



AN INNOVATIVE PEDAGOGICAL SIMULATION AND ANIMATION OF A SHOVEL-TRUCK SYSTEM

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Abstract

This paper aims to simulate and animate a shovel-truck system in an open pit mine using Arena® Software for teaching and learning purposes. The shovel-truck system is the use of loading and dumping units in the transportation of materials. The shovel-truck system has wide application in open pit mining. Animation of a shovel-truck system in Arena® is a reflection of the logic defined by the module's flowcharts. Arena® software is a widely used simulation software based on Discrete Events. The data were analysed by an input analyser tool in Arena® software to get distributions and expressions for the shovel-truck system. The shovel-truck system was then modelled in the software. The developed animated model depicts the exact activities in open pit mines.

Keywords Shovel-Truck Systems, Simulation, Arena® Software, Animation.

1.0 INTRODUCTION

The ultimate objective of any simulation is to evaluate various alternatives for the operation of a system by means of the model developed [1]. Generally, a simulation study can be divided into seven components problem formulation; solution methodology; system and simulation specification; model formulation; verification and validation; experimentation and analysis; and documenting, reporting and dissemination [2]. The various steps in the simulation process are illustrated in Figure 1.

At some stage in a simulation process, the designed model should be able to be translated into a language that will be acceptable to the computer. According to [4], some common simulation languages are General Purpose System Simulation (GPSS), Simulation Language for Alternative Modelling (SLAM), SIMSCRIPT, SIMAN (ARENA®), FORTRAN, BASIC, PASCAL, and C++. The Arena was chosen because of its flexibility, availability and ease of use of programme.

Research [4] posits that the numerous advantages of simulation are as follows:

- i. Reduced programming task;
- ii. Conceptual guidance;

- iii. Increased flexibility when changing model;
- iv. Fewer programming errors; and
- v. Automated gathering of statistics.

The practical aspect of mining engineering is observed through field trips. However, these field trips are organised only at the end of the first year. At the University of Mines and Technology, the use of simulation models will help first-year students appreciate mining courses better. Visualising what happens in the mining industry would then become clearer to the students. This project seeks to simulate and animate a shovel-truck system in an open pit mine to aid all first-year students in appreciating mining engineering. The model will be uploaded on all computers at the mining engineering laboratory to assist students during their period of study.

The objective of this research is to study and simulate the shovel-truck system in AngloGold Ashanti Iduapriem Limited (AAIL) open pit mine using Arena® Software to create an animation of the model to enhance learning.

1.1 Location and Accessibility of the Mine

AngloGold Ashanti Iduapriem Limited (AAIL) Mine is located in the Western Region of Ghana, about 85

km north-west of the coastal city of Takoradi, 10 km south-west of Tarkwa, and 240 km west of the capital of Ghana, Accra. The mine can be accessed by a 6 km unsealed road southward of the village of Bankyim. Figure 2 shows the location of Iduapriem on the map of Ghana, scribed in brown colour at the bottom left of the map.

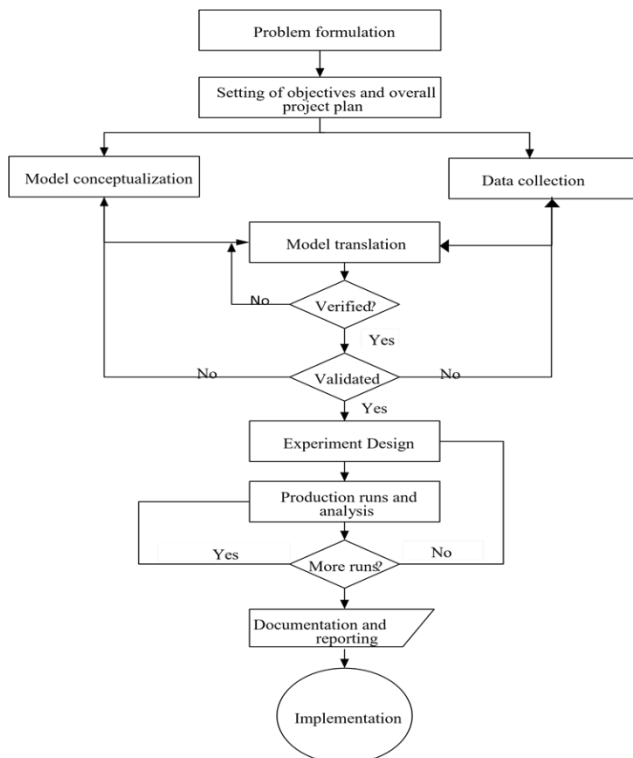


Figure 1: Steps in Simulation [3]

Open pit mining is a type of mining conducted from a sequence of benches with the radius of each circular bench decreasing with depth, resulting in a pit comprising a series of inverted truncated cones. Materials handling refers to the unit of operations involved in excavating and transporting bulk materials during mining [6]. Excavation in open pit mines is mostly done by the hydraulic backhoe or hydraulic shovel. Materials haulage is done by means of off-highway trucks in open pit mines. Off-highway trucks exist in capacities up to 363t (400 tons) [4]. The widely and commonly used off-highway trucks are the conventional rear dump truck, the tractor-trailer dump truck, the integral bottom dump truck, and the trolley assist dump truck [4].

Simulation is the process of designing a model of a real-world system and conducting various tests with the designed model to understand the behaviour of the system. A model is a representation of a group of ideas or objects in some form other than the entity itself. A

system is a collection of interrelated elements that cooperate to accomplish a particular objective [4].

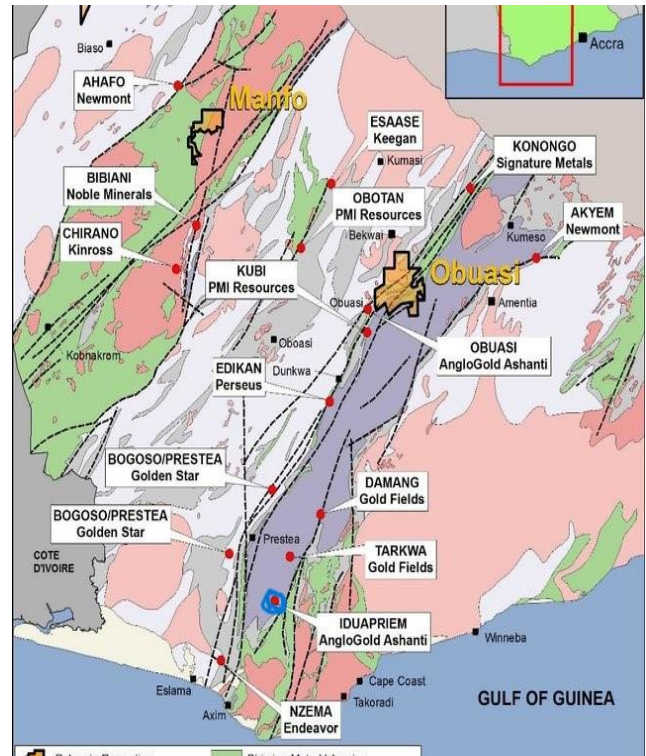


Figure 2: Location of Iduapriem on the Map of Ghana [5].

1.2 Simulation of Shovel-Truck System in Arena®

The start-up screen in Arena® has similar features and operations just like most Microsoft Window Application. The model window is divided into two parts or views, the flowchart view, which describes dynamic processes in the model and the spreadsheet model, which defines the characteristics of the various process element. The project bar hosts panels containing objects to be worked on. These include the Basic Process panel, which contains the fundamental building blocks called modules, the navigation panel, the advanced process panel, the advanced transfer panel, as well as the flow process panel [2].

When building models in Arena® for a truck-shovel system, trucks can be referred to as entities since they are the objects of interest, and their movement brings about the occurrences of events. Shovels and the various dump sites can also be represented by the processing module since they provide services for the entities (trucks). The haul roads that link the pits to the dumping sites are often represented by the route model. In modelling truck shovel systems, entities, after being created, do not get disposed of since they always move through the system cyclically [7].

According to [3], the processes that entities (trucks) go through in the Arena® environment are summarised in the following subsections.

The Create Module, which is also known as the birth node for the arrival of entities from the basic process panel, is used to generate the arrival of trucks into the system. Various entries can be inputted into the create module when it is double-clicked. Such entries include the entities per arrival, which is used to stipulate the number of trucks that arrive at a time from the start of the shift, and the time between arrivals is used to specify the nature of the truck arrival time. Units of the time can be changed in the Create module.

The loading of materials into the trucks is represented by the Process Module in which entities (trucks) enter the system, seize a number of units of the resource after a possible delay or wait in a queue and also delay other entities waiting to be serviced by the same resource after which it releases the trucks for other entities to use the resource. The trucks enter the pit to be loaded by the shovel. Upon its arrival, if there are trucks being loaded, it has to wait for its turn; it seizes the shovel so that the shovel can load no other truck. It delays other truck while it is being loaded, after which it releases the shovel.

The travel path is represented by the Route Module. The loaded trucks have to travel through the haul road to its dump site, depending on the material it is carrying and back to the loading face after emptying its content.

The Process Module is used to model the dumping process since the dumps also seize the truck, delay it for a dumping time, and releases the truck to travel from the dumping station to a shovel or parking station depending on the time of a day's operation.

There are a lot of paths or routes for the dump truck to travel through after an event. The Decide Module is used when the dump truck has to make a decision on the path to travel. The decision is made based on either condition or choice in the Decide Module. After all the parameters have been inputted into the model, the model is run. Settings can be made according to the analyst's choice and needs. Entries include run length, number of replications, warm-up period, and type of initiation to be performed. The simulated model is used to generate the report.

2.0 METHODOLOGY

AngloGold Ashanti Iduapriem Limited (AAIL) had four pits, but three were active; cut 1, cut 3 and cut 4. This study data was taken from cut 3. At the beginning of the shifts, trucks travelled from the workshop to the pit. Four excavators operated at different locations in the pit. Every excavator was assigned a number of trucks according to the production target. Trucks either moved to crusher 01 or waste dump 06 for dumping. During a lunch break, trucks parked at the pit park and returned after 30 minutes. When the day shift was over, the trucks travelled back to the workshop and waited to be hauled back to the pit for the night shift. Trucks also travelled to the pit park during the night shift and went for a break for 30 minutes. The process was repeated daily.

A conceptual model was necessary to brief the activities and stages in the shovel-truck system before building the model. In the initial stage, trucks travelled to the loading area by choosing the shovels they were assigned to. The trucks were then assigned and loaded from the shovels. The total payloads of the trucks were then recorded. The material type carried by trucks determined the dumping site they travelled to. The ore production of the trucks was recorded at crusher 01. The trucks either travelled to crusher 01 with ore or waste dump 06 with waste. After dumping, the trucks were assigned empty. Trucks hauled to Pit Park during lunchtime or night shift break. Trucks were hauled back to the workshop after every shift. This process is illustrated in Figure 3.

Data collection helped in monitoring the activities in the pit. The dispatch section was first visited to understand the processes the trucks and shovels undertake. Afterwards, primary data was taken at Teberebie cut 3 using time and motion studies. At Teberebie cut 3, four Liebherr excavators (Ex 72, Ex 73, Ex75 and Ex 76) at different locations were considered. The size of dump trucks available in the pit was Caterpillar 773, Caterpillar 775 and Caterpillar 777. The loading times for the excavators were taken first by standing at a safe area in the pit. The queue and spot time, travel loaded time, dumping time, and travel empty time of the dump trucks were also taken. This was done by sitting in the trucks with the help of a stopwatch. The whole primary data collection happened for a period of one month (February 2019). A tool in Arena® called input analyser aided in analysing the data by providing the following:

- i. Summarised information on the empirical data;
- ii. Statistical results of the goodness of fit test;

iii. Graph of the best-fit distribution superimposed on a histogram; and

iv. Expressions and parameters of the best-fit distribution.

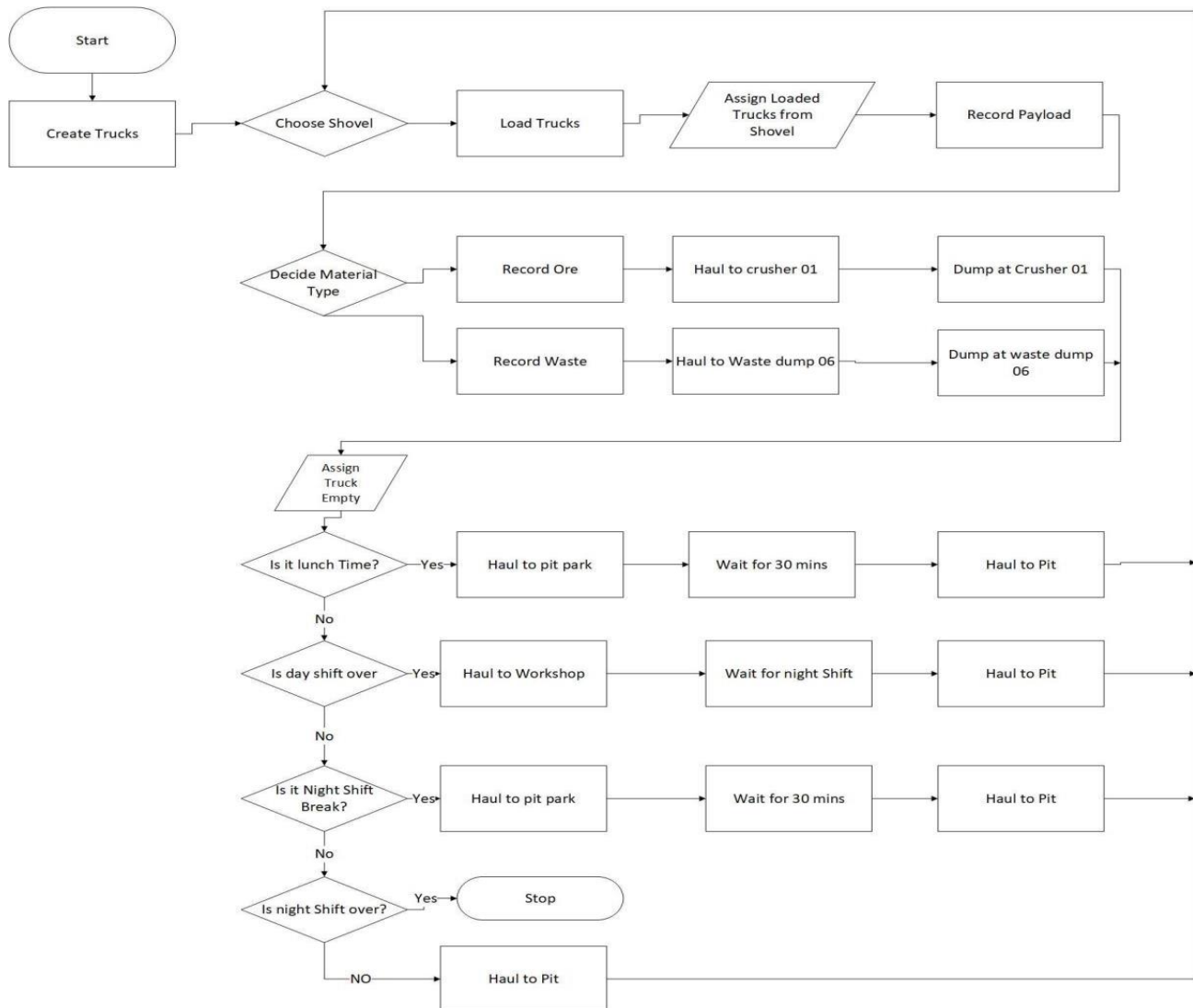


Figure 3: Conceptual Model of the Shovel-Truck System

3.0 RESULTS AND DISCUSSION

The purpose of the input analyser was to fit distributions and give expressions of the data. Four main steps were required in order to use the input analyser.

These include:

- i. Importing an Excel file with the data values;
- ii. Fitting one or more distributions on the data;
- iii. Selecting the best-fit distribution; and
- iv. Copying the expressions generated.

After importing the Excel file with the values, the input analyser automatically fitted a distribution on a histogram. Different distribution fits were selected for various data. The square errors of the theoretical distributions and the hypothesised distributions were also calculated. The smaller the square errors, the

better the hypothesised distributions and the greater the square errors, the worse the hypothesised distribution. Figures 4 to 7 illustrate the distributions of loading times for Ex 72, Ex 73, Ex75 and Ex 76, respectively. The parameters and expressions as Arena® modules input data were calculated. The goodness-of-fit tests employed by Arena® for figures 4 to 7 were the Chi squares and the Kolmogorov-Smirnov test. The goodness-of-fit test was done to confirm that there were negligible discrepancies in the theoretical distributions and the hypothesised distributions. The p-value at a 5% level of significance is used to corroborate the quality of the decision made and accepted by the Chi-square test. The smaller the p-value compared with the 5% significant level, the stronger the null hypothesis for rejection. The larger

p-value is, relative to the 5% level of significance, the stronger the null hypothesis acceptance.

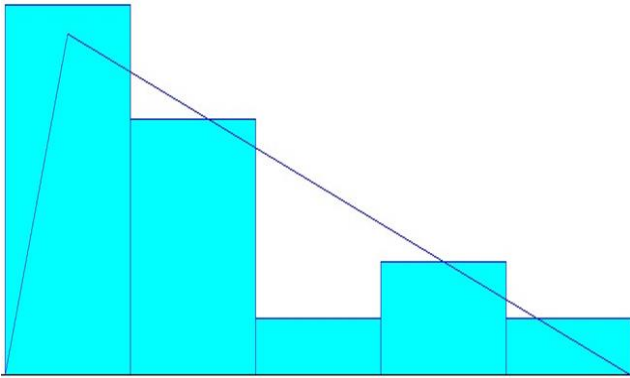


Figure 4: Histogram of loading time for Excavator 72

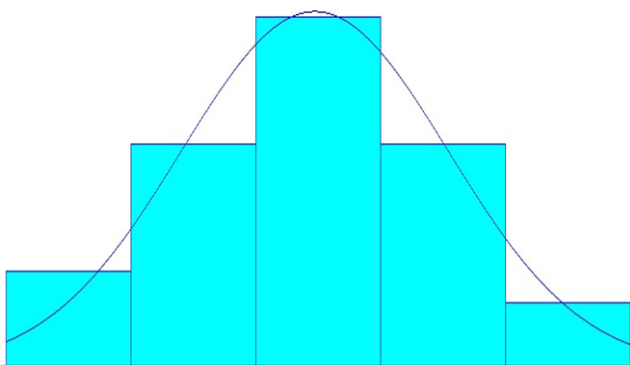


Figure 5: Distribution for Ex 73 Loading Time

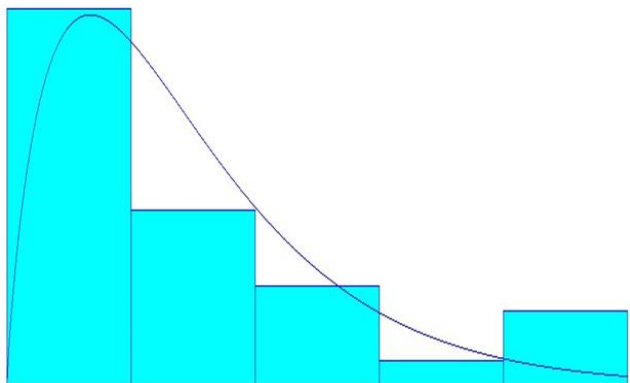


Figure 6: Distribution for Ex 75 Loading Time

A summary of distributions and expressions obtained from the data collected by means of the input analyser is illustrated in Tables 1 to 4.

Table 1: Distributions, Expressions and P-Values for Cyclic Activities of Trucks Assigned to Ex 72

Random Cyclic Activities	Distributions	Expressions (Minutes)	P-Values
Loading time	Triangular	TRIA (2.3, 2.35, 2.78)	0.0666

Travel Loaded Time	Weibull	7.66 + WEIB (1.9, 1.05)	0.43
Dumping Time	Beta	0.07 + 0.8 * BETA (2.1, 3.08)	0.0364
Travel Empty Time	Triangular	TRIA (2.5, 3, 7.5)	0.0473

Table 2: Distributions, Expressions and P-Values for Cyclic Activities of Trucks Assigned to Ex 73

Random Cyclic Activities	Distributions	Expressions (Minutes)	P-Values
Loading time	Normal	NORM (3.63, 1)	0.005
Travel Loaded Time	Gamma	7.66 + GAMM (0.58, 2.21)	0.0412
Dumping Time	Beta	0.07 + 0.8 * BETA (2.1, 3.08)	0.0893
Travel Empty Time	Normal	NORM (4.9, 1.4)	0.0266

Table 3: Distributions, Expressions and P-Values for Cyclic Activities of Trucks Assigned to Ex 75

Random Cyclic Activities	Distributions	Expressions (Minutes)	P-Values
Loading time	Gamma	2.83 + GAMM (0.221, 1.82)	0.005
Travel Loaded Time	Triangular	TRIA (7.58, 7.82, 10)	0.125
Dumping Time	Beta	0.07 + 0.8 * BETA (2.1, 3.08)	0.4
Travel Empty Time	Beta	3 + 4 * BETA (0.602, 0.729)	0.0294

Table 4: Distributions and Expressions for Cyclic Activities of Trucks Assigned to Ex 76

Random Cyclic Activities	Distributions	Expressions (Minutes)	P-Values
Loading time	Normal	NORM (1.6, 0.862)	0.0396
Travel Loaded Time	Beta	7.58 + 2.42 * BETA (0.677, 0.701)	0.355
Dumping Time	Beta	0.07 + 0.8 * BETA (2.1, 3.08)	0.0975
Travel Empty Time	Weibull	3 + WEIB (1.9, 1.05)	0.0437

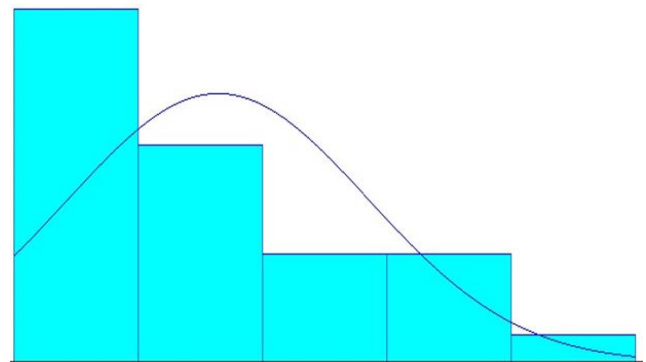


Figure 7: Distribution for Ex 76 Loading Time

4.1 Modelling of the Shovel-Truck System in Arena®

Below are some assumptions employed in the shovel-truck modelling:

- i. Trucks were assumed to be the same with respect to their speed;
- ii. Queuing was allowed at the shovel and crusher area because these stations could only serve one truck at a time; and
- iii. Overtaking by trucks was also allowed.

Stochastic models were built to mimic the activities of the shovel-truck system in open pit mines. In the mine, trucks normally moved from the workshop to the pit at the beginning of each shift, that is, day and night shifts. The create module in Arena® helped to introduce trucks into the model. The trucks were

regarded as entities. The created trucks moved through a decide module to be assigned an excavator only for the beginning of the shifts. The excavators were modelled as stations. A process module was used to model the excavator loading. The process was such that each excavator seized a truck, delayed it for loading and released it to travel to a dump site. The dump sites were crusher 01 and waste dump 06. The trucks were assigned to either travel to waste dump 06 or crusher 01. A recording module was used as well to count the payload of each truck based on the expressions from the product distribution. Another decide module was used to determine the material type in the trucks. Figure 8 shows the entity creation and assignment logic of the model.

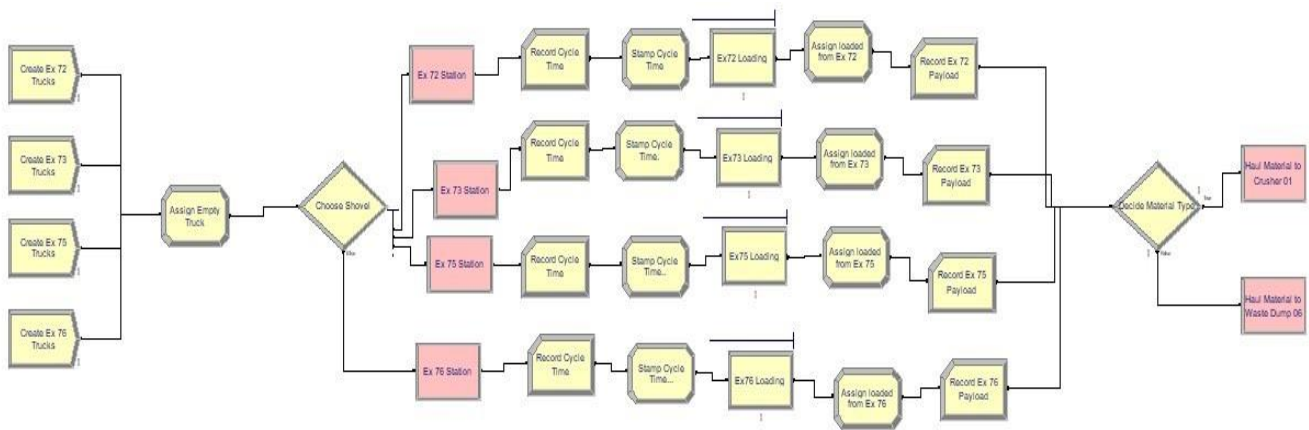


Figure 8: Entity Creation and Assignment Logic in Arena®

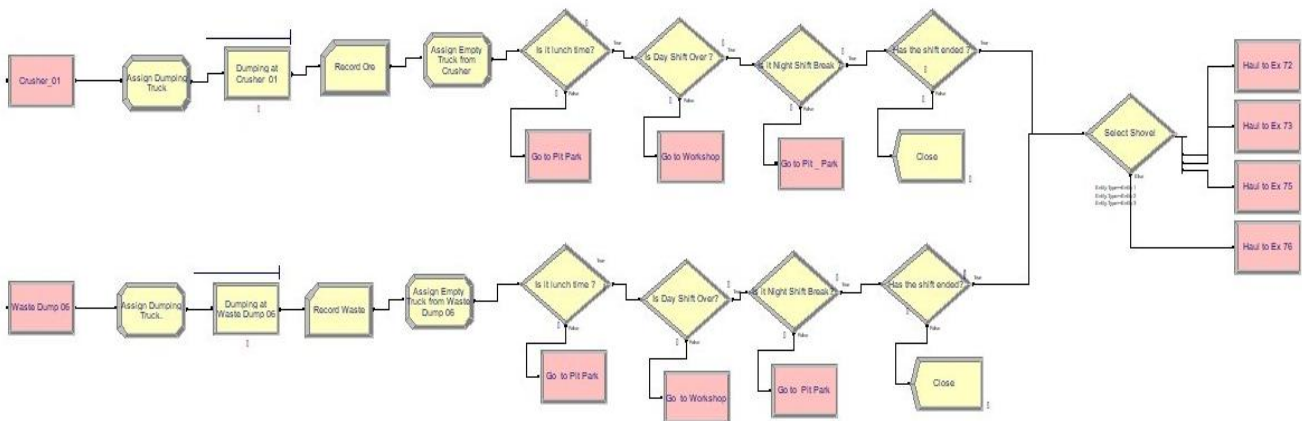


Figure 9: Dumping Process at Crusher 01 and Waste Dump 06

Crusher 01 and waste dump 06 also stations were modelled as resources. The crusher seized a truck, delayed it for dumping and released it to return for loading. Figure 9 illustrates the dumping process at the various dump sites. Queuing was allowed at the crusher. The waste dump only delayed trucks for dumping. Two or more trucks were able to dump at the waste dump at the same time. Break times for

lunch and shift end were included in the model by using the Decide Module. Trucks went for lunch or shift breaks when the time assigned for the break was due. The process was such that the truck that went on break first returned to the pit first (first in, first out). The break time modelling is demonstrated in Figure 10. The distribution expressions of each activity were copied into the modules.

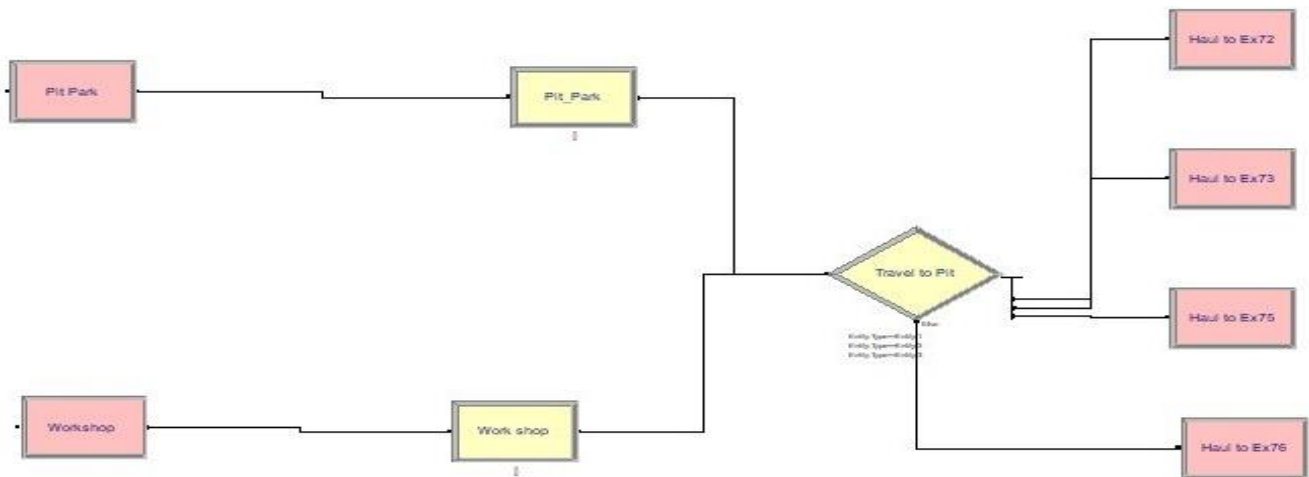


Figure 10: Break Time Modelling for the Trucks

4.2 Animation of Shovel-Truck in Arena®

The model was allowed to run and observed closely to ensure that the trucks followed the same directions specified and stopped at the right stations corroborating with [8]. All break times were also observed to ensure that trucks stopped for lunch during the day shift and night shift. The model ran successfully because all errors were corrected.

The model of the shovel-truck system was animated for visualising and learning purposes. A picture of an

open pit mine was imported into Arena® to animate the model. To start the animation, click the Go button in the standard toolbar, and to end the animation, click the End button. Busy excavators were assigned a green colour, but when idle, they changed to yellow. Trucks moved from the excavators loaded and returned to the empty pit. The screenshot of the animation is shown in Figure 11. The trucks travelled along the haul routes and queued before the resources (shovels or dumps), depicting similar results obtained in [9].

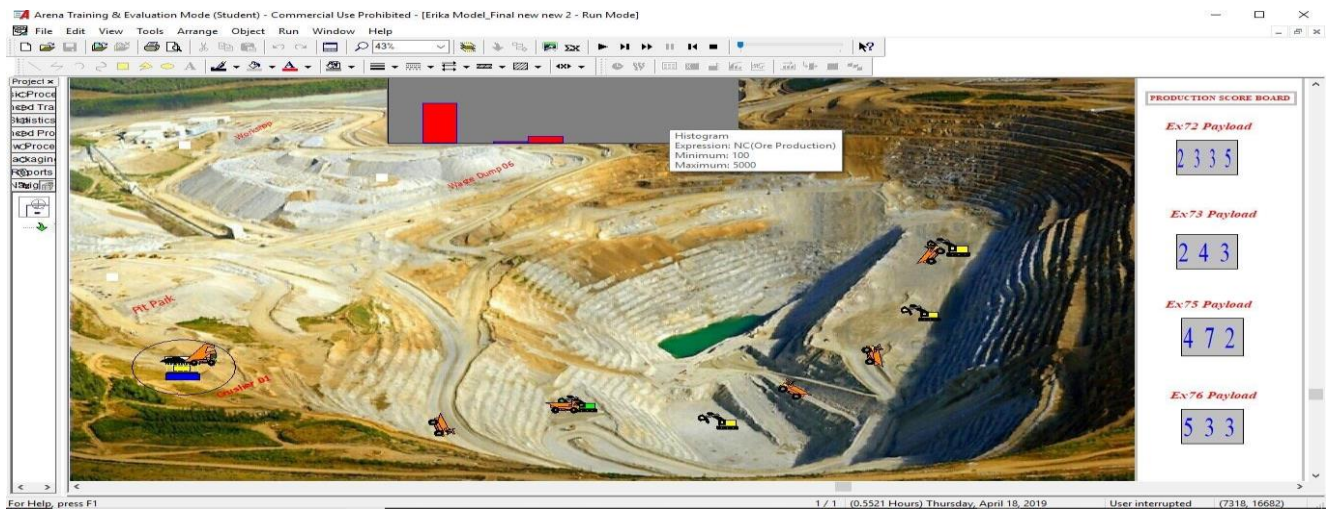


Figure 11: Animation of the Shovel-Truck System

4.0 CONCLUSIONS

The following was concluded from the simulated process and animation of the shovel-truck system:

- i. Shovel-truck system in an open pit mine at AngloGold Ashanti Iduapriem Limited (AAIL), Ghana, was simulated, and the various processes followed the designed order;

- ii. Shovel-truck system in an open pit mine was simulated, and the various processes followed the exact order; and
- iii. The animation of the model was done successfully, and all breaks were observed by the trucks.
- iv. Simulation shovel-truck system in AngloGold Ashanti Iduapriem Limited (AAIL) open pit mine using Arena® Software to create an animation of

the model to enhance learning was successfully done. The fundamental objective achieved in the project was to create a model using simulation and animation for first-year Mining Engineering students of the University of Mines and Technology, Ghana.

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