Optimization of Truck-Loader haulage system in an underground mine: A simulation approach using SimMine

Abubakary .J. Salama, PhD student, Luleå University of Technology
Jenny Greberg, Assistant Professor, Luleå University of Technology

Abstract

In underground mining, the truck-loader haulage system involves mucking of the material from the working face and transporting it to the dumping point where it is reloaded into trucks for further transportation. In some cases, trucks can be loaded directly at the working face or at a dumping point. Due to a limited size of the drifts and the ramps used in transporting material, the size of the haulage equipment is an important factor to consider when seeking to optimize the haulage system. This paper studies the haulage system of a mine which operates a fleet of three Load-Haul-Dump (LHD) machines and three dump trucks, using SimMine simulation software. Its aim is to evaluate the effect of increasing the number of trucks on the overall mine throughput. The results indicated that the capacity of the existing loading equipment does not match the number of trucks; this affects the haulage system and the mine production. The study resulted in the recommendation to increase the fleet of dump trucks.

Biography

Salama A.J *Holds a Master's degree in Mining Engineering from Paris School of Mines in France. His mining experience is in Sub level stope mining operations. Currently he is pursuing a PhD in Mine Production at Luleå University of Technology. His research interest is production simulation and optimization with respect to mining at great depth.*

Greberg J. *Holds a PhD-degree from Lund University of Techlonolgy in Sweden. Before joining Luleå University of Technology as an assistant Professor, she worked in the Aerospace industry and as mining consultant. Currently she is the head of division of Mining and Geotechnical Engineering at the Luleå University.*

1. Introduction

In underground mining, a Truck-Loader haulage system is used to transport fragmented material from the production area to the desired location. The haulage system depends on the mining method employed. When a mine uses the sublevel open stope method, the truck-loader haulage system involves mucking material from the mine face, transporting it to loading areas where it is reloaded into trucks for transportation to the mine surface (Sweigard, 1992). Trucks can be loaded directly at the face or at separate loading areas. In hard rock mines, ramps size cannot accommodate more than one vehicle traveling in opposite direction at a time (Sabuncuoglu, 1992). Due to the limited size of drifts and ramps used as haul ways, the selection of effective loading and hauling machines becomes an important factor to consider if a mine wishes to optimize its haulage system. This paper presents a simulation study of the truck-loader haulage system with a view to optimizing the mine's fleet.

2. Simulation in Mining operations

Simulation is the imitation of the real world processes or systems over time (Banks, 1999). The ultimate goal is to model a real life system with the aim of understanding the behaviour of the system by evaluation various strategies within the limits imposed by a criterion or set of criteria for the operation of the systems (Saiang, 2008). Examples of Systems that can be simulated include transportation logistics, business processes, mining operations, emergency response systems etc. Simulations can apply a number of rules and procedures, thereby increasing the understanding of the interaction between variables and their importance in the system performance and suggesting possible system modifications (Banks, 2000).

In mining operations, simulation methods can be used to simulate various systems and study various issues such as fleet requirements, the flow of hauling machines, and mine planning, with the aim of optimizing, improving, and analyze existing and future systems. Simulations can also be used to make critical decisions and to increase the overall understanding of the mining system (Sturgul & Li, 1997).

A large number of simulation languages, including GPSS/H, SLAM, ARENA, etc, are available and widely used in mining operations, making the traditional methods such as manual calculations less common when solving complex problems. The use of simulation tools increases the understanding of the system performance and the interaction of the many variables involved. Most simulation studies applied to mining operations have focused on selected parts of the mining operation, such as development loading, transport and processing of material. More recent studies have attempted to simulate larger parts of the mining system or even a complete mine (Greberg & Sundqvist, 2011).

3. The simulation study

This paper presents the case study of a deep underground mine. The mine is currently operating at 1300m depth, but recent exploration shows that the ore body extends beyond 2000m. Underground levels are accessed by a vertical shaft and two ramps; the vertical shaft extends about 1000m below the surface. Below 1000m depth, there is only one ramp with a single lane extended. Materials from the lower levels are transported by dump trucks to the lowest tipping point of the shaft and then hoisted to the surface by skips.

The ore body is divided into zones A, B, and C, with an average thickness of 3.5m, 3.1m, and 2.4m respectively. The mine uses four different mining methods: sublevel open stoping in zones A and B; drift and fill mining in zone C; narrow vein mining in zone C; Alimak mining in zones A and B. This paper focuses on the sublevel open stoping mining used in zone A. In this method, top and bottom accesses are mined to reach the sublevel open stope. Slots are formed by conventional raises and occasionally drop raises. Stopes are drilled using both up and down holes as shown in Figure 1. Upholes are drilled up from the lower level to half the distance between the two drives (10m); downholes are drilled down from the upper level to half the vertical distance between the drives (10m). After a stope is mined and mucked out, the opening is backfilled with paste. The mining of adjacent stopes starts after three days when the paste fill reaches the required strength of 90KPa for a 2.5% recipe, or after seven days when it reaches 350KPa for a 6.5% recipe.

In zone A, the major production occurs at mine drifts below the lowest point of the main shaft. At this point, the lowest level of production is about 300m vertical distance from the shaft's lowest load point. Below this levels mine development is going on.

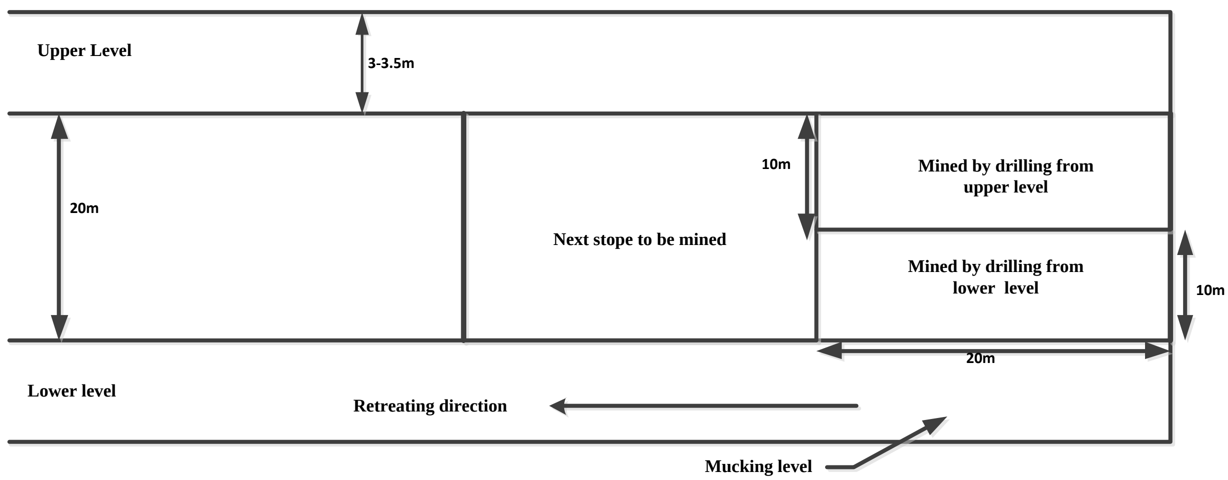

Figure 1: schematic layout for sub level open stoping

3.1 Purpose of the study

Three stopes can be mined at a time. In each stope, a single Load-Haul-Dump (LHD) machine is used to serve the trucks. When one truck is assigned to each stope, the ore produced per month is 52% of the planned production. It is assumed that the reasons for the low production include the limited size of drifts, the ramp design, traffic on the ramps, etc. These factors increase the cycle time of the hauling machines. Reducing the cycle time would increase equipment effectiveness and mine output. This paper simulates the haulage system in order to optimize the number of trucks for the overall mine production and thus increasing the possibilities to reach the production targets.

3.2 Description of Equipment and other facilities

3.2.1 Mining equipment

In zone A area, materials from ore production drifts are loaded and hauled by Load-Haul-Dump (LHD) equipment with a bucket capacity of 10-tonne to the loading point. Material is loaded and transported to the shaft point by dump trucks each with the capacity of 30-tonne. The mine operates three stopes at a time and a maximum of ten stopes can be mined per month.

3.2.2 Hoisting system

Material is transferred by the dump trucks from the stopes to the lowest load point of the shaft and hoisted to the surface. The shaft uses two skips, each with a 10-tonne capacity. The shaft can hoist a maximum of 5,500 tonne of ore per day.

3.2.3 Ramp configuration

The ramp has an average width of 5.5m, and a height of 5m, with grades ranging from 11% to 15%. The ramp length in deeper levels where development is still going on is estimated by using the standard Euclidean length:

$$L_{(k,l)} = |Z_l - Z_k| \sqrt{(1 + \frac{1}{m^2})}$$

where $L_{(k,l)}$ stands for the length of the ramp link, $|Z_l - Z_k|$ represents the difference in vertical elevation between the two end points of the link, k and l are two end points of the link, and m is the ramp grade.

4. Data Collection

At a mine visit in August 2011, data were collected for 14 days on the dayshift and 6 days on the nightshift. There were constraints on acquiring data during the nightshift, as it was more difficult to access the mine at that time. Data collected and which used in the simulation model include truck cycle times, LHD cycle times, ore production, haul route profiles, rock overbreaks, and machine settings.

4.1 Truck cycle time

Truck cycle time includes spotting or truck maneuvering time, loading time, travelling time when fully loaded, dumping time, and travelling time back to the loading point. A cycle time survey was done by following the truck from the loading point to the shaft bottom point. The survey found that the time varies from one run to another: for example, the first cycle can last 19 minutes, the second can take 19.8 minutes, and so on. Many factors contribute to these variations, which include payload variations, ramp curvatures, operator efficiency, ramp grade, lighting, etc. (B. Morgan, 1994). A total of 57 cycles for the dayshift and 33 for the nightshift were recorded from three working drifts.

4.2 LHD loading time

LHD-machines are used to load the trucks at the loading bay as shown in Figure 2. When there is no truck to load, LHDs haul the material and dump it on a stockpile. Loading time per pass includes bucket travelling time when empty, digging time, bucket travelling time when loaded, and loading time. The study recorded a total of 43 cycles for the dayshift and 29 cycles for the nightshift in different loading locations.

4.3 Planned and actual production

The ore mucked out from each stope is transported to the bottom point of the shaft and then hoisted to the surface. The amount of ore hauled from the sub level stopes in zone A is recorded at the end of each shift. The study found that the amount of ore produced per month is approximately 52% of the mine's production target when stopes located at the upper drifts are in operation. The percentage of ore produced is expected to fall as the mine depth increases.

4.4 Face profile

A stope pattern of 20m by 10m is blasted per round from the end of the drifts back to the access. Face profiles of the openings are shown in Table 1. The footwall access at the shaft tipping point is high enough to allow trucks to tip the material. The ramp has several refuge chambers which allow vehicles to give way to each other.

Table 1: Face profiles for different openings

Face profile			
	Description	**Width (m)**	**Area (m^2)**
Ore drifts	Production drifts	3.5	10.5
Main Levels	Footwall access	5.5	30.25
Ramp	Fleet hauling tunnel	5.5	27.5
Access	Crosscut between ramp and drift	4.5	20.25

4.5 Shift schedules

The mine operates two shifts per day of 10 hours each. The dayshift starts at 6:00a.m and ends at 4:00 p.m., with two hours for a meal break and shift preparations. The nightshift starts at 6:00 p.m. and ends at 4:00 a.m., also with two hours for shift preparations and a meal break. The blasting is conducted once a day during the shift change. This makes the effective working time 16 hours a day, resulting in 80% shift utilization. The interaction of dump trucks with other mine vehicles is estimated to be 5% of the total available working time. The actual shift utilization used to build the model was 75%.

4.6 Rock properties

The ore zone consists of black quartz veins containing pyrite, chalcopyrire, and pyrrhotite. There is more overbreak in the hanging wall than in the footwall. The overbreak used in the model varies between 6%-10% due to the sheared and annealed properties of the hanging wall and the footwall rocks that are in contact with the ore zone. The bucket and truck fill factor is assumed to be 95%.

4.7 Machine setting

The description of loading and hauling machine properties is based on information from the manufacturer and data from the mine. The machine setting includes empty and full speeds on flat, inclining, and declining roads, the acceleration and deceleration rate, tire rolling resistance, and road gradients. For trucks and LHDs, the coefficient of rolling resistance is in the range of 0.006-0.01. When a machine breaks down, it is replaced by another machine, and the time loss is included in the simulation.

5. Simulation method

5.1 SimMine simulation software

This study uses SimMine simulation software to build a model. SimMine is a mining simulation and evaluation software designed for underground and development modelling with the ability to import a mine layout. It can also be used to evaluate the design of the production facilities and the selection of production equipment (SimMine, 2012). For validation purposes and to increase the understanding of users, the software has a 3D environment and animation. It is based on discrete event simulation principles and uses a full graphical user interface to set up the model; no coding is required. It utilizes statistical distribution functions to model variations in process times.

5.2 Model of haulage system in SimMine

The model was developed by importing the mine layout from an Autocad drawing into the SimMine software. The layout includes a $5.5m^2$ ramp, loading bays, and cross-cuts. There are 7 production drifts each ranging from 250m to 550m in length, 20m apart vertically, and connected by a ramp. Each drift contains over 30 stopes, with a 20-25m strike length and an average thickness of 3.5m. Loads from all production drifts go to a single dumping point at a shaft location. The complete mine layout used in the simulation is shown in Figure 2. In this part of the mine, the general mine sequence allows 3 stopes to be mined at a time. Due to the limited size of the drifts, only 1 LHD can be used in each production drift. During the simulation, the number of trucks was changed from 3 to 9. Thus, each LHD serves 1 to 3 trucks.

The LHD tramming distance depends on the length of the drift. The tramming distance is defined as the distance from the loading location to the active face and is ranging from 250m to 550m. The cycle time will be higher for equipment working at the far end of the drift than for equipment in the middle or near the access. Therefore, the simulation was run for the stopes located at the end, centre, and near the loading point of the drift.

The total length of the haul road includes a 1.1km ramp, and 0.8km on the main level. Trucks working on lower levels will have lower productivity than those working on higher levels. To check for the effect of haulage distance to the dumping point, the simulation was repeated by changing the stope locations. Figure 3 shows the stopes selected from the top drifts in the first run, the middle drifts in the second, and the bottom drifts in the third. In this figure, stopes located from drifts 1 to 3 are termed as upper drift stopes, those in drifts 3 to 5 are classified as mid-drifts stopes, and those in drifts 5 to 7 are called lower drift stopes. The simulation was run for three stopes at a time; two stopes were chosen from the same drift but on opposite sides, and the third was taken from the two drifts down or up for stability reasons. For example, for the upper drift stopes, if two stopes are chosen from drift 1, the third will be chosen from drift 3.

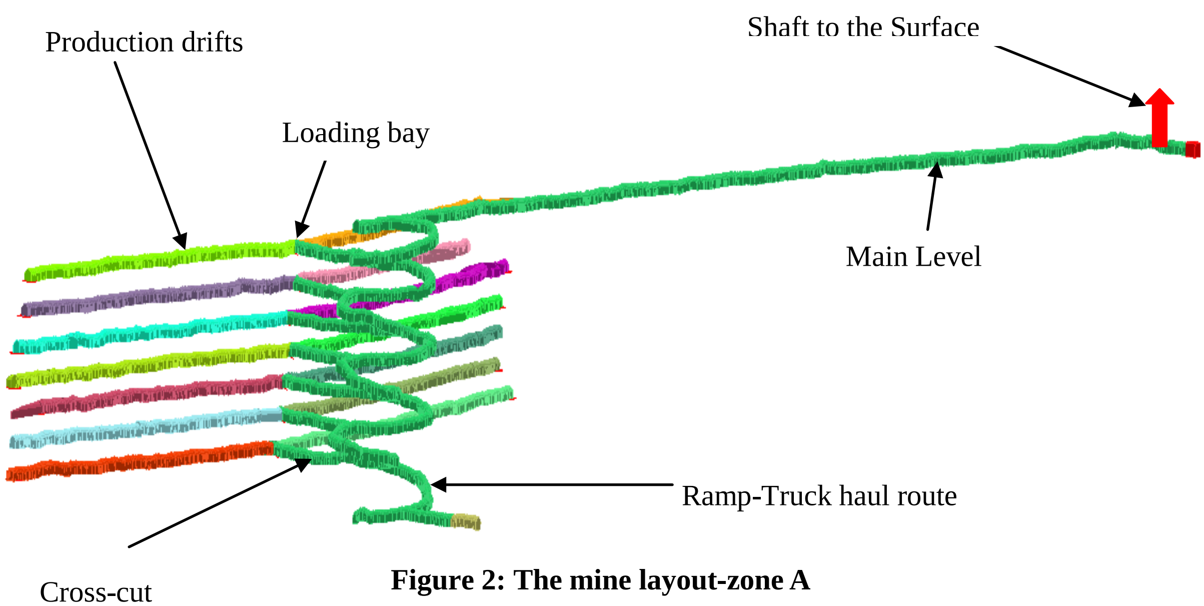

Figure 2: The mine layout-zone A

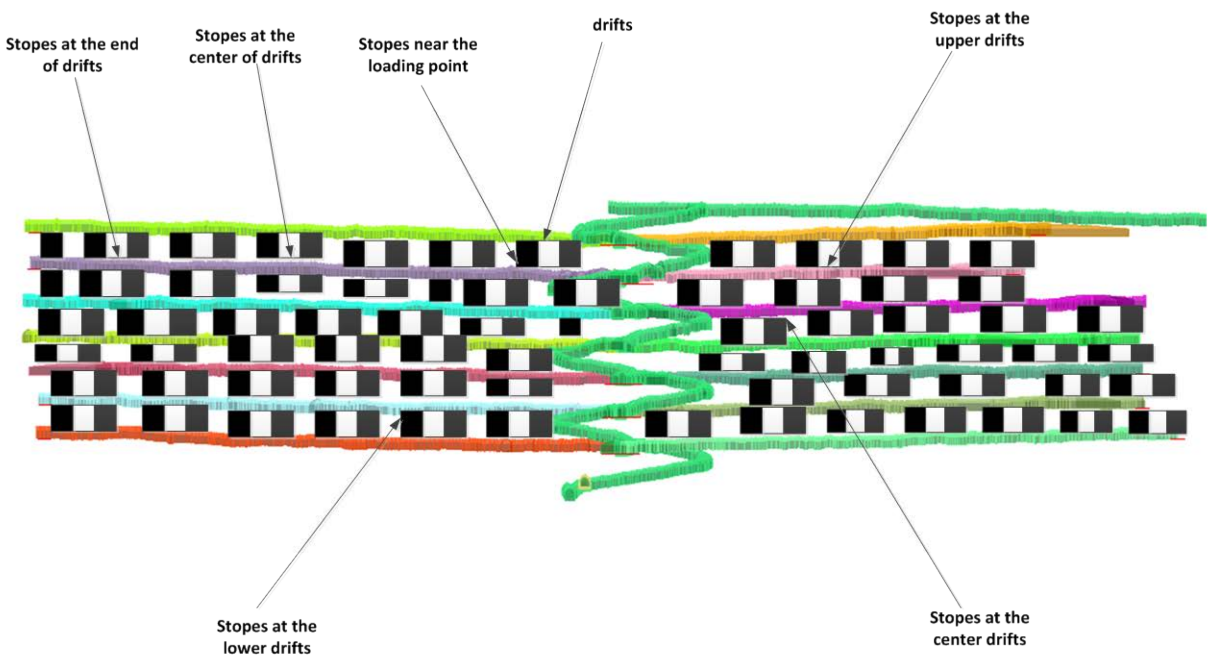

Figure 3: Stopes location

5.3 Model verification and validation

Model verification is to ensure that the computer program of the computerized model and its implementations are correct (Sargent, 2003). Model is valid when the theories and assumptions underlying the conceptual model are correct and that the model represents the real system of the simulated model (Sargent, 2003). Verification and validation was done by testing a model to check if it conforms to the sequence of real events and processes of the time. In data collection it was seen that there is variability in the loading and dumping times of the hauling and loading machines; this created a wide range in the data used in the simulation tool. To determine the proper range, the study performed a statistical analysis and selected a triangular distribution characteristic to model the loading and dumping times. This distribution was chosen because the times are fairly uniform around the mean, but not symmetrical. The load and haul unit properties are shown in Table 2.

Table 2: Load and Haul unit properties

Description	Unit	Minimum	Average	Maximum
Loading a bucket	sec/bucket	17	18.5	20
LHD dumping ore	sec/bucket	5	6	7
LHD loading a truck	sec/pass	60	65	70
Truck dumping ore	sec/box	65	70	75
Maneuvering time	sec	30	35	40

6. Simulation Results

Simulation was conducted independently for the stopes at the top, middle, and down drifts of the mine layout. For each simulated drift, the simulation was run at the end, centre, and near the loading point to determine the effect of reducing the tramming distance for the operation cycles. During simulation, the LHDs were fixed in the drifts, and the number of trucks was increased from 3 to 9. Figures 4, 5, and 6 compare production in these locations. Simulation results show that when 3 trucks and 3 LHDs are in operation at the top drifts, the amount of ore produced per month at the end, centre, and near the loading point is respectively 52 %, 53.7 %, and 54.8% of the planned production; for the mid-level stopes, production is 45.7 %, 49.8 %, and 51.6 % respectively, and for the lower levels, production is 42%, 44.4%, and 48.1% respectively.

The average production is greater when the LHDs are working near the loading point than when they are at the Centre or end of the drift. In all cases, the amount of ore produced increases as the number of trucks increases. With 4 and 5 trucks in operation, this means each LHD will serve one truck, and the extra trucks will be moving to the loading point of minimum queue. The increase in the number of trucks leads to a reduction in individual truck utilization with lowest values noticed when operations are in the stopes which located at the end of the drift. The result is also indicating that, the increase in the number of trucks also increases LHD performance, especially when operations are at the end of the drift. It can be seen that the traffic is minimal when 3 trucks are in operation. The term traffic here refers to the percentage of the time lost when trucks meet in the haul ways. The traffic increases when the number of trucks starts to increase with the highest percent being noted when the LHDs are working near the loading point.

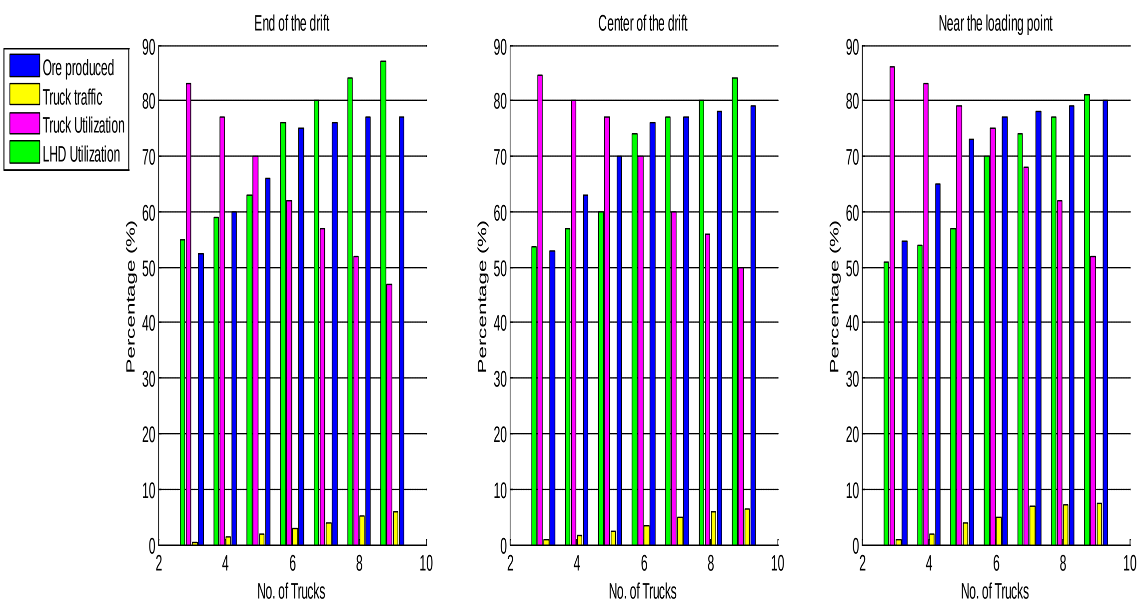

Figure 4: Simulation results for the stopes located at the top drifts

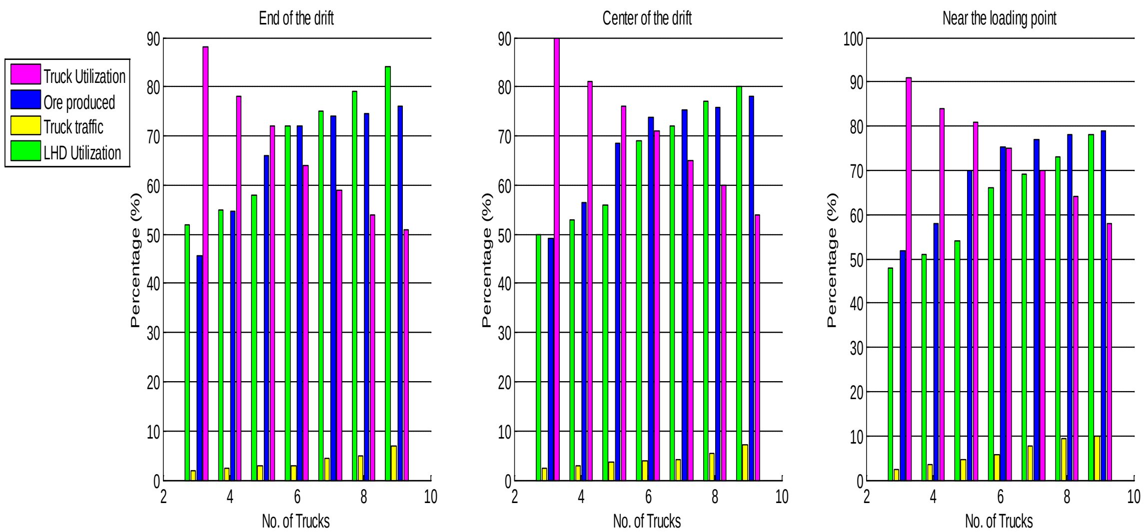

Figure 5: Simulation results for the stopes located at the mid drifts

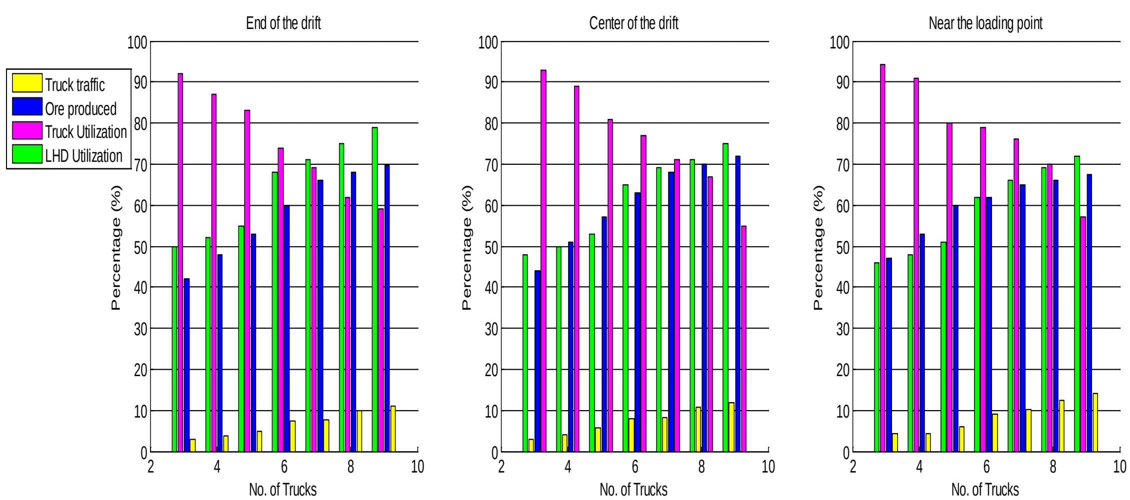

Figure 6: Simulation results for the stopes located at the lower drifts

7. Discussions

In all cases, the amount of ore produced increases when the number of trucks in operation increases. The production is greater when the mine is working on the stopes located in the upper drifts than those in the mid and lower drifts because trucks in the latter two cases have higher time to complete the cycle than the trucks in the former. When the number of trucks increases from 3 to 6, average production increases by 22%, 24%, and 26% for the upper, mid, and lower drifts respectively. The difference is not significantly greater due to the fact that trucks working on the upper drifts have a longer waiting time at the loading point than those on lower drifts. The truck waiting time increases when operations are going on at the far end of the drift; in this case, the LHDs spend more time loading and hauling material from the face to the loading point because of the longer tramming distance. When the stopes are backfilled and the length of the drift is decreased, the LHDs spend less time hauling and loading the trucks. Increasing the number of trucks also leads to an increase in the LHDs performance and truck traffic. The traffic increases to 13% of the available time; which indicate that there is a time loss when trucks wait to give way to each other when they meet at the intersection points on the ramp.

Production is sharply increased when the number of trucks is increased from 3 to 6. Beyond this point, the amount of ore produced does not rise at the same rate as the drop in truck utilization. It is observed that among all the simulated scenarios, a combination of 2 trucks and a single LHD for the upper drifts and 3 trucks and 1 LHD for the lower or mid drifts improves the average production to 75% of planned production. Reaching a production target of 100% proves infeasible in the given circumstances. Alternatively different haulage system should be considered, especially when the mine depth is increased

8. Conclusion

In an underground hard rock mine, the combination of LHDs and trucks play the important role in the rock material handling systems. The simulation technique was used to study their impact on the production. Three simulation models were created using SimMine software, to study the impact of these equipment for the productivity optimization. The results suggest that to improve the monthly production of ore, 1 LHD can be assigned to serve a fleet of 2 trucks when working in the stopes close to the dumping point, and a fleet of 3 trucks can be used for the stopes on the mine's lower levels. Future studies in this area should consider using other type of low profile haul unit with bigger box size than the one used in this article, and also considering the increase of number of intersection points on the haul routes to reduce the truck traffic.

References

Banks, J, (1999). Descrete Event Simulation. Proceedings of the 1999 Winter Simulation Conference (ed: P.A. Farrington, H.B Nembhard, D.T. Sturrock, G.W Evans):7-13.

Banks, J, (2000). Introduction to simulation. Proceedings of the 2000 winter simulation conference, Orlando, 9-16.

B.Morgan (1994), Optimizing truck-loader matching. Proceedings of mine planning and equipment selection, 313-320

Greberg, J & Sundqvist, F (2011). Simulation as a tool for mine planning, in proceedings Second International Future Mining Conference, Melbourne, 273-278.

Saiang, D. (2008). Simulation of truck haulage queue system at an open pit mine using SIMIAN, Proceedings of the 5th International conference and exhibition on mass mining, 607-616.

Sabuncuoglu, I. & Hommertzheim, D.L, (1992). Dynamic dispatching algorithm for scheduling machines and automated guided vehicles in flexible manufacturing system. *International journal of production research*, 30, 1059-1079. doi: 10.1080/00207549208942943.

Sargent, R. G (2003). Verification and validation of simulation models. Proceedings of the 37th Conference on winter simulation. 130-143. Syracuse, NY, USA.

SimMine (Version 1.19) [Computer Software]. Malå, Sweden: SimMine AB.

Stugul J.R & Li (1997). New development in simulation technology and applications in the mineral industry, *International Journal of Surface Mining, Reclamation and Environment*, 11(4). 159-162. doi:10.1080/09208119708944087

Sweigard, R. (1992). Materials handling: Loading and haulage. In SME Mining Engineering Handbook, 2nd ed. Edited by H.L Hartman.Littleton, CO: SME.