Evaluation of Load and Haulage Efficiency for Performance Enhancement: Pit A and Pit B of Mangal Cement Company, Iluhagba, Kogi State

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ORIGINAL RESEARCH

Abstract — The loading and hauling operations in mining and cement production are critical for ensuring the efficient movement of raw materials. The aim of this research is to critically evaluate the loading and hauling efficacy at the two mining pits at Managal cement quarry, Iluhagba and analyzing the operations for better performance. The research will also focus on evaluation of loading and hauling efficiency in two pits (Pit A and Pit B) at Mangal Cement Company. By identifying key performance indicators (KPIs), analyzing operational data, and implementing optimization strategies, to enhance overall operational performance, reduce costs, and improve productivity. A total cycle time approach was adopted to evaluate the efficacy of the equipment productivity and utilization rate approach was also adopted to evaluate the effectiveness of the machines. The methodology adopted for this project involved a combination of field measurements, observational studies, data collection from quarry records, and analytical techniques aimed at evaluating the performance of loading and haulage systems. The approach was designed to ensure accuracy, reliability, and practical relevance to the operational context of Manga Cement Quarry. The methodology adopted for this project involved a combination of field measurements, observational studies, data collection from quarry records, and analytical techniques aimed at evaluating the performance of loading and haulage systems. The approach was designed to ensure accuracy, reliability, and practical relevance to the operational context of Manga Cement Quarry. From the findings, it indicate that while a low rate often signals idle time due to maintenance downtime, operator unavailability, poor scheduling, or inefficient dispatching systems.

Keywords— Bioclassic, Cement, Downtime, Productivity, Performance.

1 INTODUCTION

Mangal Cement Company operates several pits for the extraction of limestone, which is used as a primary raw material in cement production. Loading and hauling processes significantly impact the operational performance and profitability of the mines. Efficient loading and hauling can minimize costs, reduce unnecessary downtimes, and improve material handling (Salati et al., 2026). Researchers have observed that optimal cycle durations clusters around 35–40 seconds, where payload per cycle was maximized (George and Nojabaei, 2023; Salati et al., 2026). Cycle times shorter than 25 seconds or longer than 80 seconds often corresponded with lower payloads or greater variability, interpreted as signaling operator inefficiencies or excessive floor cleanup at loading faces. Importantly, the study revealed that operator technique, fill factor and consistent cycle rhythm significantly affect aggregate yield even when bucket capacities remain constant (Sermin and Birol, 2010). This aligns well with observations from African operations where operator behavior accounts for up to 40 percent of cycle time variability.

Moreover, determining the match factor for Manga's loader-truck fleet would allow planners to calibrate truck numbers so that neither loader sits idle waiting for trucks nor trucks clog the loading face. This would follow Nigerian practice at other cement factory sites where queuing models revealed excessive idle time when fleets were unbalanced. Regression or queuing models could help translate Manga's unique haul distances, loader output, and dispatch rhythm into an optimized schedule and an ideal fleet complement (Hardy, 2007; Mohammed et al., 2015).

Operator training and workload scheduling emerge from Tanzanian and Malawi studies as pivotal. Consistent cycle times around 35-40-second target windows enhance payload filling efficiency and reduce variability. Manga might consider similar operator training protocols, cycle-time monitoring via dashboards, and shift coordination to encourage consistency (Patel and Prajapati, 2012). Operational clarity could be further improved by employing simulation modeling: quarry management could model alternate dispatch scenarios, haul-road configurations, or loader positioning strategies to forecast impacts on throughput—even before making physical changes. Tools like Simio or discrete event

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simulators have proven valuable in analogous studies for enabling scenario planning across fleet-scheduling and road-design combinations (Andre, 2006; Zhang et al., 2022; Ogbeida, 2024).

The concept of loading and haulage in quarry operations is far more complex than the simple transfer of materials from one point to another. It is a finely tuned process that interweaves machinery capacity, human performance, operational logistics, and safety protocols (Choudhary, 2015). In quarries such as Manga Cement's in Kogi State, where limestone is extracted on a large scale, a deep and dynamic understanding of these systems is vital.

Efficiency in loading and haulage not only determines output but also impacts fuel usage, maintenance costs, workforce safety, and environmental sustainability (Krause, 2006). As new technologies emerge and global benchmarks for quarry performance evolve, the future of loading and haulage lies in a balanced integration of intelligent systems, trained operators, and data-driven decision-making. Grounding these practices in the local realities of Manga Quarry can pave the way for significant improvements in Nigeria's cement production and resource management.

The aim of this research is to critically evaluate the loading and hauling efficacy at the two mining pits at Mangal cement quarry, Iluhagba and analyzing the operations for better performance.

2 METHODOLOGY

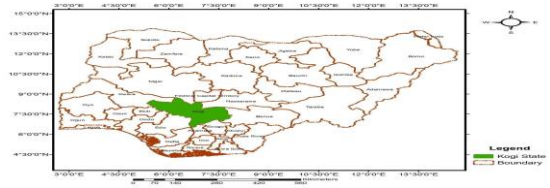

Fig. 1. Location of Kogi State.

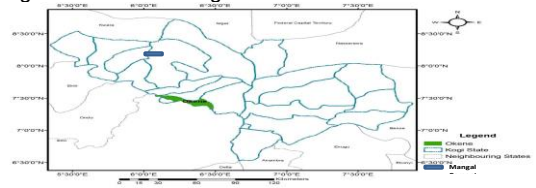

Fig. 2. Location of Mangal Cement in Kogi State

The methodology adopted for this research involved a combination of field measurements, observational studies, data collection from quarry records, and analytical techniques aimed at evaluating the performance of loading and haulage systems. The approach was designed to ensure accuracy, reliability, and practical relevance to the operational context of Manga Cement Quarry.

2.1 Research Design

This study employed a descriptive and analytical field-based approach. The descriptive aspect involved observing and recording real-time operational parameters, while the analytical aspect involved evaluating the performance metrics based on both measured and recorded data. The goal was to assess how effectively materials are being loaded and transported within the quarry and to identify factors influencing productivity.

2.2 Study Area and Equipment Considered

The study was conducted at the Manga Cement Quarry, located in Iluhagba, a rural community in Ijumu Local Government Area of Kogi State, North-Central Nigeria. The quarry serves as a major limestone source for cement production in the region and contributes significantly to the operations of the Manga Cement Company, a key player in Nigeria's growing cement industry.

2.3 Geographic Location

Iluhagba is situated approximately 20 kilometers southwest of Kabba, the administrative headquarters of the local government area. The quarry lies within the coordinates Latitude 7°45'N and Longitude 5°55'E, with an elevation ranging between 250 and 320 meters above sea level. The area is accessible via a network of rural roads that connect to major highways leading to Lokoja, Abuja, and other urban centers. Map of Nigeria showing Kogi State and the map of the state showing the study location are shown in Figure 1 and 2.

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2.4 Geology and Mineral Resources

The Manga Quarry is situated within the Benue Trough geological formation, a sedimentary basin well known for its limestone and shale deposits. The limestone found in this area is of high quality, characterized by its high calcium carbonate ($CaCO_3$) content, low silica, and minimal impurities—making it ideal for cement manufacturing. The rock formation is predominantly composed of bioclastic and crystalline limestone, interbedded with some clay and shale layers.

2.5 Climate

Iluhagba experiences a tropical savannah climate, with two distinct seasons: a rainy season (April to October) and a dry season (November to March). Average annual rainfall ranges from 1,100 to 1,500 mm, while temperatures fluctuate between 24°C and 35°C. These climatic conditions influence equipment performance and access roads, particularly during the rainy season when haul roads may become slippery and prone to degradation.

2.6 Vegetation and Land Use

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The vegetation is primarily Guinea Savannah, characterized by scattered trees, shrubs, and grasses. Land use in the area includes subsistence farming, mining, and limited commercial activities. The establishment of the quarry has led to land conversion from agricultural to industrial use, which has both economic and environmental implications for the local population.

2.7 Economic Importance

The Manga Cement Quarry plays a vital role in the local and regional economy. It provides employment to skilled and unskilled labor, supports ancillary businesses, and contributes to infrastructural development. The loading and haulage operations, in particular, are essential to the material flow from the blasting site to the crusher and ultimately to the cement plant, thus making them a central focus of efficiency and cost management.

2.8 Operational Setup

The quarry uses truck-and-shovel loading systems, where materials are excavated using front-end loaders or hydraulic excavators and transported using articulated dump trucks (ADTs) or rigid dump trucks. Haul roads within the quarry span several kilometers and are subject to constant wear due to the volume and weight of the loaded vehicles. Efficient coordination between the loading points and the crushing plant is critical to maintaining steady production and minimizing equipment idle time.

2.9 Data Collection Techniques

2.9.1 Field Observation and Time-Motion Study

A time-motion study was used to measure the time taken to complete each segment of the loading and haulage cycle. This included:

1. Loading time (from bucket fill to truck departure)
2. Haul time (from loading point to dump site)
3. Dumping time
4. Return time (empty travel back to loading point)

Stopwatches and time logs were used to record cycle times over multiple shifts to account for variations in operator behavior, traffic, and environmental conditions.

2.9.2 Equipment Performance Data

Data such as fuel consumption rates, equipment payload capacities, bucket sizes, average trips per shift, and engine hours were obtained from equipment logs, operator daily reports, and quarry supervisors. This information was crucial for computing productivity and utilization rates.

2.9.3 Secondary Data

Operational records such as:

1. Daily and monthly production reports
2. Maintenance schedules and downtime logs
3. Shift rosters and dispatch records were reviewed to provide insight into equipment availability, mechanical reliability, and average material moved per day.

2.9.4 Interviews and Expert Opinions

Structured interviews were conducted with quarry managers, dispatch officers, equipment operators, and maintenance personnel. These interviews provided context on:

1. Perceived operational challenges
2. Equipment matching and scheduling
3. Haul road conditions and traffic management
4. Safety practices and their impact on operational speed

2.10 Data Analysis Methods

The data collected were analyzed using quantitative performance metrics, including:

Cycle Time Analysis: Average time taken for each complete truck cycle (from loading to dumping and return).

2.10.1 Bottlenecks in Performance Measurement

Despite the structured approach, Manga Cement Quarry faces challenges such as weather variability, equipment downtime, operator skill variability, fuel and lubricant quality that affect accurate performance measurement.

To address these challenges, the quarry has begun integrating predictive maintenance tools, upgrading haul roads, and conducting operator retraining programs aimed at reducing loading inefficiencies and unsafe practices. At Manga Cement Quarry, the measurement of equipment performance is an essential part of maintaining productive and efficient operations. By focusing on key indicators such as availability, utilization, productivity, cycle time, and match factor, the management is able to monitor performance trends and identify areas for improvement. Continuous investment in data collection tools, personnel training, and fleet balancing strategies will further enhance the ability to measure and optimize equipment performance, ultimately contributing to the long-term success and profitability of the quarry's operations.

2.10.2 Time and Cycle Study

A time and cycle study in the context of quarry operations is a detailed investigation aimed at understanding how time is distributed across the various stages of a repeated work cycle—particularly in loading and haulage activities. At Mangal Cement Quarry in Iluhagba, this kind of study is essential to assess the efficiency of moving limestone from the excavation point to the crushing plant or conveyor system. It provides critical insights into how effectively equipment and labor are being used and identifies sources of delay, downtime, or underperformance that could impact production targets.

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At its core, the time and cycle study focuses on measuring the duration of each action involved in a single haulage trip. This includes the time taken for a truck to arrive at the loading site, wait for the loader, be filled with material, travel to the dump or crusher site, unload the material, and return to the original position for the next cycle. The total cycle time is then analyzed to find patterns—such as excessive waiting, slow travel speeds, or equipment bottlenecks—that can be optimized to improve throughput.

In an active quarry like that operated by Mangal Cement, understanding the precise timing of each part of the process has significant operational implications. For example, if haul trucks are frequently delayed due to long queue times at the dump point, this not only reduces the number of cycles completed per hour but also leads to underutilization of expensive machinery. Similarly, if loading takes longer than necessary due to operator inefficiency or poor bucket fill factors, the productivity of both trucks and loaders is compromised. By conducting a time and cycle study, quarry managers can quantify these inefficiencies. This is especially important in operations like Mangal's, which combines conventional truck haulage with a conveyor system. Since the conveyor handles a portion of the limestone transport, trucks are often tasked with shorter, internal trips or support functions. Studying their cycle times helps ensure these support activities don't become hidden sources of delay.

The results from a cycle study are often used to calculate key performance indicators such as tonnes hauled per hour, loader productivity, and average fuel consumption per tonne moved. These metrics enable decision-makers to adjust fleet sizes, shift patterns, or haul road maintenance schedules to boost output. They also help determine whether it is more cost-effective to invest in new equipment or better utilize what is already available.

Importantly, the value of a time and cycle study extends beyond production efficiency. It also informs maintenance planning, safety assessments, and environmental impact mitigation. For instance, prolonged idling due to inefficient cycles can increase fuel use and greenhouse gas emissions. Recognizing this through detailed timing data allows for corrective action that aligns with both operational and sustainability goals.

In summary, a time and cycle study at Mangal Cement Quarry is more than just a technical evaluation—it is a strategic management tool. It enables a data-driven approach to improving equipment usage, reducing operational costs, and achieving higher levels of productivity and environmental performance. As Mangal Cement continues to grow its operations, such studies will be indispensable in aligning quarry output with plant demand while maintaining cost control and operational reliability.

2.10.3 MineSched Software

Loading and hauling in quarries using GEOVIA MineSched software, requires a structured process that leverages its scheduling algorithms and data integration capabilities. Below is a step by step of the software's functionality for open-pit operations such as quarries.

1. Data input and setup

1. Input geological and operational Data: Begin by importing geological models, ore reserves, and quarry infrastructure details into MineSched. This include block models defining material types, grades, and volumes, as well as equipment specification (e.g. loader and truck capacities). Ensure data accuracy for reliable scheduling.
2. Define equipment parameters: input details about loading equipment (e.g. excavators, wheel loaders) and hauling equipment (dump trucks), including cycle times, capacities, availability, and maintenance schedules. This allows minesched to account for equipment constraints in the schedule.

2. Model the Quarry

1. Build a geological model: Use minesched to create or import a detailed geological model of the quarry, identifies material zones (e.g. overburden, aggregates, waste). This helps define extraction areas and material flow.
2. Specify mining areas and phases: Divide the quarry into mining benches or push-back. Define the sequence of extraction based on operational needs, such as prioritizing high-quality material or minimizing waste haulage distances

3. Optimize Loading and Hauling

1. Schedule Mining Activities: Use minesched automated scheduling tools to generate a tactical schedule for loading and hauling. The software optimize the sequence of bench extraction and assign equipment to tasks to minimize idle time and maximize productivity.
2. Calculate Haulage Requirement: MineSched calculate haulage needs based on material volumes, distance and truck capacities. It can optimize truck fleet size and routing to reduce fuel consumption and cycle times.

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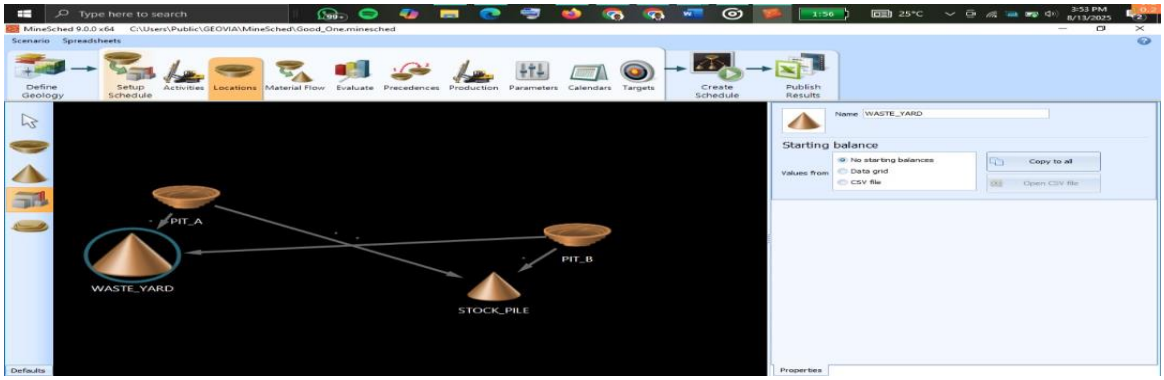

Fig. 3. Dialog Box of MineSched indicating trucks movement at Manga cement Pit A & Pit B

4. Stockpile Management: Configure stock pile strategies (e.g. for marginal materials or high grade stockpiling) to balance loading and hauling operations, ensuring a consistent feed to processing plants.

5. Scenario Analysis

1. Run multiple scenarios: MineSched allows you to compare thousands of scheduling scenarios by varying equipment configurations, haul routes or production targets. Analyze these to identify the most efficient loading and hauling plan, balancing productivity and costs.
2. Evaluate economic viability: For financial modelling tools to assess cost (e.g. fuel, maintenance) against production outputs. This helps to optimize hauling operation for productivity.

6. Visualize and Adjust

1. Review Outputs: Visualize schedules using Gant charts, 3D models or animation to assess equipment utilization and material flow. Identify bottlenecks, such as overloaded trucks or underused loaders and adjust the plan.
2. Dynamic Adjustment: if real-world condition change, (e.g. equipment downtime or unexpected material grades) update the schedule to MineSched to maintain optimization.

2.10.4 Parameters Evaluated

In the assessment of loading and haulage performance at Mangal Cement Quarry, Iluhagba, the parameters evaluated are those that directly affect the efficiency, reliability, and productivity of material movement from the quarry face to the crusher or conveyor system. These parameters are observed over time to identify delays, calculate equipment output, and determine areas for operational improvement. The first critical parameter is the total cycle time, which is the time taken for a haul truck to complete a full trip—from arriving at the loading point to dumping and returning. This includes spotting time (positioning the truck for loading), loading time (how long it takes to fill the truck with limestone), loaded travel time (duration from the loading point to the dump location), dumping time, and return time (empty haul back to the loading point). Each of these sub-components is timed and analyzed individually to determine where delays or inefficiencies occur. Another core parameter is equipment productivity, especially the tonnage moved per hour by each truck or loader. This depends on truck capacity, number of trips per hour, and effective working time without interruptions. For example, if a truck carries 25 tonnes and completes three trips per hour, it moves 75 tonnes/hour. This figure is used to evaluate whether the fleet size is appropriate or if more trucks or loaders are needed.

Closely related is the utilization rate, which refers to the proportion of time that trucks or loaders are actively working compared to their total scheduled time. Low utilization can indicate excessive idling, poor dispatching, or frequent mechanical downtime. Equipment availability—the percentage of time equipment is mechanically fit for use—is also measured to assess maintenance performance and reliability. Fuel consumption per tonne hauled is another key parameter, reflecting operational efficiency and cost-effectiveness. Haul roads with poor gradients or surfaces may cause increased fuel use and slower travel speeds. As a result, haul distance and road condition are also evaluated, since they significantly affect travel time, vehicle wear, and energy use. Environmental and operational safety considerations are factored in through parameters such as dust generation during haulage, braking frequency on slopes, and truck queuing time, all of which can affect community relations, health, and vehicle performance.

3 RESULTS AND DISCUSSION

This research brings to the limelight that, to effectively assess and analyze the loading and hauling operations for efficient performance at Manga Quarry, several KPIs which include match

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factor, cycle time of both loading and hauling equipment, machine availability, operator efficiency, haul road condition, weather, and material fragmentation. Equipment availability, in turn, depends on the frequency and quality of maintenance. Manga Quarry maintains a rigorous preventive maintenance schedule based on equipment run-hours rather than calendar days, minimizing unplanned downtime. This is consistent with findings by Grayson et al. (2001), who noted that quarries implementing condition-based monitoring and preventive maintenance programs achieve up to 10% higher equipment utilization rates than those using reactive maintenance strategies.

3.1 Match Factor

Table 1. The Match Factor between the Loaders and Dump Trucks at Manga Cement

match factor	((Total no of truck * loading time) / (No of Loading unit * Truck cycle time))

match factor for Bulk (mass) mining		match factor for Selective mining	
Total no of truck	26	Total no of truck	26
loading time	7	loading time	18
No of Loading unit	14	No of Loading unit	14
Truck cycle time	49	Truck cycle time	49
	182		468
	686		686
match factor	0.265306122	match factor	0.682215743

match factor < 1	Loader queue
match factor > 1	Truck queue
match factor = 1	Balanced

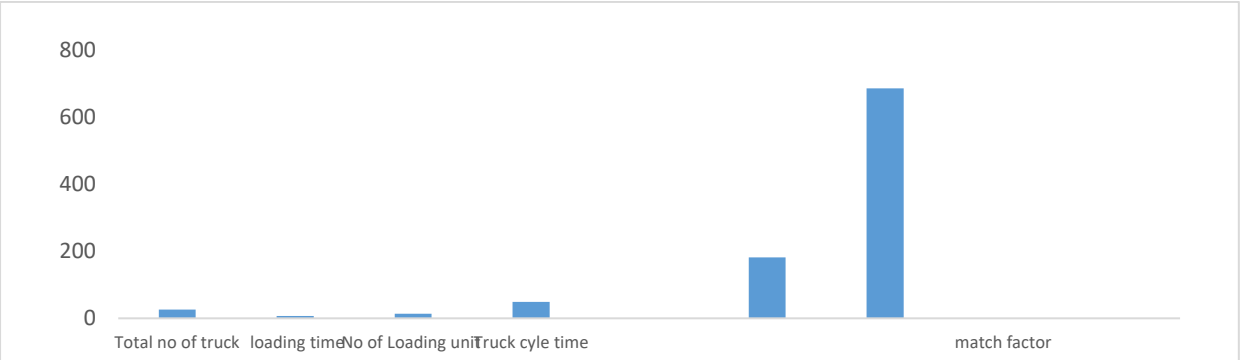

Fig. 4. Match factor of the equipment in relation to the loaders

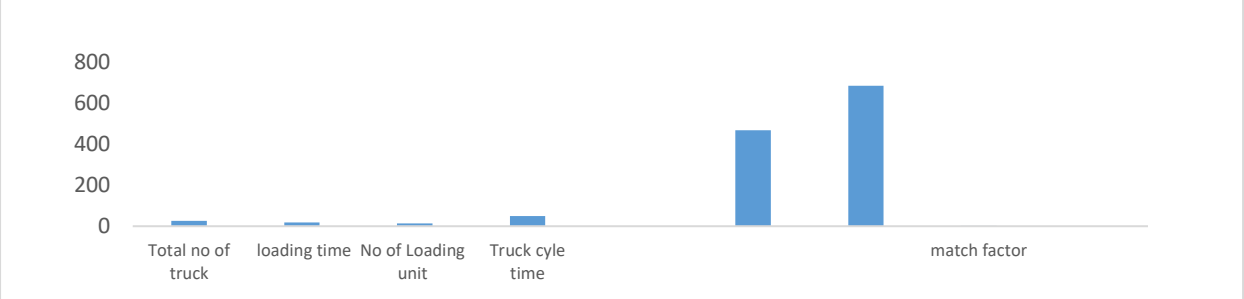

Fig. 5. Match factor of the equipment in relation to the dump trucks

The analysis result show that base on the existing excavator and trucks combination are over truck on this note the productivity of loader shall be used to budgeting and scheduling. Parameters such as shovel loading time, haul cycle time, capacities of trucks and shovels were determined and quantitatively analyzed to determine their contribution to trucks queuing at the loading site. Numbers of allocated trucks together with cycle times were assessed to investigate their impact on the match between loading and hauling units. For this reason, it is very important to consider the productivity of an excavator or loader in other to calculate the optimal fleet in surface mining quarries. It also depends on the capability of loading equipment and haulage equipment (match factor) due to this parameter can

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be used to match the truck arrival rate to loader productivity rate or in other words it can be determined the number of transport units for each loading unit. To estimate the compatibility, the number of buckets per truck must be between 4 and 6, so that the choice for the capacity of the loader bucket is chosen after selecting the transport unit.

3.2 Cycle Time

Table 2. Total Cycle time from Pit A and Pit B to the Crusher unit, Stockyard and Waste Yard/Dump.

		Bulk (mass) mining to crusher			
Location	Loading Cycle Time	Hauling Cycle Time	Dumping time	Return time	Delay time
Pit A	0:07	0:20	0:02	0:20	0:03
Pit B	0:07	0:12	0:02	0:12	0:03

Cycle time mining to crusher	
Pit A	0:52
Pit B	0:36

		Bulk (mass) mining to Stockyard			
Location	Loading Cycle Time	Hauling Cycle Time	Dumping time	Return time	Delay time
Pit A	0:07	0:17	0:02	0:20	0:03
Pit B	0:07	0:08	0:02	0:12	0:03

Cycle time mining to Stockyard	
Pit A	0:49
Pit B	0:32

		Bulk (mass) mining to Waste Yard			
Location	Loading Cycle Time	Hauling Cycle Time	Dumping time	Return time	Delay time
Pit A	0:07	0:05	0:02	0:20	0:03
Pit B	0:07	0:18	0:02	0:12	0:03

Cycle time mining to Waste Yard	
Pit A	0:37
Pit B	0:42

Table 3. Summary of the Total Cycle Time

	Pit A	Pit B
Cycle time mining to crusher	0:52	0:36
Cycle time mining to Stockyard	0:49	0:32
Cycle time mining to Waste Yard	0:37	0:42

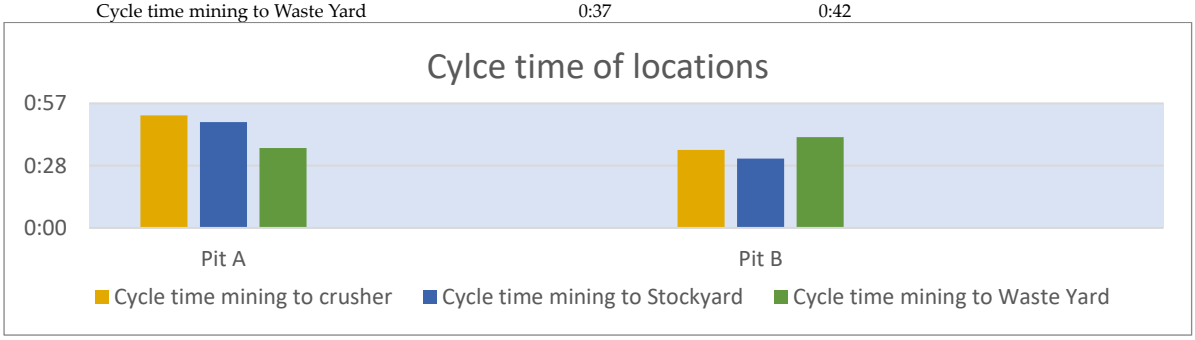

Fig. 6. The cycle Time of loaders and dump trucks at different locations

At its core, equipment utilization rate is defined as the ratio of the actual operating hours of a piece of equipment to the total number of available or scheduled hours, often expressed as a percentage. A high utilization rate indicates effective deployment of machines, while a low rate often signals idle time due to maintenance downtime, operator unavailability, poor scheduling, or inefficient dispatching systems. According to the Society for Mining, Metallurgy and Exploration (SME, 2011), optimal utilization rates for critical equipment like haul trucks, loaders, and excavators should range between 65% and 85%, depending on mine layout, shift design, and equipment age.

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At Manga Quarry, equipment such as hydraulic excavators, wheel loaders, haul trucks, and dozers are the backbone of the material handling process. The quarry operates primarily in two shifts, with the potential for 20–22 operational hours per day, excluding scheduled maintenance and refueling breaks. Utilization tracking at Manga is done through a combination of operator logbooks, shift reports, and, more recently, fleet management systems (FMS) such as Caterpillar's VisionLink and Komatsu's Komtrax, which provide real-time data on machine status, fuel consumption, idle time, and total engine hours.

4 CONCLUSION

This project highlights critical inefficiencies in the loading and hauling processes at Mangal Cement Company. By implementing the recommended strategies, the company can enhance its operational performance, leading to significant cost savings and increased productivity. Continuous monitoring and evaluation of operational practices will be essential for sustaining improvements over time.

Productivity in surface quarrying operations, such as those conducted at Manga Cement Quarry in Iluhagba, Kogi State, is a critical determinant of operational success, profitability, and resource efficiency. In the context of mining and quarrying, productivity is generally measured in terms of the volume or mass of material moved, loaded, or processed per unit time—often expressed as tonnes per hour (TPH) or tonnes per man-hour. However, true productivity encompasses more than just output; it also reflects how effectively resources such as equipment, labor, energy, and time are utilized within the quarry system. At Manga Quarry, productivity is primarily tied to the performance of loading and haulage systems, which together form the backbone of the material handling process. Effective coordination between blasting, loading, and hauling ensures that limestone is delivered at a consistent rate to the crushing and processing plants, minimizing delays and reducing idle equipment time. The quarry operates on a two-shift system, with peak production expected during daytime operations when supervision and mechanical support are readily available. Productivity evaluations are therefore most commonly benchmarked against shift targets.

One of the key drivers of productivity in this environment is the match between loading equipment and haulage trucks. When this match is optimized—meaning the bucket capacity of the loader and the payload capacity of the truck are well-aligned—the loading cycle is completed more quickly, thereby increasing the number of trips a truck can make per hour. Studies by George and Nojabaei (2023) emphasize that inefficient loader-truck matching can reduce system productivity by more than 20%, particularly in quarries with short haul distances, such as Manga. At this site, wheel loaders and hydraulic excavators are used interchangeably for loading, and the loading time per truck averages around 3–5 minutes, depending on the fragmentation size of the blasted rock and operator skill.

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