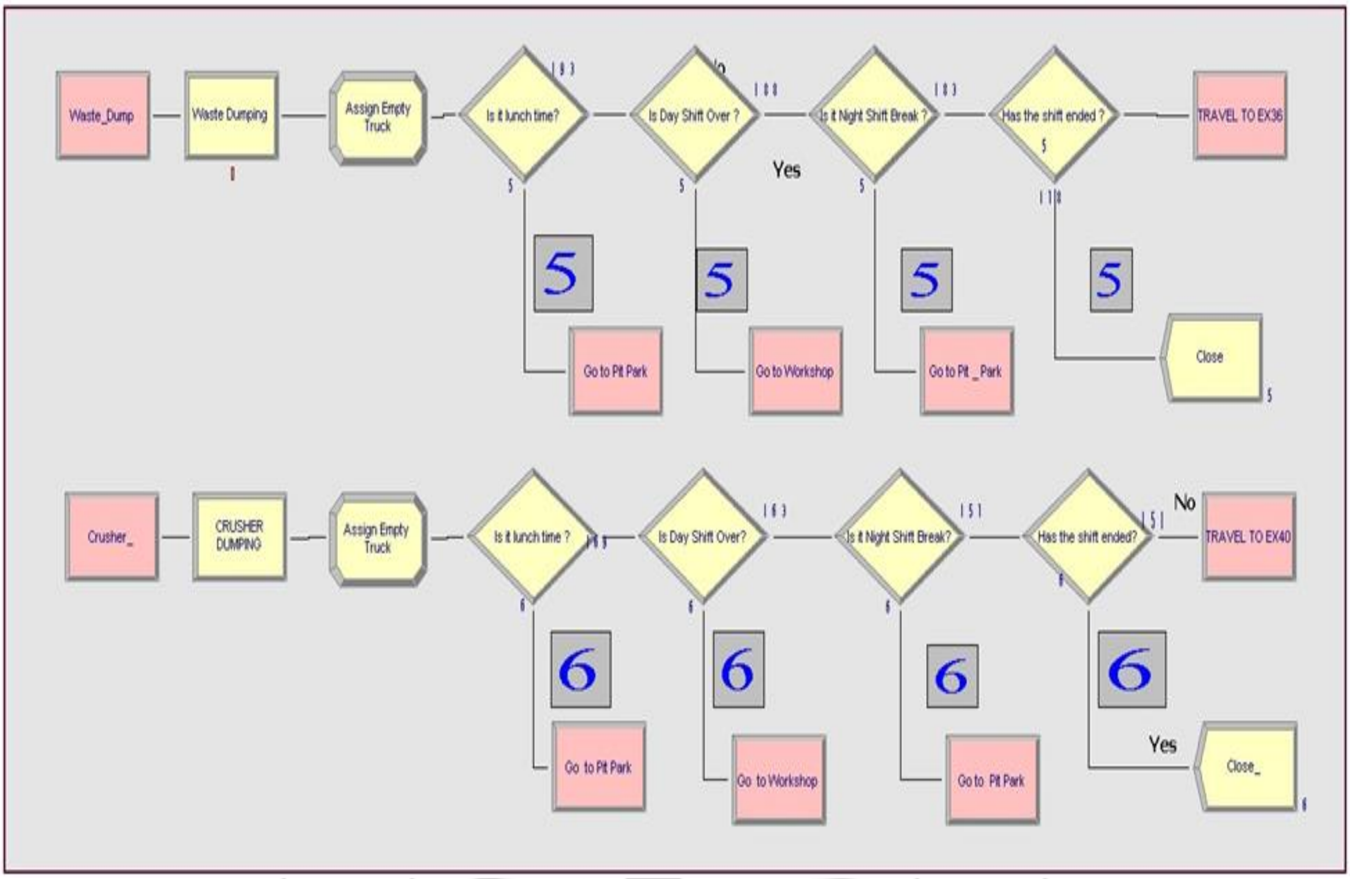

Figure 2.2: Dumping processes and break time decisions

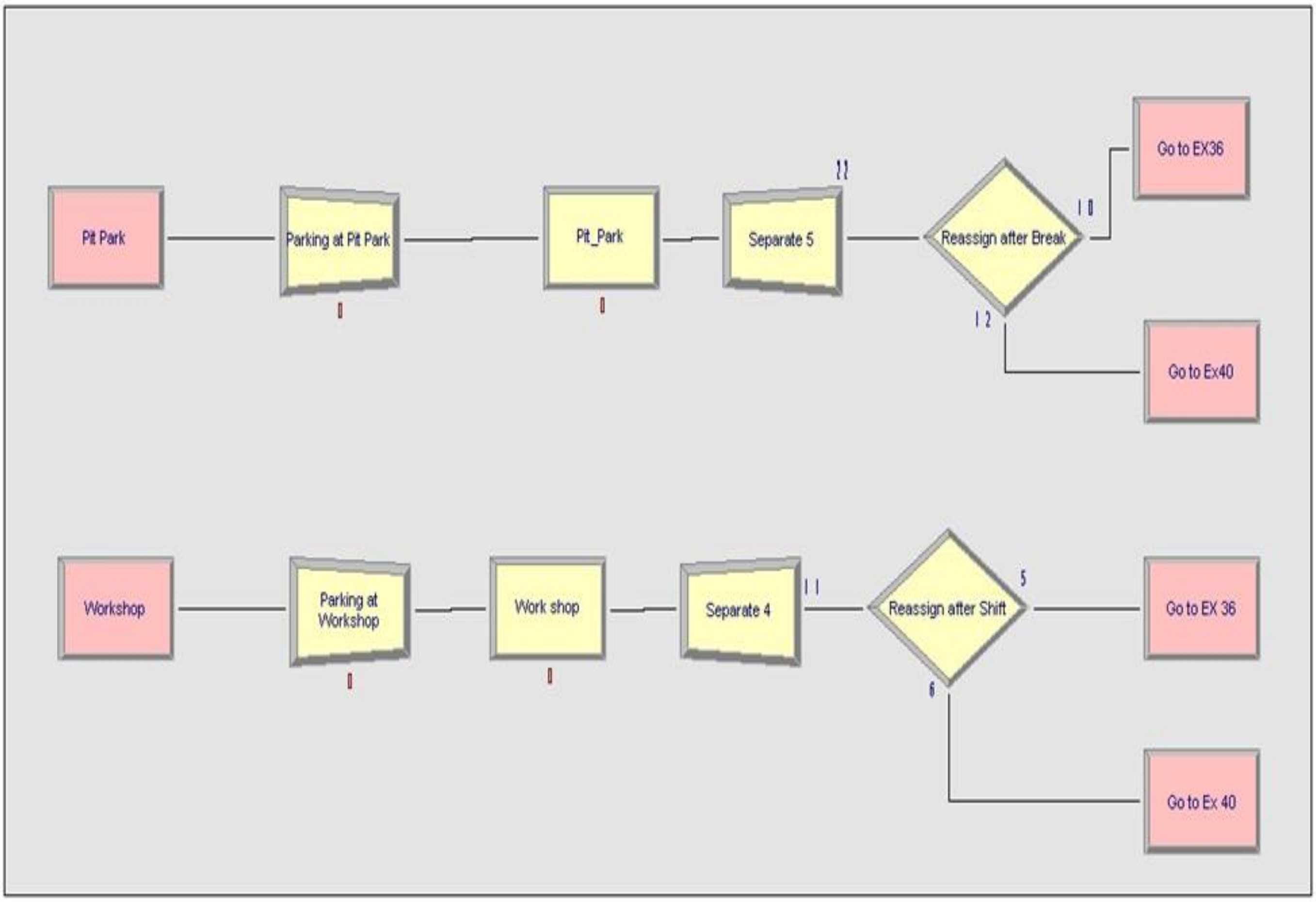

Figure 2.3: Break times modelling

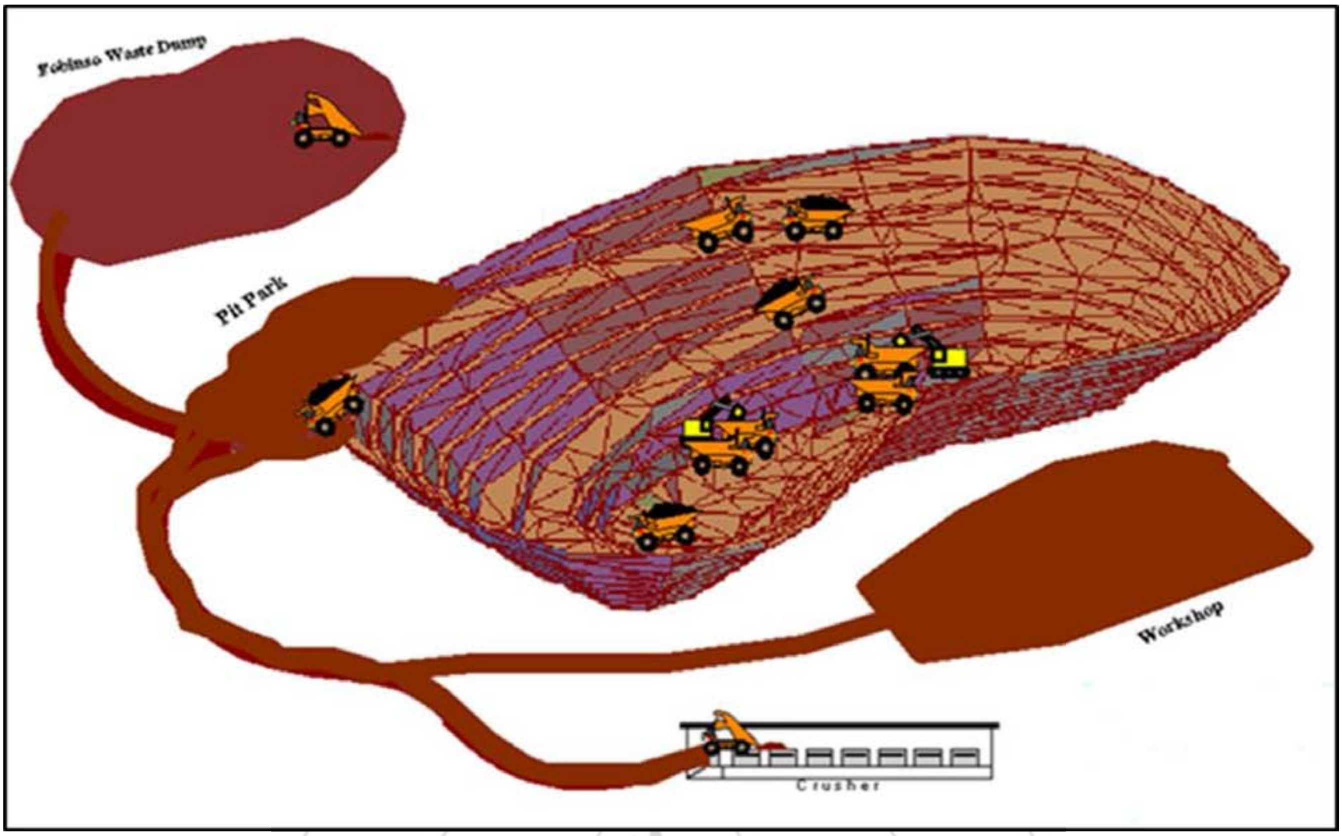

Figure 2.4: Animation of the truck haulage system

3. Analysis of Results

After testing various machine combinations using the simulation model, the shovel-truck combinations that gave satisfactory results were recorded. Table 3.1 summarizes the various shovel-truck combinations aimed at achieving the desired daily production target.

Table 3.1: Simulation results

No. of shovels	*No. of Trucks*	*Volume of material (BCM)*	*Total Truck waiting time (mins)*
2	11	14,210	5.38
2	13	15,155	8.04
2	15	15,225	11.43
2	16	15,267	15.44
2	17	15,673	18.91
2	20	15,764	27.16

From Table 3.1 above, 2 shovels with 13 trucks would be able to meet the 15,000 BCM daily production target at minimal truck waiting time of 8.04mins with trucks and shovels operating at their maximum capacities. Prior to the simulation, the same daily target was achieved using 17 trucks. For the purpose of this analysis, the cost of operating a Caterpillar 777D dump truck is approximately $45/hr, which implies that $180/hr would be saved by eliminating the extra 4 dump trucks. Truck cycle times are also shortened due to minimal waiting times improving productivity.

4. Conclusion

This paper seeks to identify the optimum shovel-truck combination that meets the 15,000 BCM daily mining target at Perseus Mining Ghana Limited (PMGL) using Arena-based stochastic discrete event simulation. Results of the simulation shows the daily mining target can be accomplished using 2 shovels with 13 trucks versus the company practice of using 17 trucks for the same mining volume. Cost incurred on extra four trucks including the operator cost, cost of fuel and lubricants, maintenance and repairs costs are eliminated, thus maximizing overall profitability. The above shovel-truck combination also achieves a relatively minimal truck waiting time of 8.04mins, hence improving productivity.

5. Acknowledgement

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