Comparative Analysis of Excavator 755's Lost Productivity between Day and Night Production Shiftsat African Mining Services-Ghana, Nzema Site

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Abstract-**The study investigates the comparative productivity of the Leibherr 984 Excavator (EO755) day and night shifts at the Nzema gold mining site of the African Mining Services (AMS) in Ghana. To determine the unique working conditions in both shifts to reduce delays and maximise productivity. The study uses mix-method by combining questionnaire and interviews and none-participant operational observations to elicit deeper response from 25 production shift workers in addition to gathering statistical primary and secondary data on operations and productivity at the site. The key finding that emerged from the study was that, the day shifts' lost hours of 393.13 translating into some production and revenue loss of 143,175 bcm and US$ 691,253.50 respectively, was greater than that of night shifts' lost hours of 333.68 equivalent to a production and revenue loss of 121,525bcm and US$ 586725.57 respectively. In addition, at was revealed that day shift working context was more stressful than night shift.The conclusion drawn from the study was that the Leibherr 984 Excavator (EO755) is more productive in night shift than day shift base on the environmental and working conditions context of the study site. The study thus recommends for strong cooperation between the supervisory and managerial staff ("big men") of the companies (ARL and AMS) and production crew members to create an environment of "partners- in change" which will eradicate the perception of intimidation and minimize the feeling of tension by the worker which translates to stress and delays in the day shifts which in turn impact negatively on productivity.**

Keywords**–Production, Productivity, Utilization, Excavator, Delay.**

I. INTRODUCTION

Ghana's mining industry continues to be the leading contributing sector to the nation's economy. Its contribution to direct domestic revenue improved from GH₵ 1.3 billionin2015 to GH₵ 1.6 billion in 2016, which represented a 23% growth rate (Anon., 2017a). This industry was responsible for over 9000 jobs in 2015 (Anon., 2017a).

The labour that occupied these jobs together with other factors is responsible for the revenues generated by the industry. However, this labour force is productive only if they make effective use of time allocated for production in the mining industry.

As a mining company, Endeavour Mining, Nzema Gold Operations, includes materials handling for loading and hauling fragmented materials from the pit to their appropriate destinations. Endeavour Mining, however, has contracted African Mining Services (AMS) to undertake drilling and blasting, loading and hauling, crusher feeding, pit dewatering and other ancillary mining services.

African Mining Services-Ghana' main objective is achieving its clients call. Due to this, time is of great importance and for that matter its effective use. In order to make effective use of time daily, AMS Nzema Site operates two shifts, which are the day and night shifts with two production crews. Different working conditions arise from these two working times resulting in differences in productivity of excavators on the AMS site. This project, therefore, seeks to compare the lost productivity of Excavator 755 on AMS Nzema site between these two production shifts to identify the more productive shift.

A. Excavators

Excavators, also known as diggers or 360-degree excavators (sometimes abbreviated simply to 360) are heavy construction equipment consisting of a boom, dipper (or stick), bucket and cab on a rotating platform called the "house". Underneath the house is an undercarriage with tracks or wheels (Temeng, 2016). All movement and functions of an excavator are accomplished using hydraulic fluid, with hydraulic cylinders and hydraulic motors if they are hydraulic. Hydraulic excavators' mode of operation (linear actuation of hydraulic cylinders) is different from cable-operated excavators, which use winches and steel ropes to accomplish the movement (Temeng, 2016). A typical hydraulic excavator is shown below.

Fig. 1A typical hydraulic excavator

Modern excavators come in a wide variety of sizes and types such as (Anon., 2017c):

i. Compact excavator;
ii. Dragline excavator;
iii. Long reach excavator;
iv. Amphibious excavator;
v. Power shovel;
vi. Steam shovel;
vii. Suction excavator;
viii. Walking excavator; and
ix. Bucket-wheel excavator.

Excavators have wide ranges of usages. These include (Anon., 2017c):

i. Digging of trenches, holes and foundations;
ii. Material handling;
iii. Forestry work;
iv. Construction;
v. Demolition;
vi. General grading/landscaping;
vii. Mining; and
viii. River dredging etc.

Fig. 2 An excavator in operation - mining

1) Excavator Productivity:

Productivity is the measure of the efficiency of persons or machine per unit time thus the highest ratio of output to the input of individuals or equipment (Anon, 2018a) and hence excavator productivity can be defined as the measure of the efficiency of an excavator per unit time. Mathematically, excavator productivity can be expressedas:

The productivity of an excavator = $\frac{Production}{Effective\ hours}$

To obtain the effective hours of the excavator, the excavator's time usage statistics must be studied well, and this includes:

i. Calendar hours, which are the total hours in a given period of a mining forecast;
ii. Unscheduled hours, which are hours the machine is not required to operate. E.g. holidays, shutdown days etc.
iii. Scheduled hours, which are the hours required for the machine to operate, thus, scheduled hours = Calendar hours – Unscheduled hours;
iv. Downtime hours, which are the hours that the machine is not mechanically and electrically ready to operate (Temeng, 2016). These may be planned or unplanned maintenance hours;
v. Available hours, which are the hours that the machine is mechanically and electrically ready to operate, thus, Available hours = Scheduled hours – Downtime hours; and
vi. Utilized hours, which are hours that the machine uses to operate effectively to its full potential, thus; Utilized hours (Effective hours) = Available hours – Delay hours.

Where delay hours are unproductive available hours.

2) Factors Affecting Excavator Productivity: Many factors affect the productivity of an excavator. These include:

i. Operational delays

These activities are non-productive and delay production. Their period of duration amounts to the delay hours making it possible to obtain the effective hours from the available hours. Example of operational delays includes tramming, hanging, chop time, etc. These delays are in two groups:

- Fixed operational delays; and
- Variable operational delays

Fixed operational delays: These operational delays are predictive as to their occurrence and duration. Periods for such delays may exceed or be shorter than the designated periods for them. Examples include; pre-shift inspection (PSI), chop time, coffee break, etc. Usually, with these delays, the digger burns no fuel.

Variable operational delays: These delays are not predictive as to their occurrence and duration. Their periods may also vary from time to time, but usually, their periods are of fewer minutes as compared to the fixed delays. Examples are; tramming on/ to/ from/ bench, under trucked, dozer on the floor, wait on surveyors, bucket scratch, etc.

ii. Excavator cycle time

Excavator cycle time consists of crowding material, swinging loaded, making a pass and swinging empty to the loading face (Adjei, 2014). In production, shorter excavator cycle time enhances higher productivity. Various factors that affect these cycles are:

- Bench height and floor
- The degree of consolidation or fragmentation of material
- Competency and experience of the operator.

Bench height and floor: Benches whose heights are higher than the boom length of the digger makes it difficult for the operator to crowd material. This increases the loading time of the digger, thus decreasing its productivity. Usually higher uneven heaps of material after blast causes higher bench heights and uneven bench floor. With this, the digger spends time in levelling the bench floor and this affects productivity.

Degree of consolidation or fragmentation of material:Less competent (oxide) material are easy to dig, these materials usually require no blasting, and these decreases cycle time of the digger, increasing its productivity. However, in very competent formation (transition and fresh), there is difficulty in digging thus the formation is blasted before excavation. The degree of fragmentation of this broken material can increase or decrease the cycle of the digger. Well, fragmented materials are faster to dig than boulders. Moreover, the presence of toes in blasted formation causes some difficulties in excavation, thus affecting productivity negatively.

Competency and experience of the operator: The operators' level of knowledge, training and skills on the job can either increase or decrease productivity, however, productivity can increase more if operators have the passion or interest in the job and are much experienced and committed. Moreover, the productivity of an operator may be affected by the degree of stress and fatigue on the operator, which results from a number of factors such as working shift schedules or hours.

B. Shift Work Systems

Shift work involves work schedules in which employees change or rotates working periods. Shift work is an employment practice, which is designed to make use of all hours within each day of the week (Anon., 2015). This practice makes sure that each day is divided into periods during which employees carry out their duties (Anon., 2016). A large number of shift systems that exist; however, it is also possible to categorize the majority under one of the following:

i. Systems without night work – straight day (two team – double days);

a. Non-overlapping (e.g.0600-1400, 1400-2200)
b. Overlapping(e.g.0600-1400, 1330-2130).

ii. Systems with night and day shifts;

a. Two teams (day and night), up to 12 hrsshifts
b. Three teams (night only), permanent night shift which is often combined with the straight day to make complete use of 24 hrsin a day.

iii. Systems with night and weekends work (continuous shift work).

a. Three teams (12 hrs shift);
b. Four teams (8 hrs shift); and
c. Irregular (varying number of teams andcycle lengths (Anon., 2010b)

The shift work system has many benefits to various industries especially in increasing output, however, it has some negative effects on workers, which affects their productivity. Some of these effects include:

i. Increased fatigue, especially for night shift workers who tend to get little sleep during the daytime;
ii. Loss of concentration and vigilance; and
iii. Poor sexual performance (Mboana, 2012)

With the above effects, the operator can be very competent, committed and experienced but will have reduced productivity.

II. METHODOLOGY

A. Data Collection method

1) Fieldwork: Fieldwork was done to determine the duration of some operational delays (in both day and night shifts) of one of the largest diggers, the Liebherr 984 Excavator, often referred to as EO755 on site. This digger was used for mining fresh material in the Adamus Final Pit, with six CAT 777D dump trucks (on a day) and seven CAT 777D and one CAT 777C (on night shift) available when all trucks are mechanically ready to operate. With all trucks available, there was one standby truck during the day shift and three standby trucks during the night shift since the digger often operated with five trucks. However, the number of trucks assigned to work under the digger was dependent on some factors such as the distance to a particular dump, the degree of fragmentation of blasted materials, digging sump material, bench height and top loading. The fieldwork was carried out for twenty effective operational days in the month of January 2018.

2) Questionnaire and Interview

Questionnaire made up of both open and closed ended questions and interviews were conducted on 25 production shift workers.The main objectives were:

i. To identify which shift the workers think is stressful;
ii. To investigate the major challenges workersface in each shift;
iii. To investigate the effects of the challenges faced on production; and
iv. To investigate other factors that boost workers enthusiasm to work.

3) Data Description: Data was collected over aperiod of ten operational day andnight shift days. This involved monitoring the digger from the control room, by direct communication with the digger operator. The periods of the digger delay parameters were monitored with the use of a watch. There were numerous operational delays. However, only seven of these were studied for this work. These delays were: under trucked; blasting delays; delay from chop; coffee break delays; Pre–Shift Inspection (PSI)/transport to pit; standbys and safety meeting. These delays were selected amongst the lot because they reflect workers attitude towards time consciousness and time management.

The delays studied for this work are further described below as:

i. Under trucked: This is when the digger hangs its bucket due to unavailability of operators (where there are available trucks) or unavailability of trucks (where operators are available). In cases of availability of trucks and operators, the digger can hang when truck operators become less active due to stress or fatigue, thus increasing the travel time of the trucks. This period starts when the bucket of the digger is hanged and ends when a truck arrives and the digger starts to crowd material.
ii. Blasting delay: This is when the digger stands by and waits upon blasting activities. This starts when the digger finishes tramming at a safe place and ends when the digger starts to tram onto its working bench.
iii. Delay from chop: This is when operators exceed the 0.5 hr allotted to them for meals. This starts at 0.5 hr after the digger has parked for a meal break and ends when the digger starts to load trucks.
iv. Coffee break delay: This is a break taken by operators to step out of their cabins and either ease themselves or stretch out. His starts when the digger stops loading trucks and ends when it starts loading the trucks.
v. PSI and Transport to pit: The PSI is a short meeting at the beginning of every shift, where operators are shown where work is to be done during the shift. Here, there is supervisor-operator interaction where operators bring out their opinions orcomments on problems facing the crew and others. The transport involves conveying workers to the pit. It starts immediately at the beginning of the shift when the bus arrived on time and ends when the digger starts to load trucks.
vi. Standbys: This is when the digger parks for some tangible reasons during operations. The digger can be on standby for late bus arrival, community agitation etc. Appendix A shows more of the digger standby activities. This starts when the digger parks and ends when the digger starts and is ready to load trucks.
vii. Safety meeting: This is a monthly meeting held by the safety department at the beginning of every month. This delay starts when the meeting starts and ends when the meeting ends.

After the periods of these delays were obtained, the average productivity of the digger and cost per bcm of mining for the month of January 2018 were also obtained. However, secondary data on these delays (for day and night shifts) were also collected over the entire period of 2016. The average productivity and cost per bcm of mining for that year were also collected.

B. Data Analysis

The start time and end time of each delay were used in calculating the period of the delay in hours. This was calculated using the below formula;

$$\text{Delay hours} = \frac{End\ Time - Star\ \ Time}{60}$$

The productivity of EO755 was also calculated using the aforementioned equation.

The lost production and lost revenue in both shifts were determined using the following equations respectively as:

- Lost Production = Productivity (bcm/hr) × Lost hours(hrs)
- Lost Revenue = Average cost of mining per bcm ($/bcm) × Lost Production (bcm).

C. Average Productivity and Cost ofMining

After the twentieth day of production in January 2018, the total material moved by the EO755 was 125 283 bcmwith its effective hours being 296.87 hrs. Hence, the productivity of the EO755 was calculated as:

$$\text{Productivity} = \frac{125{,}283\,(\text{bcm})}{296.87\,(\text{hr})} = 422\text{bcm/hr}.$$

The calculated productivity and the average cost of mining for EO755 for January 2018 and 2016 (the average of all the months in 2016) are presented in the table below:

TABLE 1 Average Productivity and Cost of Mining of EO755

Excavator 984 (EO755)		
Parameters	January 2018	2016
Average productivity (bcm/hr)	422	364
Average cost of mining ($/bcm)	5.927	4.828

III. RESULTS

A. Lost Production Hours

The calculated monthly day and night shifts lost production hours (DSLH and NSLH) are presented in Table 2 below. The results are graphically presented in Figure 3 below.

TABLE 2 Monthly Summary of Lost Production Hours for the Study Period

Months	DSLH (hrs)	NSLH (hrs)
January, 2016	22.18	11.21
February, 2016	31.05	19.39
March, 2016	7.62	26.42
April, 2016	19.40	15.75
May, 2016	28.17	16.22
June, 2016	22.15	20.08
July, 2016	30.31	16.70
August, 2016	35.83	27.56
September, 2016	42.53	33.77
October, 2016	36.60	58.08
November, 2016	35.10	50.40
December, 2016	35.52	38.10
January 2018	46.67	26.42

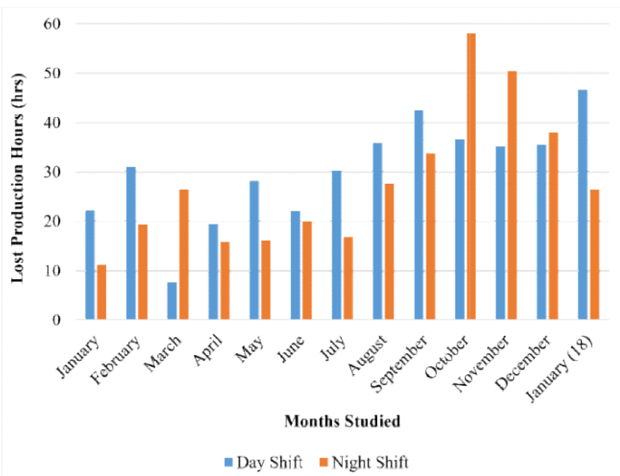

Fig.3 Monthly day and night shift lost production hours

B. Lost Production Hours due to the Delays

Table 3 shows the day and night shifts lost production hours according to delays studied. Figure 4 gives a graphical representation of the results in Table 3.

TABLE 3 Day and Night Shifts Lost Production Hours According to Delays Studied

Delays	Day shift (hrs)	Night shift (hrs)
Under Truck	129.22	135.88
PSI/Transport to Pit	118.17	108.75
Safety Meeting	9.88	10.70
Late After Chop	2.80	5.05
Coffee Break Delays	0.00	36.35
Blast Delays	12.07	0.00
Standby	120.99	36.95
Total	393.13	333.68

C. Lost Production and Lost Revenue

Lost Production and Lost Revenue due to Lost Production Hours obtained for the Delays Studied: Table 4 shows the lost production and lost revenue for both day and night shifts. Figure 3 and 4 give graphical representations of the results in Table 4.

TABLE 4 Lost Production and Revenue due to Lost Hours Based on Delays Studied

Delays	Lost Production (bcm)		Lost Revenue ($/bcm)	
	Day Shift	Night Shift	Day Shift	Night Shift
Under Truck	47060	49487	227207.87	238924.33
PSI/Transport to Pit	43037	39606	207783.98	191220.34
Safety Meeting	3599	3896	17378.34	18814.32
Late After Chop	1019	1839	4923.37	8879.65
Coffee Break Delays	0	13238	0.00	63915.95
Blast Delays	4394	0	21217.39	0.00
Standby	44064	13457	212742.52	64970.96
Total	143175	121525	691253.50	586725.57

IV. DISCUSSION

From the results as presented in Table 2 and Figure 1, the following discussions were made:

i. Out of the thirteen weeks studied, there was higher lost production hours in night shift for four months, namely March, October, November and December 2016. However, there were higher lost production hours in day shift for nine months: January (2016 and 2018), February, April, May, June, July, August and September 2016.
ii. The highest lost production hours were observed in October, followed by November in the year 2016, for night shifts. This was due to higher lost hours due to under trucking of the digger in these two months. The highest lost production hours in day shift occurred in January 2018, which was also due to under trucking.
iii. In the January 2016 and 2018, there was a higher loss of production hours in day shift; however, they were different in values, with January 2018 lost production having higher values than January 2016. This tremendous increase in the value of lost hours in January 2018 was due to higher lost hours due to under trucking and standby. In January 2018, the company was operating in two pits in the day shift and in one pit in the night shift with seven CAT 777D and one CAT 777C.

The EO755 was scheduled with six CAT 777D dump trucks (on day shift) and seven CAT 777D and one CAT 777C (on night shift) available when all trucks are mechanically ready to operate. However, most of these six trucks for the day shifts went down frequently, leaving few available trucks to work with the digger. This however led to frequent under trucking of the digger. During this month too, there was a major breakdown of all service trucks that issue out fuel to the trucks in the pit, resulting in frequent fuel shortage for the digger and the trucks. In situations where there were less than three trucks available for the digger, it went on standby, hence high loss of hours in January due to standby.

iv. The lost production hours due to the delays studied have inconsistent values for the two shifts.

A. Lost Production Hours due to the Delays

Based on the results in Table 3 and Figure 2 the following discussions were made:

i. The delay that gave the highest lost hours was under trucking, in both day and night shift, sand followed by standby in day shift then PSI and transport to pit for both shifts. The least lost hours are due to late after chop, resulting from no lost hours due to late after chop in some of the months studied. Lost hours due to safety meetings was also low because it is done once in a month for both day and night shift.

ii. The lost hours in day shift due to under trucking and PSI and transport to pit are closer to that of the night shift. However, that of the day shift standby hours is much higher than that of the night. This is due to higher standby hours in day shift for most of the months studied.

iii. There are no lost hours due to coffee breaks delays in the day shift. This is because usually coffee breaks are only taken in the night shifts for a little release of fatigue aside the chopping time. Moreover, there are also no lost hours due to blast delays in the night shift. This is because; blasting is only done in the day shift. However, the total hours lost due to blast was due to just fourteen days of blasting within the period studied

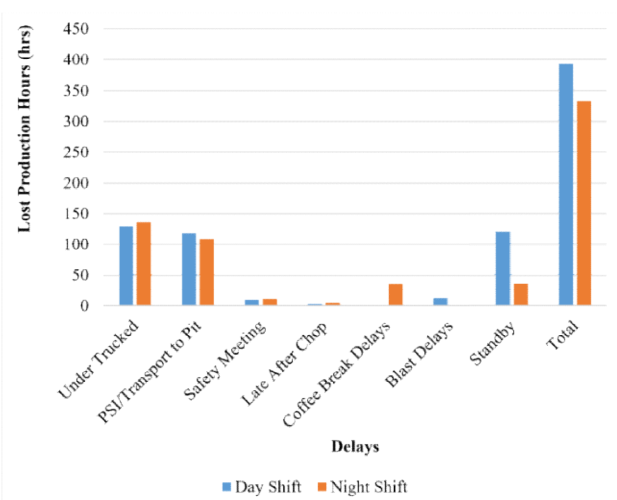

Fig.4 Day and night shift delay hours

B. Lost Production and Lost Revenue

Due to Lost Production Hours obtained for the Delays Studied: Based on the results in Table 3, Figure 3 and 4 the following discussions were made:

i. The total production lost due to lost hours in the day shift was 143,176 bcm, equivalent to a total of \$691,253.50. The lost production in night shift was 121,526 bcm, which also equivalent to \$586,725.57.

ii. Since the lost production and lost revenue are directly proportional to one another, the highest production and revenue lost were due to under trucking of the digger for both shifts. This was followed by lost hours due to standby for day shift, then PSI and transport to pit for day and night shifts. The least lost production was due to late after chop.

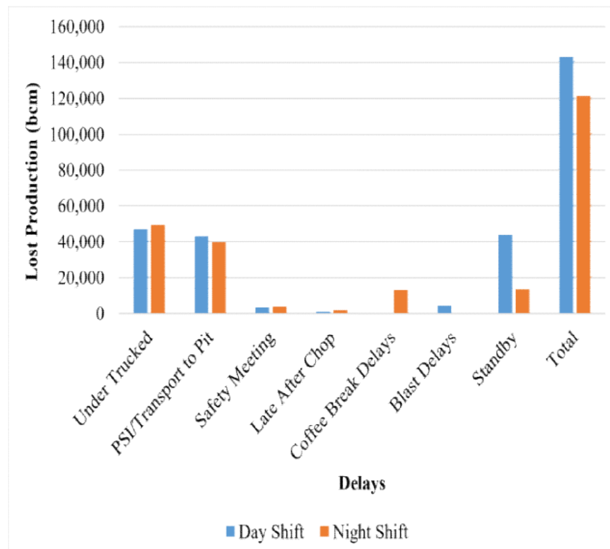

Fig.5 Day and night shifts lost production due to delay hours

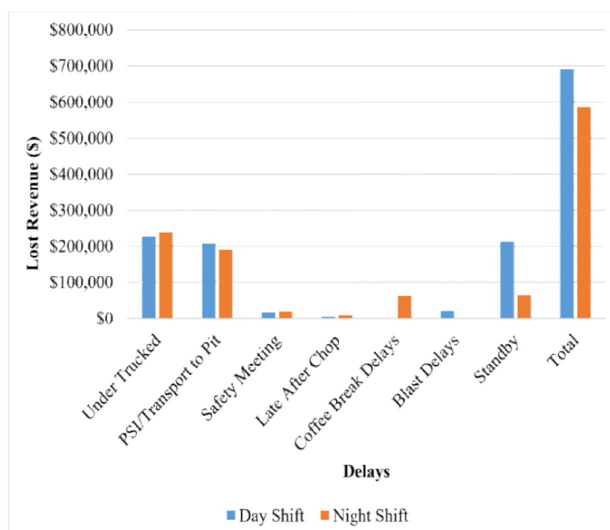

Fig.6 Day and night lost revenue due to delay hours

D. Results from Interviews

After the questionnaires were analyzed the following results were gleaned:

i. 100 % of the workers that were interviewed were of the notion that day shifts were more stressful than night shifts. This was because when they were on day shift there was much pressure on them to deliver than when they were on night shift.
ii. 95 % of the workers that were interviewed also testified that in night shift, sleepiness and poor visibility were the main challenges. Therefore, they took coffee breaks most often in the night shifts to release some stress or fatigue. Moreover, to knock off some sleep most operators said being chatty on the radio was of great help.in night shift. They said no pressure from any supervisory and managerial staff ("big man"), so they are able to push harder since they are much more comfortable but they are constantly conscious of their safety.
iii. 100 % of the workers interviewed testified that in day shift, pressure from the supervisory and managerial staff were their greatest challenge. Their presence and so many different instructions from most "big men" made them feel a little uncomfortable, but also made them much conscious of work and safety. This also made them productive but not extra enthused to work harder, they only work cautiously to prevent any issues.
iv. 70 % of workers interviewed said they did not depend on little motivations coming from anyone to work. However, these motivations only excited them and boost their enthusiasm sometimes.
v. 80 % of workers interviewed said situations such as sudden change in roster, leave days and working hours had a great impact on them since they might have made their plans for those periods. Some think about what they might have been doing at home; this makes them a bit unconscious of the work when they are at work during these periods. Some also said these situations had no impact on their ability to deliver at work.

V. CONCLUSIONS

From the analysis and discussion, the following conclusions were deduced:

i. From the day shift lost production hours of 393.13 hrs and that of night shift being 333.68 hrs, night shift is concluded to be the more productive shift for EO755 at AMS Nzema site.
ii. Based on the lost hours, 143,175 bcm and 121,525 bcm were lost in day and night shifts respectively. Their corresponding loss in revenue were \$691,253.50 and \$586725.57 for day and night shift respectively.
iii. From workers, day shift was stressful than night shift. The main challenge (working condition) in the day is pressure from the supervisory and managerial staff while that of night shift was poor visibility and sleepiness.

VI. RECOMMENDATIONS

Based on the observations and the conclusions drawn from the project, the following recommendations are made:

i. Continues improvement required in thoroughly educating production crews on the effect of a lost second on the company. Here, the workers should be made to be time conscious especially in adhering to periods assigned to some delays such as PSI/ Transport to pit, safety meeting and chop time.
ii. Increased cooperation required between the supervisory and managerial staff ("big men") of the companies (ARL and AMS) and production crew members to create an environment of "partners-inchange". This will eradicate the perception of intimidation and minimize the feeling of tension by the worker any time these staff members were present.
iii. All activities to be performed by the digger in a shift should be thoroughly discussed amongst the supervisory and managerial staff ("big men") to minimize delays during production.
iv. AMS Nzema site should continue scheduling blasting hours out of production hours.
v. Since this work was done on EO755, a Liebherr 984 excavator, working on fresh material, a study should be done on different excavator models working in a different material. Moreover, it should be done studying more of the delays for longer periods of production, say two years, and a comparative analysis made between the same months of different years.

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