ABUAD Journal of Engineering Research and Development (AJERD)
ISSN (online): 2645-2685; ISSN (print): 2756-6811

Volume 5, Issue 2, 28-34

Determination of Load-Haul Equipment Match Factor at Ashaka Cement Quarry, Gombe State, Nigeria

Abayomi Paul AKINOLA[1], Yahuza Musa AHMED[1].

[1]*Department of Mining Engineering, University of Jos, Jos, Nigeria*
akinolaa@unijos.edu.ng / yahuza0013@gmail.com

Corresponding Author: akinolaa@unijos.edu.ng, +2348030704642

Date Submitted: 04/08/2022
Date Accepted: 15/12/2022
Date Published: 16/12/2022

Abstract: *This research aims to determine the match factor at the Ashaka cement quarry. The match factor of the equipment was determined by first taking into consideration the total number of hauling equipment, and the cycle time for each piece of equipment was determined. It was observed that the type of hauling fleet used is a homogenous loader and heterogeneous trucking fleet. A model by Burt was used to determine the match between the equipment. The match factor considering the As-Is cycle time data was 1.16. From the match determined, it is observed that the match factor was more significant than 1.0; therefore, it is said to be over trucked. From the As-Is result, Assuming the Volvo has a perfect match factor, i.e., 0.61 and the match factor of the CAT truck is unknown x,x=0.39 to get a perfect match. Also, assuming the CAT has a perfect match factor, i.e., 0.55 and the match for Volvo is unknown, y,y=0.45. It can be observed that the match factor can be optimized, and a better match can be obtained, dead times can be reduced to their minimum, and thus increase in productivity can be obtained.*

Keywords: *Match-factor, loading and hauling equipment, haul time, load time, cycle time.*

1. INTRODUCTION

Mining is a very capital-intensive industry, and one of the high costs in a mine is related to the purchase and application of equipment [12]. Therefore, proper equipment utilization is critical. In an open pit, the haulage and loading of materials require about 50-60 percent of equipment cost and more than 60 percent of the operating cost, making it a requisite for the productivity and profitability of any quarry [9].

As affirmed by [3] the volume of transport work significantly increases. The cost of transportation of mine rock reaches up to 40-60 percent of the prime cost of mining activity.

The most common transport method in surface mining is the truck-shovel combination. It is necessary to use the shovel-truck combination efficiently to improve the economy in the mining sector [8].

Truck allocation plays a significant role in fleet efficiency and productivity in the mining industry. An imprecise determination of the required number of trucks leads to significant challenges during a haulage operation, including loader idle times (under-trucked estimations), truck waiting times, and queues at the loader (over-trucked estimations), [2].

One of the major problems faced by the mining industries, as [8], is not the absence of load haul equipment but the improper allocation of the load and haul equipment and how suitable they are paired with each other; this is being referred to as the equipment match factor [11].

According to [4], a match factor of 1.0 is said to be a perfect match. If the ratio exceeds 1.0, trucks arrive faster than they are being served. Therefore, it results in over-trucking. A low match factor (0.5) correlates with low overall efficiency (under-trucking).

1.1 Study Area

Ashaka Cement Plc. is located in Ashaka town in Funakaye Local Government Area, Gombe State, Nigeria. With latitude 100 401N to 100 591N and a longitude 110 171E to 110 351E. The project area is in the ganglia basin, between the Chad Basin to the north and the upper Benue trough.

1.2 Match factor

The term match factor is the suitable allocation or pairing of loaders and trucks and how suitably they work together and thus have minimal unproductive time. Different researchers and authors have defined the match factor, such as [8, and

[11]. They defined the term as the ideal capacity and number of trucks paired in operation with a loader and how well they are suited to each other. According to [5], the term match factor is the ratio of the truck arrival rate to the loader service time.

Also, [10] define the match factor as the relationship between the loading and haulage equipment and the actual rate of reaching a truck to the servicing rate of the loader.

According to [5], a match factor of 1.0 represents a balance point, where trucks are arriving at the loader at the same rate that they are being served. Typically, if the ratio exceeds 1.0, the trucks arrive faster than they are served. In this instance, it is expected that the trucks will queue. A ratio below 1.0 indicates that the loaders are serving faster than the trucks are arriving. We expect the loaders to wait for trucks to arrive in this case.

The Match Factor model is given below [6].

$$MF = \frac{\text{(number of trucks)(loader cycle time)}}{\text{(number of loaders)(truck cycle time)}} \quad 1$$

1.3 Types of match factors

According to [5] the following are the types of match factors:

i. **Homogeneous fleet**: This section considers the case of uniform trucks and loaders.
ii. **Homogenous trucks and heterogeneous loaders**: This section considers the case of mixed loaders in the fleet, while the trucks remain uniform in type.
iii. **Heterogeneous trucks and heterogeneous loader**: This section considers the case of mixed loaders and trucks in the fleet

1.4 Match factor ratio for heterogeneous trucking fleets:

In a case where the loader is the same, but the trucks are different.it can be calculated as [7];

$$MF = \frac{\Sigma i \text{ (trucks}i\text{)(truck loading time}i\text{)}}{\text{(number of loaders)(truck cycle time)}} \quad 2$$

Where i denotes the type of truck.

An alternative method for calculating the match factor for heterogeneous truck fleets is to add the individual match factors from each homogeneous sub-fleets.

***1. Heterogeneous truck and loader fleets*:** When both truck and loader fleets are heterogeneous (different), An additional parameter in the formula is denoted by lcm (unique loading times) j, which is the least common multiple of all the truck loading times for loader type j [4].

.

$$MF = \frac{\Sigma j\text{(number of trucks)}\times L\text{cm}\times\text{(loader cycle time)}}{\text{(loader}j\times\Sigma j)(\Sigma j\times lcm\times unique\ loading\ time j)(truck\ cycle\ time)} \quad 3$$

2. Cycle Time: The term cycle time is essential when determining the match factor. According to [13], cycle time is defined as the time spent by any equipment to complete one cycle of operation. For a truck, cycle time includes the time to spot and load, travel to the dump site, manoeuvre, spot, and dump, and drive back to the loading point; predictable delays, unpredictable and wait times are included in the cycle.

cycle time = load time + dump time + queuing time at the loader + queuing time at the dump + loaded haul time + empty haul time.

3. Definition of Term Used in Cycle Time

i. ***Spot time:*** the time the dump truck takes to maneuver into position for loading
ii. ***Load time:*** Is the time the loader takes to complete the number of passes that will fill the dump truck or the time it took the dump truck to be loaded with material.
iii. ***Haul time:*** This is the time it takes the dump truck to travel with the load from the loading face to the crusher or stockpile.
iv. ***Dump time:*** This is the time it takes the dump truck to dump the material into the crusher or stockpile.
v. ***Return time:*** This is the time it takes the dump truck to return to the loading face empty.
vi. ***Wait time:*** This is the time it takes the dump truck to wait at the loading face before being loaded or to wait at the crusher or stockpile before it dumps the material; wait time may occur due to the following reasons:
   - If over-trucking exists, the number of truck times in the system exceeds the number of loading equipment.
   - Bunching results from the spacing between truck times being reduced due to the mixing of faster trucks with slower trucks.

 ISSN (online): 2645-2685; ISSN (print): 2756-6811

- Operators' performance can also lead to variations in truck cycle time due to human interference during working operations [1].

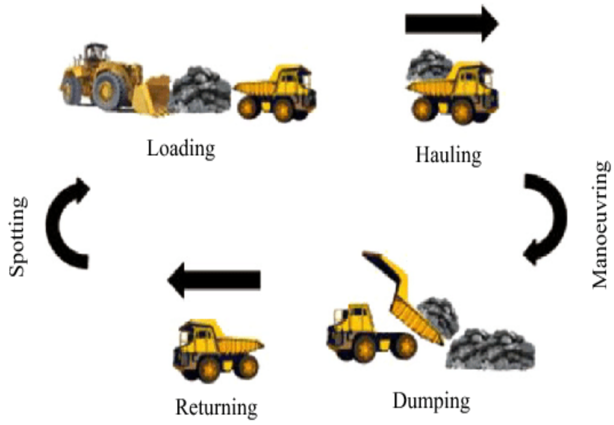

Figure 1: Schematic of Hauling Operations [14]

1.5 Mining Equipment Selection

According to [12], Equipment selection is one of the most critical aspects of open-pit design. Mining cost is mainly affected by the number and capacity of the equipment. Equipment selection for open-pit mines is a critical decision that significantly impacts the economic viability of an operation.

Factors for Consideration in Equipment Selection

i. *Performance factor:* This relates to machine productivity, including cycle speed available force (power), digging range bucket capacity, travel speed, and reliability.
ii. *Design factor:* The design factor provides insight into the quality and effectiveness of detail design, including the sophistication of the human-machine interface for operators and maintenance personnel, the level of technology employed, and the kind of control and power available.
iii. *Support Factor:* Sometimes overlooked in machine evaluation, support factors are reflected in servicing and maintenance. Ease of servicing, special skills, parts availability, and manufacturer's support are important considerations.
iv. *Cost Factor:* Probably the most quantitative (and ultimate) factor, costs are determined by standard estimating procedures for large mining and construction equipment. If reasonable assumptions about the life interest rate, inflation, fuel, and maintenance are made, results should be meaningful.

2. MATERIALS AND METHODS

2.1 Identification of Loading and Hauling Equipment

The equipment used in the quarry is identified visually, and their capacity and specifications were obtained from the manufacturers' handbooks. The quarry uses several dump trucks with different capacity respectively. These dump trucks are Volvo and CAT. A Volvo Loader is being deployed to serve as loader to the dump truck.

2.2 Determination of Cycle Time

The cycle time for each of the loading and haulage equipment used in the quarry was determined by recording all the independent variables that make up the cycle time. These variables include spot time, load time, travel time, dump time, and return time. After all the independent variables are determined, they are summed together to determine the cycle time for a piece of equipment. The cycle time is the time spent by any equipment to complete one cycle of operation. For a truck, cycle time includes the time to spot and load, travel to the dump site, maneuver, spot, dump, and drive back to the loading point; predictable delays, unpredictable and wait times are included in the cycle. The distance between the loading zone to the dumping zone is around 6km

cycle time = load time + dump time + queuing time at the loader + queuing time at the dump + loaded haul time + empty haul time.

2.3 Determination Match Factor Model

The match factor model by [5] was used to determine the match between the trucks and loaders used to transport material (limestone). This model is based on the assumption that the truck and loader fleets are homogeneous. All the trucks are of the same type, and all the loaders are of the same type.

In reality, mixed fleets are typical such as; a heterogeneous trucking fleet, a heterogeneous loading fleet, and the case where both truck and loader fleets are heterogeneous. Nevertheless, a heterogeneous trucking fleet is paired with a homogeneous loader in the case study. An alternative method for calculating the match factor for heterogeneous truck fleets is to add the individual match factors from each homogeneous sub-fleets. At Ashaka cement, a heterogeneous trucking fleet system is being used. The below model is being used to determine the match factor.

$$\mathrm{M}F = \frac{\Sigma i \text{ (trucks}i\text{)(truck loading time}i\text{)}}{\text{(number of loaders) (truck cycle time)}} \qquad 4$$

Where

trucks$i$ denotes the type of truck

Truck loading time i- this is the time taken to load the truck i

Truck cycle time- this is the time taken to complete one cycle of operation

After the match factor has been determined, if the match ratio exceeds 1.0, the trucks are arriving faster than they are being served. In this instance, we can expect the trucks to queue. A ratio below 1.0 indicates that the loaders are serving faster than the trucks are arriving. We expect the loaders to wait for trucks to arrive in this case.

3. RESULTS AND DISCUSSIONS

In comparing results, the case contains two models; As-Is and To-Be. The As-Is represent the quarry's current status and the To-Be's optimized quarry status. The results obtained were cycle times represented in minutes, which will be used to determine the As-Is Match factor. There are a series of activities that make up a cycle of operation. These activities are categorized into productive time, such as the Haul loaded, Spot time, and Load time, and unproductive times such as queue at load and dump as shown in table 1 for Volvo trucks and table 2 for CAT trucks. They also contain the As-Is match factor to be optimized, and a To-Be match factor is to be determined

Table 1: As-Is Cycle Time Data Generated from the Quarry (Volvo Trucks)

Activity	Sub Activity	Truck fleet 1 (volvoA40)	%	Truck fleet 2 (VolvoA35)	%	Truck fleet 3 (volvoA35f)	%
Productive Time	Spot Time load	1.18	2.99	0.42	1.27	1.15	3.24
	Load Time	9.22	23.41	5.96	18.07	6.89	19.43
	Haul Time	9.55	24.25	9.47	28.72	9.52	26.85
	Spot Time Dump	1.10	2.79	0.38	1.15	1.14	3.21
	Dump Time	1.32	3.35	1.18	3.57	1.35	3.80
	Empty Haul	10.25	26.03	9.67	29.32	9.45	26.65
Unproductive Time	Queue at load	4.54	11.53	3.04	9.22	3.11	8.77
	Queue at dump	2.21	5.61	2.85	8.644	2.84	8.01
Total	Productive time	32.62		27.08		29.50	
	Unproductive time	6.75	17.14	5.89	17.86	5.95	16.78
	Cycle time	39.37		32.97		35.45	

Table 1 represents the various cycle time of each truck being used in operation. Figure 2 below shows the sub-activities of the total cycle time per truck. The difference between each sub-activities is displayed, which allows for comparing each truck's performance during the cycle time.

From figure 2, it is observed that the loading and hauling time have a great significance in the total cycle time. The increase in the loading time is due to the availability of large material boulders. Due to a large boulder, the loader spends more time selecting and mucking material for loading.

 ISSN (online): 2645-2685; ISSN (print): 2756-6811

Table 2: As-Is Cycle Time Data Generated from the Quarry (CAT Trucks)

Activity	Sub Activity	Truck fleet 4 (CAT773F)	%	Truck fleet 5 (CAT770)	%
Productive time	Spot Time load	1.37	3.11	1.18	3.30
	Load Time	12.63	28.73	9.44	26.47
	Haul Time	11.47	26.09	10.30	28.88
	Spot Time Dump	1.18	2.68	1.10	3.08
	Dump Time	1.24	2.82	1.03	2.88
	Empty Haul	11.37	25.86	10.09	28.29
Unproductive time	Queue at load	3.50	7.96	1.00	2.80
	Queue at dump	1.20	2.72	1.52	4.26
Total	Productive Time	39.26		33.14	
	Unproductive time	4.7	10.68	2.52	7.06
	Cycle time	43.96		35.66	

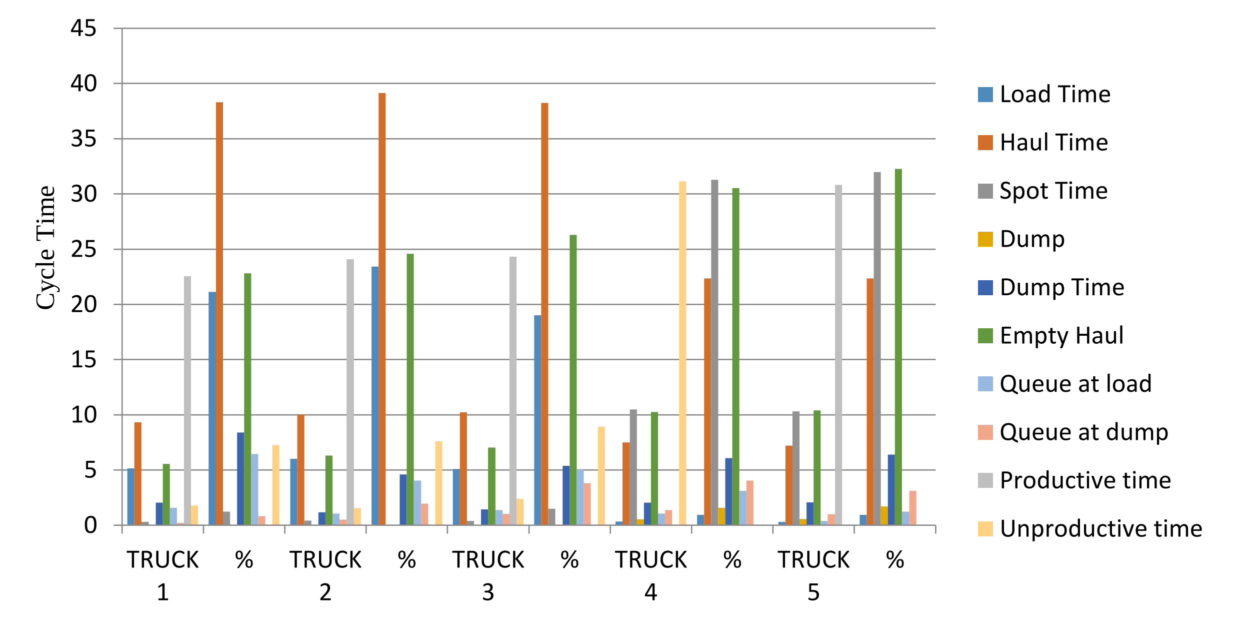

Figure 2: Subactivities of the Total Cycle Time Per Truck.

3.1 Match Factor Calculations for the Load-Haul Equipment

When calculating for match factor, the types of fleets being used must be defined. The type of fleet used in the case study is a heterogeneous truck fleet paired with a homogeneous loader. According to [5] an alternative method for calculating the match factor for heterogeneous truck fleets is to add the individual match factors from each homogeneous sub-fleet.

$$MF = \frac{\Sigma i\ (\text{trucksi})(\text{truck loading timei})}{(\text{number of loaders})\ (\text{truck cycle time})} \quad 5$$

Parameters;
MF: Match factor
Trucks i = the number of trucks of type i in the fleet
truck loading time = The cycle time of one loader type when working with a truck type i
Where i denotes the type of truck. in this case, the Volvo trucks.

$$\text{Truck loading time i} = \frac{9.22+5.96+6.89}{3} = \frac{22.07}{3} = 7.36(\text{mins})$$

$$\text{Truck cycle time i} = \frac{39.37+32.97+35.45}{3} = \frac{107.79}{3} = 35.93(\text{mins})$$

MF $= \frac{(3)\ (7.36)}{(1)\ (35.48)} = \frac{22.07}{35.93} = 0.6145$

$$MF = 0.61$$

For CAT

Where i denotes the type of truck. in this case, the CAT trucks.

Truck loading time i = $\frac{10.63+9.44}{4} = \frac{22.07}{2} = 11.04(\text{mins})$

Truck cycle time i $= \frac{43.96+35.66}{2} = \frac{79.62}{2} = 39.81(\text{mins})$

MF $= \frac{(2)\ (11.04)}{(1)\ (40.19)} = \frac{22.08}{39.81} = 0.55463$

$$MF = 0.55$$

Summation of Eqn1 and 2= 0.61+0.55= 1.16

The match factor (MF) = 1.16

The match factor of 1.16 indicates that the machinery is not fully utilized. Commonly, if the value of the match factor exceeds 1.0, in this scenario where the truck queue can be observed due to trucks arriving faster than being loaded with materials, however, if the match factor is below 1.0, it can be observed that the loader is waiting for the trucks to arrive. In this case, the trucks arrive faster than they are being served

1. To-Be Model

From the As-Is result, Assuming the Volvo has a perfect match factor, i.e., 0.61, we can denote the equation:

$0.61 + x = 1$

$x = 1 - 0.61$

$x = 0.39$

Where x is the perfect match factor of CAT

Nevertheless, if it is the CAT is the one that has a perfect match factor, i.e., 0.55, then we can say:

$0.55 + y = 1$

$y = 1 - 0.55$

$y = 0.45$

Where y is the perfect match factor of Volvo.

2. Determining Number of Trucks Required

$$\text{Number of trucks require} = \frac{\text{total truck cycle time(mins)}}{\text{sum of spotting time and loading time (mins)}} \qquad 6$$

total truck cycle time(mins)= $39.37 + 32.97 + 35.45 + 43.96 + 35.66 = 187.43(\text{mins})$

sum of spotting time (mins) $= 2.28 + 0.8 + 2.29 + 2.55 + 2.28 = 10.2(\text{mins})$

sum loading time (mins) $= 9.22+5.96 + 6.89 + 10.63 + 9.44 = 42.14(\text{mins})$

Number of trucks require $= \frac{187.43}{10.2+42.14} = \frac{187.43}{52.34} = 3.581$

Number of trucks required for the operation = 3trucks

Therefore 3trucks are expected to be paired with a loader in other to obtain a balance and a better match between the equipment

4. CONCLUSION

After determining the As-Is and To-Be match factor for the quarry, it has been proven that unproductive time can be reduced and brought to its minimum. It can also be concluded that an improper allocation of the load and haul equipment and how suitable they are paired with each other will increase unproductive time, thereby altering the match factor.

It was noted that the increase in cycle time was due to poor road maintenance and the presence of giant boulders, thereby making it challenging to muck and therefore creating queues, a mixture of older vehicles with newer vehicles, thereby causing brunching. However, when looked into, the following recommendations can aid in the optimization process of the quarry.

ISSN (online): 2645-2685; ISSN (print): 2756-6811

ACKNOWLEDGMENT

The researchers acknowledged the contribution of the management of Ashaka Cement in Gombe State for their contribution to this research.

REFERENCES

[1] Abayomi, A.P., Komolafe K. & Chidebelu, H. U. (2020). Optimization of Loading and Haulage of Materials in selected Quarries in Jos Using Arena Simulation Software. *Nigerian Society of Mining Engineers Journal*, 1-14.

[2] Amin, M.M., Mohammad, P.M., Hamid, A. & Javad, S. (2019). A Methodology for Truck Allocation Problems Considering Dynamic Circumstances in Open Pit Mines, Case Study of the Sungun Copper Mine. *Mining Geology-Petroleum Engineering Bulletin MGPB*, 57-65. doi:10.17794/rgn.2019.4.6

[3] Burmistrov, K.V., Osintsev, N.A. & Shakshakpaev, A.N. (2017). Selection of Open-pit Trucks During Quarry Reconstruction. *International conference on industrial Engineering ICIE*, 1696-1702.

[4] Burt, C., Caccetta, L., Hill, S. & Welgama, P. (2005). Models for Mining Equipment Selection. in *Proceedings of MODSIM 2005 International Congress on Modelling and Simulation*, 170-176

[5] Burt, C.N. & L. Caccetta. (2007). Match Factor for Heterogeneous Truck and loader Fleets. *International Journal of Mining, Reclamation, and Environment, 21*(4), 262-270.

[6] Burt, C., Caccetta, L., Welgama, P. & Fouché, L. (2011). Equipment selection with heterogeneous fleets for multiple-period schedules. *Journal of the Operational Research Society*. 62. 10.1057/jors.2010.107.

[7] Caccetta, Louis. (2014). Equipment Selection for Surface Mining: A Review. Interfaces. 44. 143-162. 10.1287/inte.2013.0732.

[8] Choudhary, R.P. (2015) Optimization of Load-Haul-Dump Mining System by OEE and Match Factor for Surface Mining. *International Journal of Applied Engineering and Technology*, 5, 96-102

[9] Coronado, P.P.V. (2014). Optimization of the Haulage Cycle Model for Open Pit Mining Using a Discrete-event Simulator and a Context-based Alert. University of Arizona, https://books.google.com.ng/books?id=l2E5nQAACAAJ

[10] Dabbagh, A. & Bagherpour, R. (2019). Development of a Match Factor and Comparison of its Applicability with Ant-Colony Algorithm in a heterogeneous Transportation Fleet in an Open-Pit Mine. *Journal of Mining Science*, 55(1), 45-56. doi:10.1134/S1062739119015287

[11] Gransberg, Douglas. (1996). Optimizing Haul Unit Size and Number Based on Loading Facility Characteristics. Journal of Construction Engineering and Management-ASCE - J CONSTR ENG MANAGE-ASCE. 122. 10.1061/(ASCE)0733-9364(1996)122:3(248).

[12] Owolabi, A. (2019). Loading and Haulage Equipment Selection for Optimum Production in a Granite Quarry. *International Journal of Mining Science (IJMS), 5*(1), 35-40. doi:http//dx.doi.org/10.20431/2454-9460.0502004

[13] Pedro, P.V.C. & Victor, T. (2016). Developing a Context-based alert System for Haulage Cycle Optimization. Retrieved from https://www.researchgate.net/publication/305159918

[14] Soofastaei, A., Saiied, A., Kizil, M.S. & Knights, P. (2016). A Discrete-event model to simulate the effect of truck bunching due to payload variance on cycle time, hauled mine materials, and fuel consumption. *International Journal of Mining Science and Technology, 26*. doi:10.1016/j.ijmst.2016.05.047