

Enhancing Efficiency by Automated Monitoring of Dumper Performance Through Sensor Technology: A Case Study

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Abstract - The mining industry is pivotal to the economy, yet it faces significant challenges in maintaining equipment reliability and efficiency. Downtime of machinery can lead to substantial financial losses, operational delays, and safety risks. The efficiency and reliability of mining equipment are crucial for maintaining operational profitability and safety. With advancements in sensor technology and data analytics, automated equipment monitoring systems are becoming pivotal in enhancing operational effectiveness. Dumpers operate under highly demanding conditions, where variations in load, haul road quality, operator behaviour, and mechanical health directly influence productivity, fuel consumption, and machine longevity. Automated sensor-based monitoring systems provide continuous, high-resolution data on critical performance parameters such as engine load, fuel efficiency, tyre pressure, brake temperature, vibration levels, payload accuracy, and cycle times. These systems enable real-time detection of performance deviations, early identification of potential failures, and immediate corrective actions through centralized dashboards or automated alerts. By reducing manual checks, minimizing unscheduled breakdowns, and optimizing haul cycle efficiency, sensor-enabled monitoring contributes significantly to improved fleet utilization and reduced operating costs. Furthermore, integration of analytics and predictive algorithms enhances decision-making by revealing patterns related to road conditions, operator practices, and component wear. Overall, automated monitoring through sensor technology offers a transformative approach for enhancing the operational performance of dumpers, leading to higher productivity, improved equipment health, and more sustainable mining operations.

Key Words - Dumper Performance Monitoring, Sensor Technology, Mining Equipment, Vehicle Health Monitoring System (VHMS), Tyre Pressure Monitoring System (TPMS), Fuel Management System (FMS), Predictive Maintenance, Fleet Optimization, Real-time Data Analytics, Opencast Mining

1.0 INTRODUCTION

Dumpers are the backbone of material movement in opencast mines, and their performance directly affects overall production and cost. Dump trucks are one of the widely used and capital-intensive heavy earth moving equipment in the mining industry. Continuous monitoring of dump trucks' performance is essential for a mining system and it needs a well-defined performance measure (PM) [1]. Effective maintenance strategies are critical for ensuring operational reliability, minimizing downtime, and optimizing resource utilization in fleet-based industrial operations. Among these, mining truck fleets represent a particularly high-risk, high-cost context where equipment failures can lead to substantial productivity losses and safety hazards [2]. However, these machines work in tough conditions where factors like road quality, load variation, operator habits, and machine wear can change continuously. In fleet management, various challenges, including equipment breakdowns, rising maintenance costs, inefficient resource utilization, and outdated telematics systems, require a transformative approach. Traditional telematics systems encounter limitations such as closed compatibility with specific brands, unique network protocols, and insufficient data analysis and decision-making support [3]. Traditional methods of monitoring dumper performance such as manual checks or operator reports often miss important details and cannot capture real-time changes. This leads to issues like unexpected breakdowns, lower productivity, and higher maintenance costs.

In the mining industry, the use of digital transformation has become increasingly important to improve the productivity, efficiency, and availability of machinery and equipment [4]. Sensors play a key role in modern industrial plant operations [5]. With the development of modern sensor technology, it is now possible to monitor dumper performance automatically and accurately. Sensors installed on dumpers can track important parameters such as load weight, tyre pressure, fuel use, engine temperature, brake condition, and vibration levels. The data collected by these sensors is sent instantly to a central system where it can be analysed to identify any problems at an early stage.

For mining operations to increase efficiency and safety, intelligent sensor systems are essential [6]. Automated monitoring through sensors helps mines improve productivity, reduce machine failures, and make operations safer and more efficient. It also supports better planning, as real-time data allows maintenance teams to act before failures occur. Overall, sensor-based monitoring is

becoming an essential part of modern mining, helping to improve dumper performance and ensure reliable and cost-effective operations.

2.0 KEY CHALLENGES IN TRADITIONAL MONITORING

Mining operations involve continuous hauling cycles where dumpers operate in extreme conditions. Issues such as overheating, brake failure, improper loading, tire blowouts, and excessive vibration can lead to severe failures, accidents, and financial losses. The key challenges in traditional monitoring are as follows:

- 1) Lack of continuous performance data
- 2) Delay in identifying component degradation
- 3) High breakdown maintenance ratio
- 4) Inefficient fuel usage
- 5) Operator-dependent variation in performance

3.0 WHY WE NEED AUTOMATED MONITORING?

Automated monitoring in mining involves the use of advanced technologies to track the performance of machinery and equipment [7].

Enhanced Safety: Mining operations are inherently hazardous. Automated monitoring systems can identify potential failures before they lead to accidents, thereby improving workplace safety.

Increased Efficiency: By continuously monitoring equipment, operators can optimize performance, reduce energy consumption, and increase overall productivity.

Cost Reduction: Identifying and addressing issues early through automated monitoring can prevent costly downtime and repairs, leading to substantial savings.

Compliance and Reporting: Automated systems facilitate compliance with regulatory requirements by providing accurate, real-time data for environmental and safety audits.

4.0 SENSOR DATA ANALYSIS FOR EQUIPMENT MONITORING

Modern dumpers are equipped with multiple sensors integrated through vehicle electronic control units (ECUs) and Control Area Network (CAN) bus systems. These sensors continuously monitor critical parameters such as engine performance, payload, braking behaviour, tyre pressure, speed, and vibration. The sensor data is recorded at high sampling rates to capture both steady-state and transient operating conditions during loading, hauling, dumping, and return cycles [8].

Collected sensor data is transmitted from the dumper to a central server or cloud platform using wireless communication technologies such as RF, Wi-Fi, or cellular networks [9][10]. The data is stored in structured databases, allowing long-term historical analysis. Time-stamped data storage enables correlation between different sensor parameters and operational events, forming the basis for advanced analytics and reliability assessment.

Raw sensor data often contains noise, missing values, and outliers due to harsh mining environments [11]. Therefore, data pre-processing is a crucial step. This includes filtering erroneous readings, synchronizing data streams from multiple sensors, normalization of engineering units, and segmentation of data into operational modes such as idling, loading, loaded haul, dumping, and empty return.

Analyzed sensor data is presented through dashboards using charts, trend plots, heat maps, and key performance indicators (KPIs). Real-time alerts are generated for critical conditions such as tyre pressure loss, brake overheating, engine faults, and overload events. These visualization tools assist maintenance engineers, safety officers, and mine management in fast and informed decision-making.

The below fig-1 shows the block diagram regarding process flow from data collection through sensor to output display.

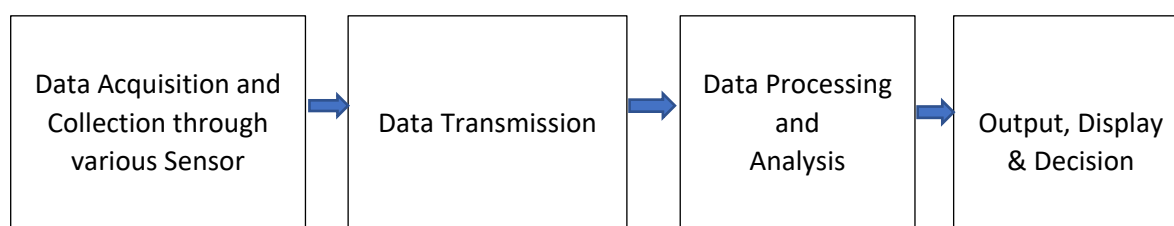


Fig-1: Block diagram of sensor data processing

5.0 CASE STUDY

For case study one large mechanised Iron Ore Opencast Mine of Odisha is selected. In this mine the shovel-dumper combination has been used for the iron ore excavation and hauling. PC1250 excavator and HD785-7 of 100Ton capacity dumper of Komatsu make are being used for the purpose. A total of 15 numbers of dumper are engaged for handling the targeted material quantity. Fig-2 is showing a 100T capacity dumper of make Komatsu and model HD785-7.



Fig-2: HD785-7 Dumper of 100T Capacity

A various numbers of sensors are used in the dumper at different sections. Table-1 shows some sensors which are used at different section for different functions.

Table-1: Shows various sensors used for different functions.

Sl. No.	Description	Function
1	Engine oil pressure sensor	Engine
2	Engine oil temperature sensor	
3	Engine oil level sensor	
4	Blow by sensor	
5	Air intake temperature sensor	
6	Boost pressure sensor	
7	Coolant temperature sensor	
8	Coolant level sensor	
9	Exhaust temperature sensor	
10	Fuel pressure sensor	
11	Fuel level sensor	
12	NE sensor	
13	G sensor/ engine speed sensor	
14	Pressure Control valve PCV1 & PCV2	
15	Air filter clogging sensor	
16	Boost temperature sensor	
17	TM/TC oil temperature sensor	Transmission
18	TM oil level sensor	
19	TM Input speed sensor	

20	TM intermediate sensor	
21	TM output sensor	
22	TM oil pressure sensor	
23	TC In oil pressure sensor	
24	TC out oil pressure sensor	
25	3 type ECMV	
26	TM filter clogging sensor	Hydraulic
27	EPC solenoid/ pressure sensor	
28	Dump body positioning sensor	
29	Emergency steering pressure switch	
30	Steering angle sensor	
31	Steering oil temperature sensor	
32	Pay load pressure sensor (PLM)	
33	Suspension oil pressure sensor	Brake
34	ASR pressure switch	
35	Wheel speed sensor	
36	Brake pressure sensor	
37	Accumulator pressure sensor for all brakes	
38	Retarder pressure sensor for front & rear wheel	
39	BCV oil pressure sensor	Body
40	Inclinometer sensor	
41	Ambient temperature sensor	

5.1 VHMS (Vehicle Health Monitoring System)

Vehicle Health Monitoring System (VHMS) is a system where equipment monitoring as well as operator performance assessment can be done simultaneously. For these activities the software analyses real time data coming from various sensors and provide valuable information to take appropriate decision.

Payload management system of VHMS software shows the total trips, total load (in ton), average load (in ton/trip) of individual dumper. Also, it shows how many percentages of trips take overload, under load and perfect load. Fig-2 is showing the pay load management system.

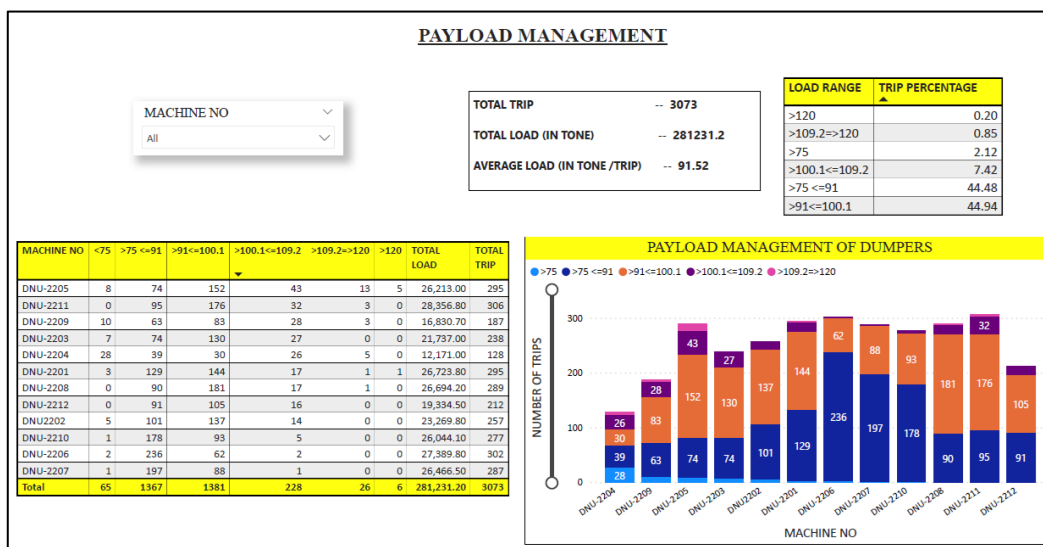


Fig-2: Payload Management System

Load parameter analysis of VHMS software shows the average trips per hour, average tonnes per hour, travel speed of the dumper. Fig-3 is showing the load parameter analysis.

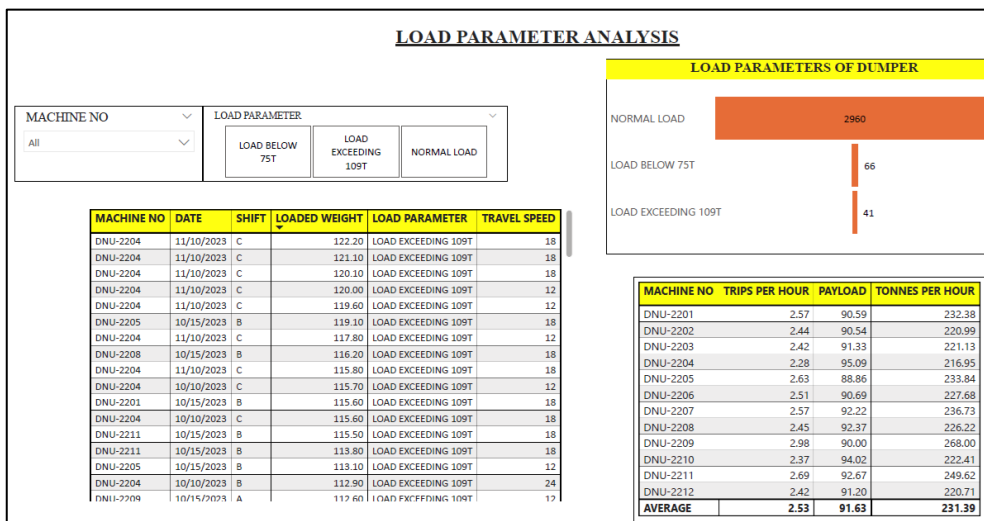


Fig-3: Load Parameter Analysis

Information related to operator, loading machine and trips are shown in the operator information which is given in the Fig-4.

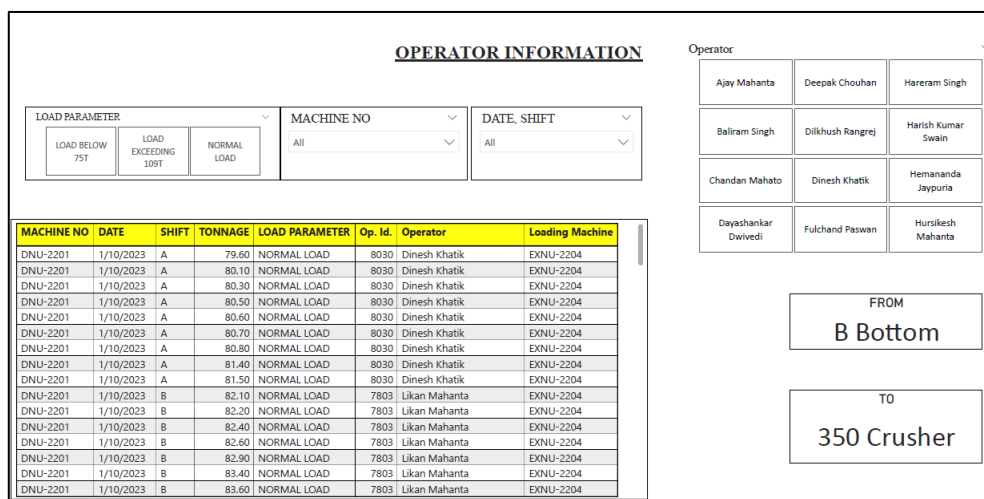


Fig-4: Operator Information

In the dumper production analysis page, the dumper cycle time including load time, loaded travel time, loaded stop time, empty travel time, empty stop time, stop time are shown. Fig-5 is showing the dumper production analysis.

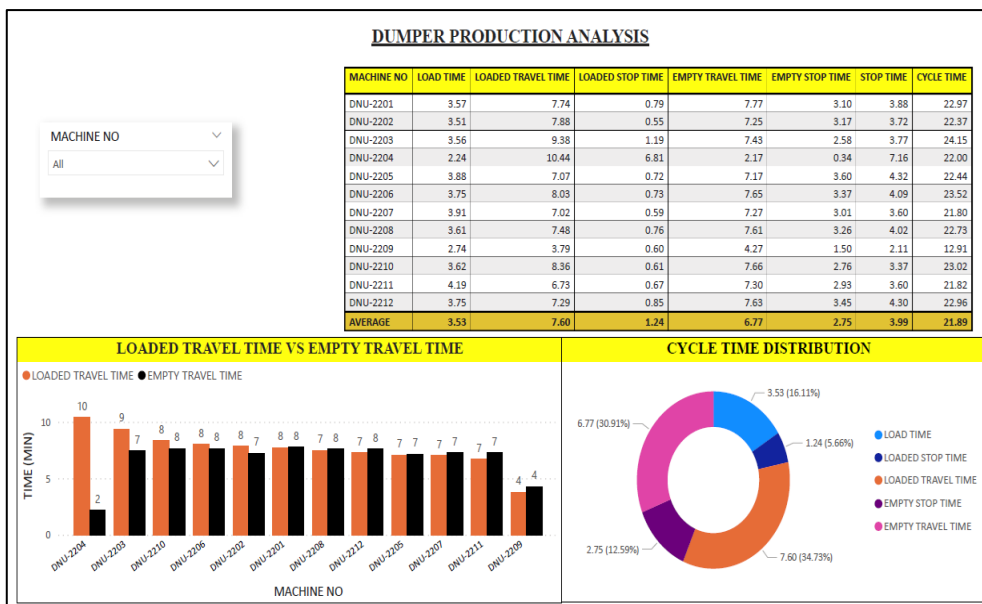


Fig-5: Dumper Production Analysis

In dumper motion analysis the loaded travel distance, loaded travel speed, empty travel distance, empty travel speed, lead distance, number of cycles are displayed. Fig-6 is showing the dumper motion analysis.

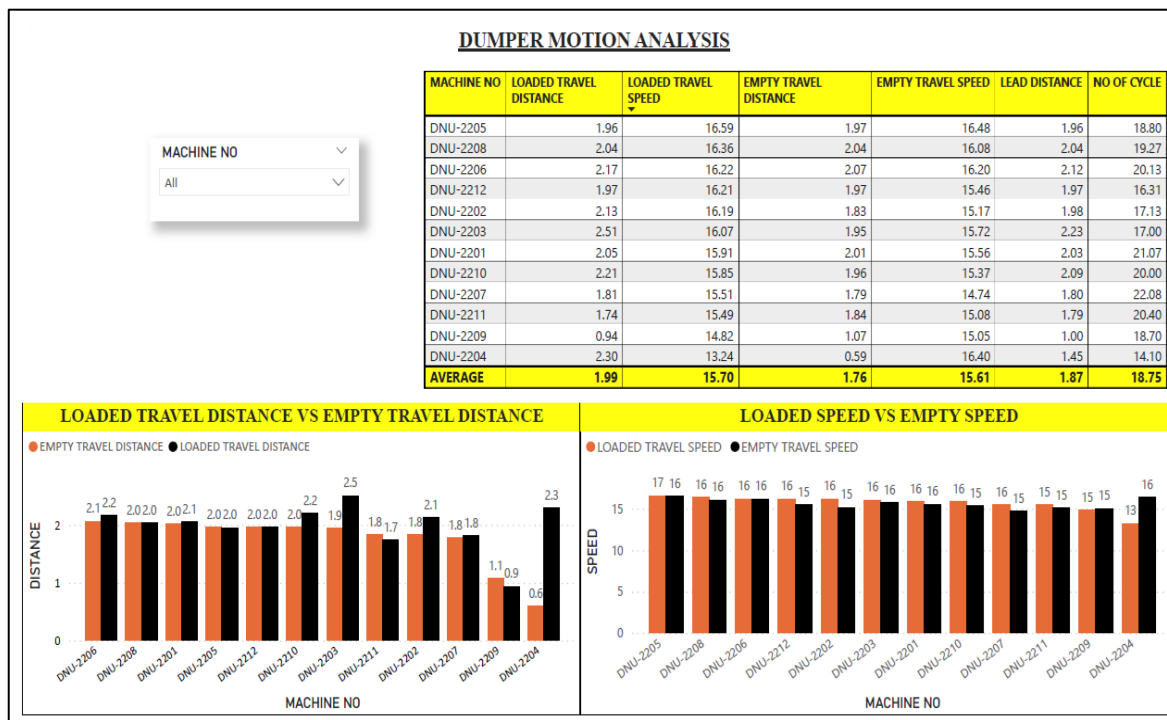


Fig-6: Dumper Motion Analysis

5.1.1 VHMS Analysis Report

The Vehicle Health Monitoring System (VHMS) is a sophisticated tool designed for real-time monitoring in open-pit mining, evaluating dumper performance, operator effectiveness, and overall productivity. It utilizes sensor-generated data to facilitate informed decision-making aimed at optimizing operations, enhancing safety, and planning maintenance. Examination of the payload management module reveals that achieving optimal loading is crucial, as overloading can lead to increased mechanical stress and a higher risk of failure, while underloading diminishes operational efficiency.

Analysis of load parameters underscores that productivity is influenced by the number of trips per hour, tonnes moved per hour, and travel speed, with any imbalance potentially indicating delays or unsafe conditions. Data on operator performance show that skilled operators maintain consistent cycle times and efficient operations, whereas poor performance results in more idle time and decreased productivity. Analysis of dumper production indicates that excessive stoppage and loading times are major inefficiency factors, often due to poor dispatch management or equipment mismatches.

Moreover, motion analysis reveals that lead distance, travel speed, and cycle frequency have a significant impact on fuel consumption, tire wear, and the overall lifespan of equipment. The comprehensive assessment suggests that productivity and safety are heavily reliant on optimizing payloads, cycle efficiency, and operator conduct, while maintenance needs can be predicted through stress-related parameters.

In summary, VHMS acts as an effective data-driven system for boosting productivity, safety, and reliability in mining operations. Its integration with advanced analytical tools can further enable predictive maintenance and aid the shift towards intelligent and sustainable mining practices.

5.2 TPMS (Tyre Pressure Management System)

Tyre Pressure Management System (TPMS) is a safety and reliability system that continuously monitors tyre pressure and alerts the operator when values go outside safe limits. TPMS is especially critical for tyre mounted heavy equipment like dumper, where tyre failures can cause serious accidents and costly downtime.

Tyre Pressure Management System (TPMS) plays a vital role in improving the safety, reliability, and efficiency of mining dumpers. By continuously monitoring tyre pressure, TPMS helps prevent tyre bursts and rim damage by ensuring that tyres always operate within the recommended pressure limits. Early warning alerts enable timely corrective action, thereby significantly reducing unplanned breakdowns and associated downtime. Maintaining correct tyre pressure ensures optimal rolling resistance, which enhances fuel efficiency during hauling operations. Furthermore, the use of TPMS improves overall tyre life, as uniform tyre wear is achieved when tyres are maintained at perfect pressure, leading to reduced replacement costs and improved equipment availability.

5.2.1 TPMS Mechanism

In the TPMS, a sensor is fitted in the tyre valve stem as shown in the fig-7, the data transmitted to the device fitted in the operator cabin which displays the real time data as shown in the fig-8. As per Original Equipment Manufacture (OEM) guideline, the tyre pressure varies between 100-110 pound per square inch (PSI). Alert system is triggered when the pressure is low or high.



Fig-7: Sensor fitted in the Tyre Valve



Fig-8: Display Unit at Operator Cabin

5.2.2 TPMS Analysis Report

The Tyre Pressure Management System (TPMS) is a vital safety and reliability tool for mining dumpers, enabling continuous real-time monitoring of tyre pressure. Maintaining tyre pressure within the OEM-recommended range (100–110 psi) is essential for safe and efficient operations. Deviations from this range can lead to significant issues, where under-inflation increases rolling resistance, fuel consumption, and tyre wear, while over-inflation reduces traction and increases the risk of tyre failure.

TPMS utilizes sensors mounted on tyre valves to transmit real-time data to a cabin display unit, providing early warning alerts for abnormal conditions. This facilitates timely corrective action, thereby reducing the likelihood of tyre bursts, rim damage, and unplanned downtime.

Overall, TPMS enhances safety, improves fuel efficiency, ensures uniform tyre wear, and extends tyre life. Its adoption supports predictive maintenance and contributes to improved equipment availability and cost-effective mining operations.

5.3 FMS (Fuel Management System)

Fuel Management system is a mechanism to prioritize fleet for refuelling through communication with the equipment. For this activity the following parts are used.

1. RFID
2. RFID Sensor for authorized fuel dispensing
3. Fuel level sensor in tank for fuel level
4. Fuel Sensor for real time fuel level monitoring to control pilferage
4. GPS for equipment live location
5. Display monitor to see the prioritization as per criticality

Fuel Management System helps in Optimizing operational cost and improve fleet efficiency, generate real-time data for decision-making, ensure accurate measurement of fuel dispensing and consumption, prevent theft, pilferage, and unauthorized usage.

5.3.1 Features of FMS

1. Real-time Monitoring: Continuously displays fuel levels and consumption patterns to prevent unexpected shortages. Fig-9 shows the display system at operator cabin which provide balance fuel in the diesel bowser, equipment diesel status, consumption rate in LPH, equipment position with distance and direction from the diesel bowser and quantity of diesel requirement to full the tank. According to the diesel availability and airlock position, the equipment status is categorized in to overdue, critical, low and good. Using this display, the diesel bowser operator can make decisions to prioritize equipment for diesel filling.

Vehicle	Last fill	Fuel Bal	LPH	Hrs to Airlock	Status	Landmark	Dist	Dir	Updated	Bowser	Fill Fuel(L)
DGJ-03		15 L (23%)	2.7L/h	-0.4	0-Overdue	Mines office	6682m	W	May 30 20:02		45
DJ-2202	11.6 Hrs	395 L (30%)	33.4L/h	2.0	1-Critical	B Block Zone I	1015m	SW	May 30 20:14		870
MLJ-01		84 L (39%)	9.1L/h	3.4	2-Low				May 30 18:32		125
DJ-2213	28.1 Hrs	458 L (35%)	33.1L/h	3.9	2-Low	Workshop	1606m	S	May 30 20:02		810
LJ-OK-511		17 L (36%)	0.9L/h	5.7	2-Low	Back Fill Area - C1	3005m	S	May 30 20:08	DBJ-2202	30
DJ-2208	12.7 Hrs	524 L (40%)	30.3L/h	6.5	2-Low	B Block Zone I	886m	SW	May 30 20:13		745
SVJ-01		284 L (67%)	25.5L/h	7.0	2-Low	Washing Point	1606m	S	May 30 20:00		135
EXJ-2206	0.8 Hrs	814 L (59%)	65.4L/h	7.2	2-Low	Hat/pit Area	2436m	S	May 30 19:55		535
EXJ-2201	9.2 Hrs	796 L (58%)	60.6L/h	7.4	2-Low	Hat/pit Area	2245m	S	May 30 20:09		555
DJ-2223	24.5 Hrs	572 L (44%)	32L/h	7.6	2-Low	C Block Working Pit	2513m	S	May 30 20:09	DBJ-2202	700
EXJ-2204	8.6 Hrs	827 L (60%)	62.2L/h	7.8	2-Low	B Block Zone I	866m	SW	May 30 20:07		525
DJ-2214	12.2 Hrs	586 L (45%)	30.4L/h	8.5	3-Good	B Block Zone I	1198m	SW	May 30 20:13	DBJ-2201	690
DJ-2221	12.4 Hrs	607 L (46%)	32.1L/h	8.7	3-Good	B Block Zone I	1034m	SW	May 30 20:13	DBJ-2201	670
EXJ-2202	5.7 Hrs	951 L (69%)	59.8L/h	10.1	3-Good	Stack Yard	2043m	SW	May 30 19:55		405

Fig-9: Display at Operator cabin

2. Theft and Pilferage detection: Instant alerts through email and messages for sudden fuel drop, unauthorized refilling, tampering with sensor.
3. Automated fuel dispensing: Fuel pump is interlocked with RFID to prevent unauthorized fuelling. Fig-9 is showing the RFID reader during fuel dispensing.

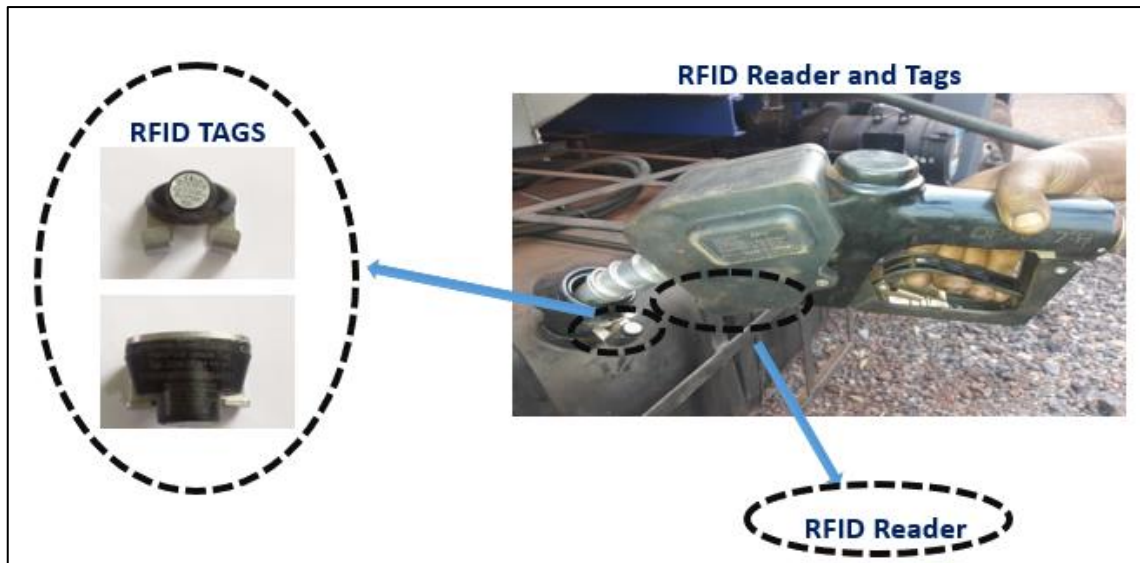


Fig-9: RFID reader during fuel dispensing

4. Idle time analysis: Analyse the equipment idle time. By this analysis the equipment idle time due to various reason can be reduced, and at the same time, equipment utilization can be increased. Fig-10 shows the equipment running time and idle time where the green dot shows the running time, red dot shows the equipment stop time and the blue dot shows the equipment start time. The time gap between the red dot and blue dot is the equipment idle time. Fig-11 shows the round the clock time analysis of the equipment.



Fig-10: Equipment running time & idle time

Date	Fleet	Vehicle	Time span	Time (Hrs)					Fuel Data (L)			Distance (KM)		Percentage	
				Ign On	Idle On	Parked	Engine On	Moving	Total Fuel	Fuel (Idle)	Fuel (Moving)	Distance	KM/100L	Utilisation %	Idle On %
2026-01-01	Dumper	DNP-2201	24.00	5.38	3.07	18.62	5.38	2.31	201.92	61.92	140.00	30.53	15.12	22.43%	57.02%
2026-01-02	Dumper	DNP-2201	24.00	9.43	4.22	14.57	9.43	5.21	472.71	100.43	372.28	76.37	16.16	39.31%	44.73%
2026-01-03	Dumper	DNP-2201	24.00	6.92	3.28	17.09	6.92	3.64	364.75	84.34	280.41	52.19	14.31	28.81%	47.43%
2026-01-04	Dumper	DNP-2201	24.00	10.07	4.10	13.93	10.07	5.97	458.32	85.41	372.91	83.11	18.13	41.95%	40.73%
2026-01-05	Dumper	DNP-2201	24.00	12.49	6.08	11.51	12.49	6.41	555.15	133.42	421.73	92.62	16.68	52.02%	48.69%
2026-01-06	Dumper	DNP-2201	24.00	12.53	5.95	11.47	12.53	6.58	535.85	124.05	411.80	87.19	16.27	52.22%	47.47%
2026-01-07	Dumper	DNP-2201	24.00	7.68	3.77	16.32	7.68	3.91	312.52	75.95	236.57	51.24	16.39	32.02%	49.06%
2026-01-08	Dumper	DNP-2201	24.00	12.85	5.28	11.15	12.85	7.57	589.39	111.18	478.21	111.60	18.93	53.54%	41.09%
2026-01-09	Dumper	DNP-2201	24.00	9.12	3.67	14.88	9.12	5.45	432.69	79.36	353.34	81.57	18.85	37.99%	40.25%
2026-01-10	Dumper	DNP-2201	24.00	6.18	3.22	17.82	6.18	2.96	243.13	64.65	178.48	38.96	16.02	25.76%	52.08%
2026-01-11	Dumper	DNP-2201	23.98	6.18	2.75	17.80	6.18	3.43	324.74	68.42	256.32	49.09	15.12	25.78%	44.47%
2026-01-12	Dumper	DNP-2201	24.00	6.75	3.77	17.25	6.75	2.98	254.29	75.41	178.88	42.59	16.75	28.13%	53.84%
2026-01-13	Dumper	DNP-2201	24.00	8.15	4.02	15.85	8.15	4.13	319.89	78.36	241.53	50.91	15.91	33.96%	49.33%
2026-01-14	Dumper	DNP-2201	24.00	1.23	0.67	22.77	1.23	0.56	43.08	12.24	30.84	6.96	16.16	5.14%	54.34%
2026-01-15	Dumper	DNP-2201	24.00	4.78	1.78	19.22	4.78	3.00	212.94	35.13	177.81	41.22	19.36	19.93%	37.22%
2026-01-16	Dumper	DNP-2201	24.00	0.05	0.05	23.95	0.05	0.00	12.15	12.15	0.00	0.13	1.11	0.21%	100.00%

Fig-11: Round the clock time analysis of equipment

5. Fuel Economy Tracking: Generates detailed reports on fuel consumed per hour, trend of increasing or decreasing efficiency. Fig-12 is showing the fuel tracking system for the equipment and auto alert and fuel dispensing system. In this system one device display in the cabin, the criticality of equipment according to the fuel level. The fuel level less than 25% of the tank capacity treat as critical position and it displays in the top of the row with red mark. The priority list prepares accordingly.

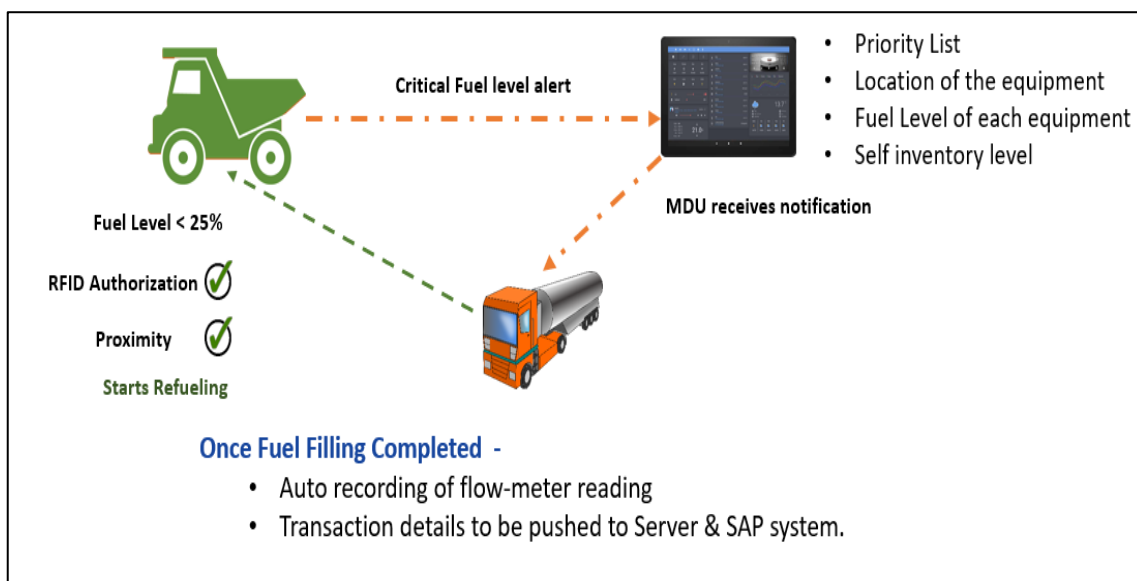


Fig-12: System for fuel tracking and automated fuel dispensing system

6. GPS Tracking of Equipment: The equipment location can be tracked through the GPS. By this the supervision can be possible from the control room. It reduces man machine interaction. Fig-13 shows the GPS location of equipment.



Fig-13: GPS Location of the equipment

5.3.2 FMS Analysis Report

The Tyre Pressure Management System (TPMS) plays a crucial role in ensuring the safety and dependability of mining dumpers by allowing for continuous real-time monitoring of tyre pressure under various operational conditions. Tyre malfunctions in heavy earth-moving equipment are a leading cause of accidents and unexpected downtime, making pressure regulation a vital operational factor. Analysis shows that keeping tyre pressure within the OEM-recommended range of 100–110 psi is essential for maintaining optimal performance and safety.

Straying from the suggested pressure range greatly affects operational efficiency. Under-inflated tyres increase rolling resistance, which leads to higher fuel consumption, excessive heat, and faster tyre wear. Conversely, over-inflated tyres reduce ground contact, causing uneven wear, diminished traction, and a higher risk of tyre bursts. The TPMS functions through sensors attached to tyre valve stems, which send real-time data to an in-cabin display system, issuing alerts when conditions are abnormal.

This system enables early fault detection and timely corrective measures, thereby minimizing breakdowns, extending tyre lifespan, and enhancing equipment availability. In summary, TPMS aids in predictive maintenance and contributes to safe, reliable, and cost-effective mining operations.

6.0 CONCLUSION

Automated monitoring of dumper performance through sensor technology represents a transformative step toward safer, more productive, and more cost-effective mining operations. The case study undertaken in a mechanized iron ore mine in Odisha clearly demonstrates how real-time data collection and analytics can significantly enhance equipment utilization, reduce operational

uncertainties, and strengthen preventive maintenance strategies. Systems such as VHMS, TPMS, and FMS collectively contribute to improved visibility of operational conditions, early identification of mechanical anomalies, and optimized fleet coordination.

The integration of payload tracking, cycle-time analysis, tyre-pressure surveillance, and fuel management enables mining organizations to transition from reactive to predictive decision-making. This reduces unplanned breakdowns, prevents catastrophic equipment failures, minimizes resource wastage, and enhances safety compliance across the mine site. Furthermore, the adoption of data-driven diagnostics empowers mine managers and operators with actionable insights, supporting consistent operational discipline and higher levels of fleet availability.

Overall, the findings reinforce that sensor-enabled automated monitoring is no longer optional but essential for modern mining systems striving to remain competitive and sustainable. As the mining sector continues to expand its digital footprint, the adoption of integrated, multi-sensor performance monitoring platforms will play a vital role in enabling reliability-centered maintenance, maximizing asset productivity, and ensuring safe, efficient material haulage in demanding mining environments.

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