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SMART AUTOMATION FOR ENHANCED LIGHTING THROUGH REMOTE CONTROL SYSTEMS IN COAL MINING AREAS

Rizqi Pratama[1], Muhammad Fachri Maulana[2], Aan Ardyantoro[3]
PT. Putra Perkasa Abadi, Indonesia

rizqiprtmaa@gmail.com, fachrimaulana91@gmail.com, aan.ardyantoro@amm.id

ABSTRACT
The coal mining industry faces significant safety challenges due to hazardous working environments and manual monitoring processes, particularly involving Tower Lamp units. These activities expose employees to risks, including harsh weather and operational incidents, leading to potential accidents and financial losses. This study proposes an intelligent safety control system employing real-time remote monitoring technology to mitigate these risks. The system enables centralized control of Tower Lamps, reducing manual interactions, improving energy efficiency through automated lighting adjustments, and enhancing workplace safety. The methodology includes designing and implementing a monitoring system with remote control capabilities supported by real-time data analysis. Expected outcomes include reduced work accidents, optimized lighting management, and streamlined operations, showcasing a scalable model for broader industrial applications. This technological innovation demonstrates a practical solution for improving safety and operational efficiency in coal mining environments.

Keywords: coal mining industry, employee safety, remote control, smart technology, tower lamp

Corresponding Author: Rizqi Pratama
E-mail: rizqiprtmaa@gmail.com

INTRODUCTION

The coal mining industry has a high level of accident risk, especially related to the use of heavy equipment and uncertain environmental conditions (ALTINDIS & BAYRAM, 2024; F. Li et al., 2024; Y. Li et al., 2025; Xuecai et al., 2024). One of the high-risk activities is the manual monitoring process of Tower Lamp (TL) units at the mine site. This manual monitoring requires direct interaction from the workforce, especially in bad weather conditions such as rain and slippery roads. These interactions increase the risk of incidents and work accidents, which can lead to minor injuries and potential death, as well as cause losses to the company in the form of lost labor and additional costs (Miao et al., 2023; Qiu et al., 2021; Shi et al., 2024; Tian et al., 2024; Yuxin et al., 2024).

PT. Putra Perkasa Abadi uses heavy equipment with high needs when carrying out mining operational activities. A good mechanical tool maintenance management process is one of the main demands for maintaining productivity. Employee safety is an important factor in operational activities because if safety is neglected, the possibility of accidents is very high. The coal mining industry has a close relationship with the activities of its workers. However, there is a problem that is always inherent with mining work, namely that each type of work has potential hazards and risks that can occur, such as losses for workers (minor injuries to death) and companies (labor losses, costs, working hours, and others) (Isnianto & Puspitaningrum, 2018; Kusuma & Oktiawati, 2022; Sukadana et al., 2021).

Employees are in direct contact with the equipment when performing mechanical tool maintenance. This increases the potential for accidents because many hard objects can contact the body. In the event of an accident to an employee, potential death can occur. Therefore, a good system is needed to minimize the potential for accidents. In addition to direct contact with the appliance, exposure to hazardous areas is a factor that can cause accidents (Liu et al., 2022; López et al., 2023; Zhao et al., 2024).

By presenting intelligent technology that functions as remote monitoring, the frequency of labor interaction with hazard exposure can be reduced. This reduces the value of hazards and risks that will occur. Manual monitoring of Tower Lamp is an activity that requires high interaction from the mining workforce. The unpredictable environmental conditions around TL units can increase workers' risk of incidents and near-misses.

Therefore, this project must be carried out in line with PPA's commitment to PT Putra Perkasa Abadi's Integrated Management System Policy, which focuses on accelerating the data and information digitization process. This project aims to reduce the frequency of labor interactions with hazard exposure. With the existence of a real-time remote monitoring system, it is hoped that exposure to hazards and accident risks in the monitoring activities of TL units can be reduced.

The project aims to develop an intelligent technology-based safety control system that reduces manual labor interaction with Tower Lamp in coal mining areas. This system allows remote control to improve energy efficiency and reduce the risk of work accidents, especially in adverse weather conditions. Operationally, the system is designed to improve the effectiveness of Tower Lamp's data management through automated data collection, more accurate analysis, and centralized monitoring. The system also addresses refueling delays due to shifting Tower Lamp locations with more precise refueling scheduling, reduced downtime, and improved fuel efficiency. From the safety aspect, the system is expected to reduce the physical interaction of workers with the Tower Lamp during maintenance, enable early detection of problems, and improve overall work safety.

Several recent studies have highlighted the significant safety risks of manual monitoring in the coal mining industry. For instance, research by Ari Wibowo (2016) demonstrated that manual interactions with equipment increase the likelihood of accidents, particularly in adverse weather conditions. Chamdareno et al. (2017) found that implementing remote monitoring technologies can significantly reduce workplace incidents. These findings underscore the urgent need for a smart safety control system that minimizes manual labor interaction with Tower Lamps, enhances energy efficiency, and reduces accident risks. This project aims to address these critical safety concerns and improve operational efficiency in coal mining areas by leveraging intelligent technology.

The formulation of the problem that became the focus was how to develop a safety control system based on intelligent technology to reduce manual interaction of workers, improve energy efficiency, and reduce the risk of accidents in mining. The project hypothesis estimates that the implementation of intelligent control systems is able to significantly reduce the risk of work accidents and improve energy efficiency through timely and on-demand lighting control. This result is expected to create a safer and more productive working environment in the coal mining industry.

METHOD

This qualitative research investigates the implementation of a smart safety control system for Tower Lamps in coal mining areas, focusing on its potential to enhance safety and operational efficiency. The study seeks to understand how this technology reduces manual intervention and its associated risks. The research examines employees at PT Putra Perkasa Abadi who are directly involved in Tower Lamp operations, with purposive sampling employed to select participants most affected by the system. This targeted approach ensures that data reflects the operational realities of those using the smart system (Afin & Kiono, 2021).

Data collection includes structured interviews, direct observations, and analysis of documentation. Employees provide qualitative insights into their experiences through interviews, while observational data captures the real-time functionality of the smart monitoring system. System logs and reports serve as supplementary data sources, enabling triangulation. The study's research procedure starts with a baseline assessment of manual operations, followed by implementing the smart monitoring system. Post-implementation observations and interviews evaluate its effects on operations (Sukadana et al., 2021).

Data analysis involves thematic evaluation of qualitative inputs from interviews and observations, complemented by descriptive analysis of system-generated data. This mixed-method approach ensures a comprehensive understanding of the system's impact on safety and operational efficiency. The findings from the thematic analysis are corroborated with real-time data from system logs to draw robust conclusions about the benefits of the smart monitoring system. This approach integrates qualitative and quantitative insights, providing a nuanced understanding of the technology's implementation and effects.

RESULTS AND DISCUSSION

Implementation of Improvement Ideas

Submission of Permit for the Implementation of Smart Monitoring Installation and Use on Tower Lamp Units

The application for a permit for the implementation and use of Smart Monitoring installed on the Tower Lamp unit has been submitted to the Owner, PT Adaro Indonesia, as well as related departments, namely Production, SHE, Engineering, and Plant.

Implementation of Smart Monitoring Installation in A2B Units and Support Units

The installation will be done for 14 days, from July 14, 2024, to July 31, 2024. Installation is done on Atlas Copco Tower Lamp units B6 +G and V5+ series. At this stage of Smart Monitoring installation, it begins with P5M from the ICT Team. Furthermore, coordinate with the Base Control Team regarding the movement of Tower Lamps in the field to the workshop. If the Tower Lamp is already at the Workshop location, the ICT Team can go to the Workshop location where the unit is located to carry out the installation process. Coordination related to permits to plant supervisors is carried out to convey the estimated work of the Smart Monitoring installation on the unit because the unit will be placed back to its original position. The installation position of Smart Monitoring on the Tower Lamp unit is as follows:

a. Unit Tower Lamp seri B6+G

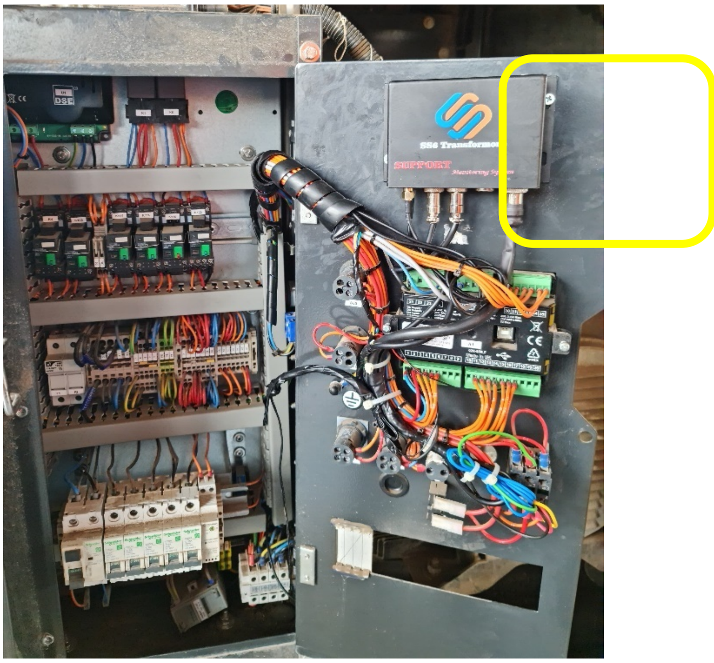


Figure 1.
Smart Monitoring Installation on Tower Lamp Atlas Copco B6+G series

The above explains the installation of Smart Monitoring placed on the box panel at the top of the controller, which is connected to several sensors needed to transmit data from the Tower Lamp sensor.

b. Unit Tower Lamp seri V5+

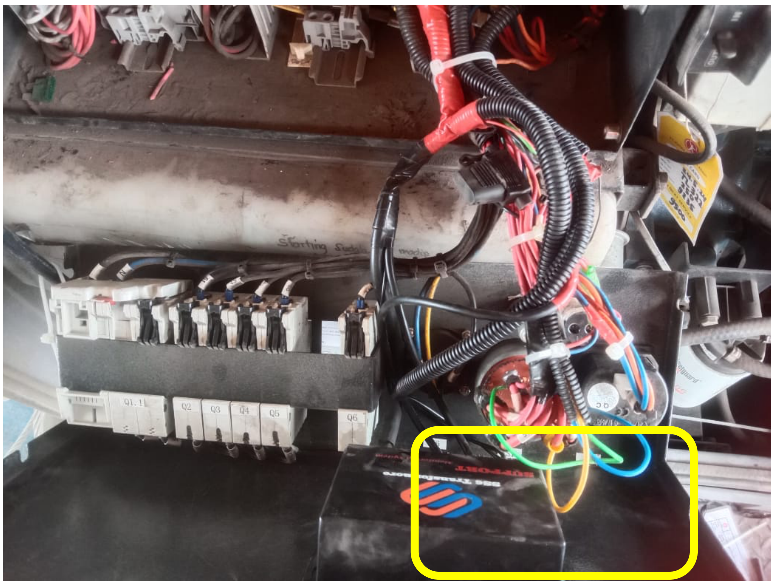


Figure 2.
Smart Monitoring Installation on Tower Lamp Atlas Copco V5+ series

The implementation of the Smart Monitoring installation on the Tower Lamp unit, which was carried out from July 14, 2024, to July 31, 2024, can be carried out optimally without any problems. The process of sending monitoring data through Smart Monitoring is carried out with LTE network media, and for the location of the Tower Lamp, GPS installed outside the cabin is used.

Figure 3.
Placement of GPS antenna and LTE antenna on Tower Lamp

Figure 4.
GPS Antenna and LTE Antenna

After the installation is completed on all Tower Lamp units, Smart Monitoring is continued to monitor Tower Lamps in real time.

Implementation of the Use of Smart Monitoring for Monitoring Tower Lamp

The implementation of Smart Monitoring for Tower Lamp monitoring is carried out to make it easier for employees to find and collect data on Tower Lamp so that time and work can be done optimally.

Figure 5.
Employees carry out the monitoring process of the Tower Lamp unit.

At this stage, the fuel man and the supervisor can find out the location of the Tower Lamp by opening the monitoring dashboard so that it does not take much time to refuel. Admins and supervisors can also report and monitor digitally. Digital monitoring can be seen in the figure as dashboard monitoring and monitoring HM unit data through the OFA (OnBoard FleetSafe Assist) application.

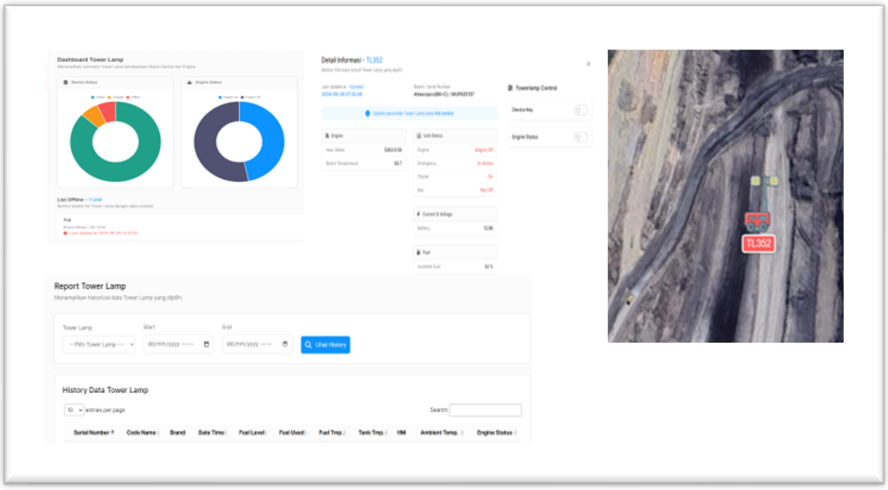


Figure 6.
Dashboard monitoring Tower Lamp

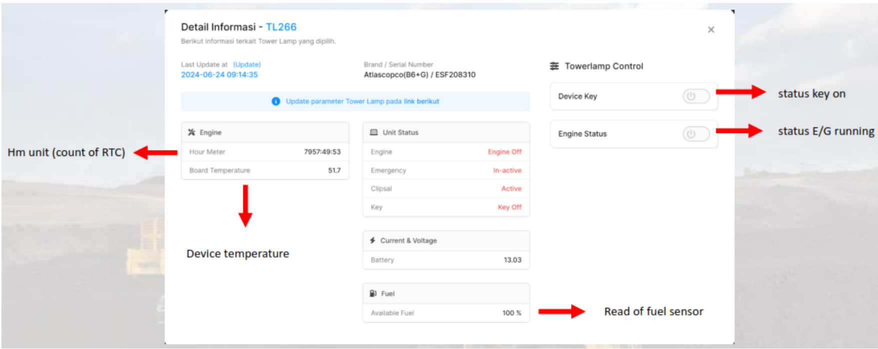


Figure 7.
Monitoring related to the Breakdown of the Tower Lamp unit

The breakdown data conditions of the units, as shown in the figure, can be displayed on the dashboard of each Tower Lamp.

Results of Improvement Ideas

In the previous explanation, the stages in implementing the change idea have been explained, so the results of the improvement idea, which will be explained later in this sub-chapter, are related to changes in Tower Lamp data monitoring activities. The following are the conditions before the change related to the process flow of monitoring data monitoring activities and filling Tower Lamp fuel:

a. The condition of the unit's cabin before the installation of Smart Monitoring

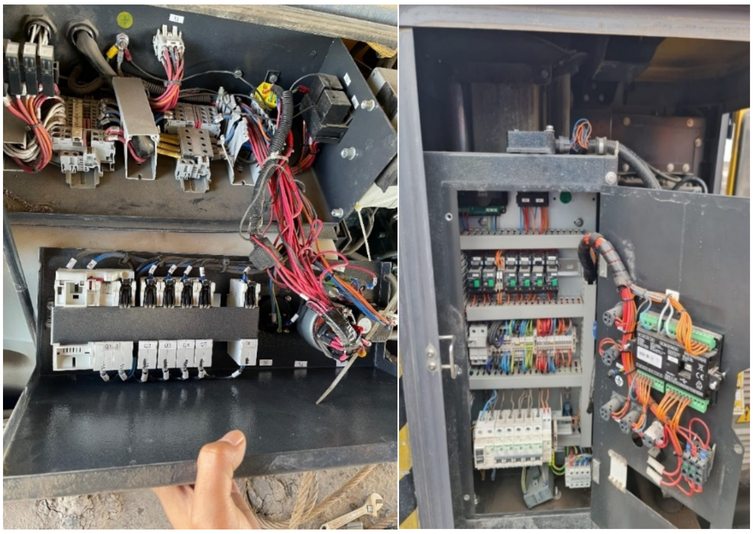


Figure 8.
Unit Cabin Condition Before Smart Monitoring Installation

The figure explains the layout of the conditions before the installation of Smart Monitoring on units where repair actions still need to be implemented.

b. The data input process and unit monitoring for the service schedule are done manually.

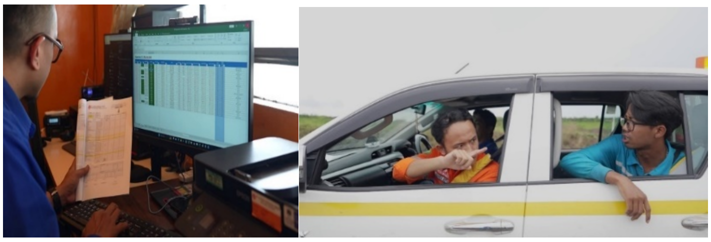


Figure 9.
The Process of Data Input and Monitoring of Service Schedule Units is Done Manually

The figure explains the admin's process of entering HM-related data from the Tower Lamp unit through two stages of the input process. The supervisor and mechanic will inspect the tower lamp unit and manually input the results of the unit inspection through the tower lamp inspection form using form paper. Then, the mechanic reported the inspection form file to the admin to continue the input process by the admin to SS6. The admin inputs data through the PPA Team application obtained from mechanics through forms, so the possibility of data input errors and forms being scattered or lost is very high. The process requires approximately one hour, determined by the number of units ranging from manual data input by mechanics to data input on the PPA Team application.

Fuel refueling activities are still constrained, and there is the potential for incidents.

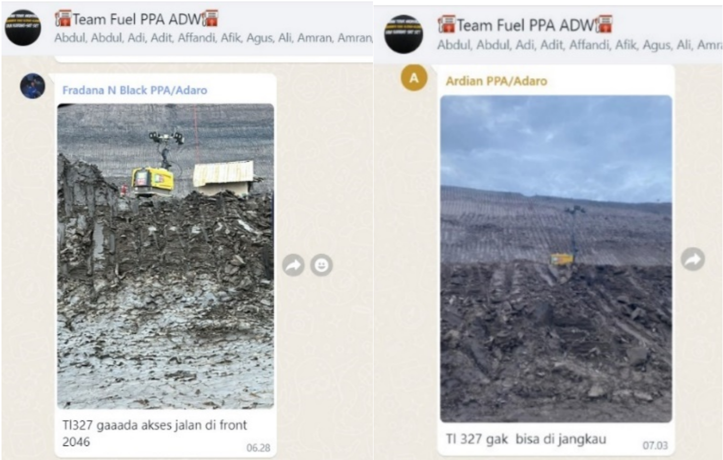
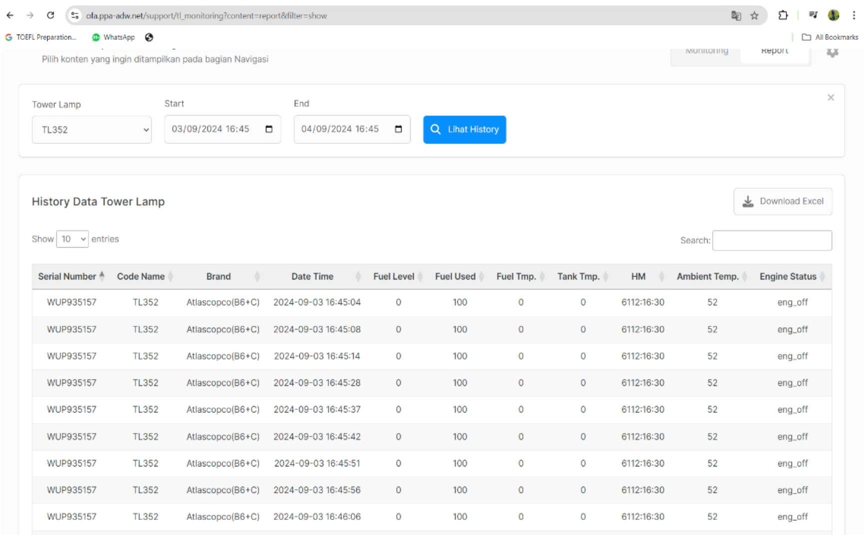


Figure 10.
Fuel Filling Obstacles

The picture above explains the obstacles to refueling activities because the location of the Tower Lamp cannot be reached, which causes unsafe conditions. This can result in high-frequency incidents between workers with many Tower Lamps. After the idea of improvement can be implemented, the provision of Smart Monitoring for monitoring on the Tower Lamp unit is carried out, the process related to the flow of the input process and monitoring activity data on the Tower Lamp that is currently running is as follows:

a. Reports and data monitoring are done through the OFA dashboard in real time.

Reporting and monitoring data related to Tower Lamp can be done through the OFA dashboard in real-time. Because of real-time data input by Smart Monitoring, errors in data input and during the data reporting process can be minimized.



Serial Number	Code Name	Brand	Date Time	Fuel Level	Fuel Used	Fuel Tmp.	Tank Tmp.	HM	Ambient Temp.	Engine Status
WUP935157	TL352	Atlascopco(B6+C)	2024-09-03 16:45:04	0	100	0	0	6112:16:30	52	eng_off
WUP935157	TL352	Atlascopco(B6+C)	2024-09-03 16:45:08	0	100	0	0	6112:16:30	52	eng_off
WUP935157	TL352	Atlascopco(B6+C)	2024-09-03 16:45:14	0	100	0	0	6112:16:30	52	eng_off
WUP935157	TL352	Atlascopco(B6+C)	2024-09-03 16:45:28	0	100	0	0	6112:16:30	52	eng_off
WUP935157	TL352	Atlascopco(B6+C)	2024-09-03 16:45:37	0	100	0	0	6112:16:30	52	eng_off
WUP935157	TL352	Atlascopco(B6+C)	2024-09-03 16:45:42	0	100	0	0	6112:16:30	52	eng_off
WUP935157	TL352	Atlascopco(B6+C)	2024-09-03 16:45:51	0	100	0	0	6112:16:30	52	eng_off
WUP935157	TL352	Atlascopco(B6+C)	2024-09-03 16:45:56	0	100	0	0	6112:16:30	52	eng_off
WUP935157	TL352	Atlascopco(B6+C)	2024-09-03 16:46:06	0	100	0	0	6112:16:30	52	eng_off

Figure 11.
Tower Lamp data report display on the OFA dashboard

Data reporting by admins related to HM and fuel levels in real-time through the OFA dashboard. The display of the Tower Lamp data report on the OFA dashboard, as shown in the image, can be accessed by the admin and monitored directly by the management team.

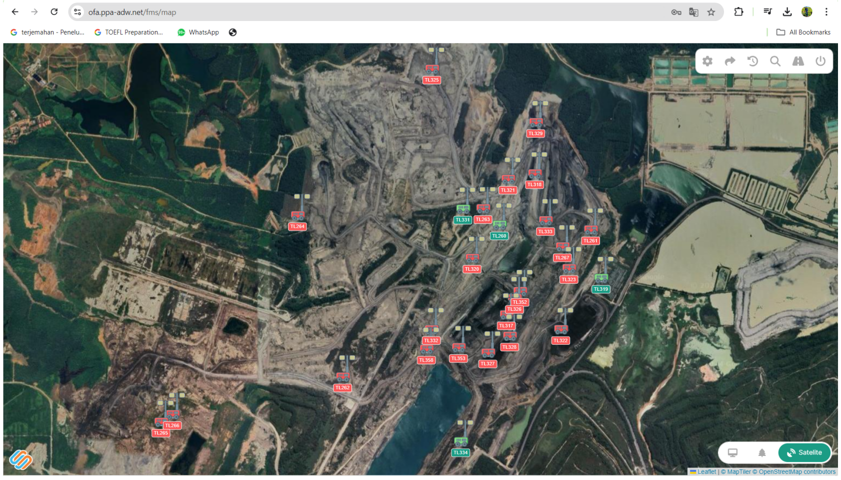


Figure 12.
Tower Lamp location map

The figure provides information related to the location of the Tower Lamp with color indicators, namely red for off condition, green for running condition, and yellow for key on condition. The Tower Lamp location map is beneficial in finding the location and determining the priority of the Tower Lamp that will be refueled. Another function of the Tower Lamp location map is that remote shutdown control can be carried out so that potential incidents can be prevented and employees can confirm and make repairs for access to the Tower Lamp.

b. Reduction in the frequency of potential incidents on employee interactions with Tower Lamp

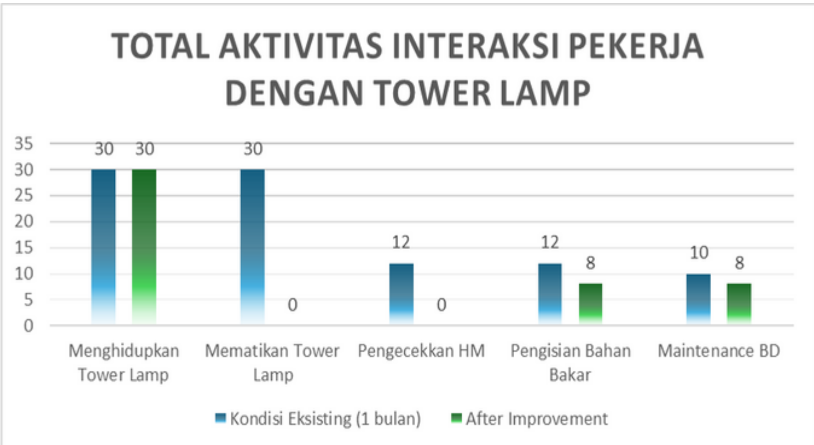


Figure 13.
Declining Worker Interaction Activity Graph

Worker interaction activities with Tower Lamp are often intense and have the potential to result in work accidents. With the Smart Monitoring technology, it can be seen in Figure 3.20 that there is a decrease in interaction between employees and Tower Lamp because it can be monitored in real-time through their respective devices, so potential hazards in the field can be prevented.

c. Tower Lamp monitoring and control via OFA dashboard

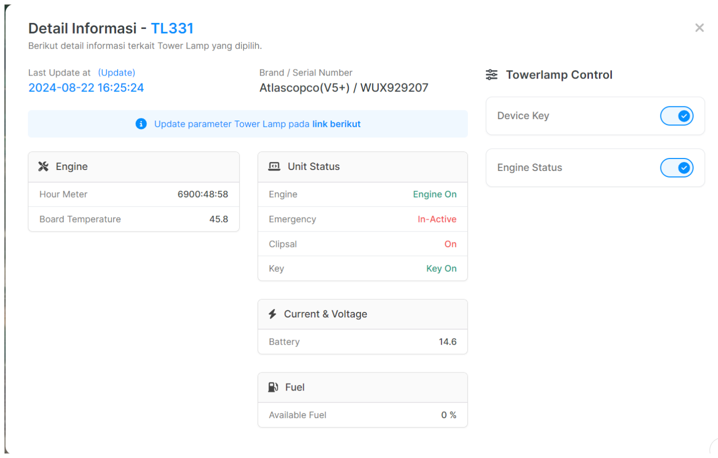


Figure 14.
Monitoring display and control of Tower Lamp via OFA dashboard

The figure explains the Tower Lamp monitoring display, which includes HM, fuel, battery capacity, engine condition, emergency, Clipsal, key, temperature, and remote shutdown control, which includes device key and engine status.

The supervisor can monitor the breakdown, HM unit, fuel, and location. The information received can be accessed in real time so that repair actions and calculations of HM units can be according to existing data.

1. Information Received by Plant Supervisors Quickly and Accurately

Plant supervisors can obtain accurate information related to the unit's condition in real-time, allowing the Supervisor to give instructions to the mechanics quickly and precisely. Because the instructions obtained from the supervisor are delivered more quickly, mechanics can quickly make repairs to the unit.

2. Report to the Head Office and the Person in Charge of Operations

Management can monitor operational data accurately and under the conditions in the field.

Standardization

Device component standards

The breakdown of the components of the Smart Monitoring device is outlined in the following table:

Table 1. SS6 Monitor Bracket Component Detail Table

Description	Picture	Sum	Specifications	Excess
GPS Antenna:		1	- Color: Black - Voltage: 3 V~5 V - Frequency: 1575.42 MHz - DC current (Max): 10 mA - Polarization: Circular (RH) - LNA Gain (without cable): 28 dB - Typ. Operating Temperature: -45 ~+85 °C	**Ease of Installation:** With the presence of magnets, these antennas can be easily mounted on metal surfaces without the need for additional tools. The magnetic design allows the

		- Storage Temperature: -50 ℃~+90 ℃ - Cable length: 3 m / 118 inch - Package Weight: 57 g	antenna to be easily removed and moved without damaging the surface of the mounting site. **Weather Resistant Design:** The magnetic GPS antenna design is resistant to various weather conditions and objects that can cause damage, such as water, dust, and so on.
LTE Antenna 	1	- Temperature Range : -55 s/d +155 ℃ (PE Cable -40~+85℃) - Vibration : 98 m/ (10~2000Hz)s^2 - Frequency Range : DC-12.4 GHz (semi-rigid cable DC-18 GHz) - Insertion Loss : 0.15 dB / 6 GHz - Withstanding Voltage 1000 V r.m.s at sea level - Working Voltage : 335 V r.m.s at sea level - Insulation Resistance : 5000 M - Durability: 500 (cycles) - Contact resistance: Center Contact 3 m, Outer Contact 2.5 m - Voltage Standing Wave Ratio: Straight flex cable 1.10+0.02f, Semi-rigid cable 1.07+0.018f Right angle, flex cable 1.20+0.03f, Semi-rigid cable 1.17+0.02f, RG174 Electrical Characteristics - Capacitance (Pf/M) : 101.05 - Impedance (Ohm) : 50 - Velocity(%): 66 - Shielding Effectiveness (>dB) : 10 - Max. Oper. Voltage (VMS) : 1500 - Max. Oper. Frequency (MHz) : 1000 - Operating Temp. (*C) : -20 to 80	▪ **Ease of Installation:** With the presence of magnets, these antennas can be easily mounted on metal surfaces without the need for additional tools. The magnetic design allows the antenna to be removed and moved easily, without damaging the surface on which it is mounted. ▪ **Weatherproof Design:** The magnetic GPS antenna design allows it to be resistant to various weather conditions and objects that can cause damage, such as water, dust, and so on.
SS6 module (product name still discussed) 	1	- Microprocessor Xtensa Dual-Core 32 Bit LX6 - Freq Clock up to 240 MHz - SRAM 520 kB - Flash memory 4 MB - 11b/g/n Wi-Fi transceiver - Bluetooth 4.2/BLE - 48 pin GPIO - 15 pin channel ADC (Analog to Digital Converter) - 25 pin PWM (Pulse Width Modulation - 2 pin channel DAC (Digital to Analog Converter)	▪ **Ease of Installation:** designed for ease of use, with a simple programming interface and an intuitive development environment (IDE). ▪ **Open Source:** Open-source, both hardware and software, allows for easy modification and customization.

		- LTE-TDD B34/B38/B39/B40/B41 - LTE-FDD B1/B3/B5/B8,GSM/GPRS/EDGE 900/1800 MHz - Operation temperature: -40 ℃ ~ +85 ℃ - USB to TTL uploader - Input power 12 V – 28 V VDC conversion to max 5 v DC - Include 4x Relay 12 V – 2 A - Data logger storage up to 16 GB - J9 Include RTC DS3231 SMD	▪ **Rapid Prototyping:** Plug-and-play features and a large number of ready-to-use libraries make it possible to quickly prototype and test ideas. ▪ **Good Interoperability / Compatibility:** Wide compatibility with a wide range of sensors and actuators and support for a wide range of communication protocols makes integration with other devices easy.
Input Cable 1 	2	- AWG 24 cable (6 cores) - Voltage Rating = Maximum 300 Volt - Temperature Rating = 80 °C - Outer sleeve diameter : 5.0 mm - Inner cable sleeve diameter : 1.3 mm - Cable copper diameter: 0.511 mm - Number of fibers : 11 fibers	▪ **International Standards:** Using standard cables that are widely known and used internationally facilitates communication and understanding of cable sizes. ▪ **Intuitive Numbering System:** AWG sizes provide an intuitive numbering system where smaller numbers indicate larger wire diameters, and vice versa. This makes it easy to select the right cable size for a particular application. ▪ **High-Quality Materials:** AWG cables are often made from high-quality materials, such as pure copper or aluminum, which provides durability and reliability in the long run. ▪ **Good Insulation Capacity:** AWG cables are equipped with good insulation, which protects the cables from physical damage

			and electrical interference, and improves safety and performance.
Input Cable 2 	1	- Cable NYYHY - double isolation - Size = 5 x 2.5 mm - Voltage Capacity: 300/500 V	▪ **High Flexibility:** Fiber copper conductors provide high flexibility, making it easy to install especially in areas with many bends or tight spaces. ▪ **Environmental Resistance:** PVC insulation provides resistance to moisture, weather, and certain chemicals, and has good flame retardant properties, reducing the risk of fire and improving the safety of use. ▪ **Multifunctional Use:** This cable can be used in a variety of applications, including permanent and temporary installations, both indoors and outdoors.

Standard Devices and Wearing Power Monitor SS6

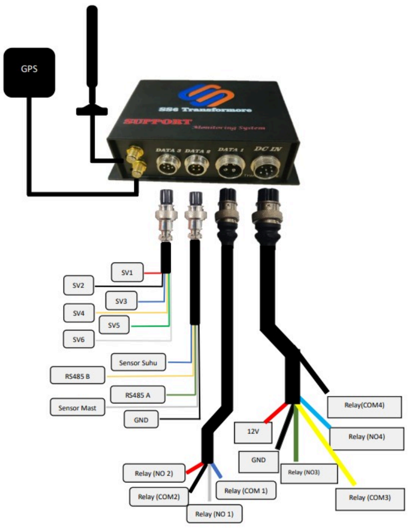


Figure 15.
Power Path Simulation Smart Monitoring Tower Lamp Module

This figure shows a connection diagram for a machine monitoring system using monitoring devices connected to various sensors and relays. The following diagram explains the components. Main Components:

1. Monitoring Devices (GG-Transformers)
   a) A central unit that collects data from various sensors and sends it to the monitoring system.
   b) There are several ports for sensor and relay connections.
2. GPS
   a) GPS antenna used for position tracking.
   b) Connect directly to monitoring devices.

Sensor and Relay Connectors :

1. Using Vention brand USB type C cables with lengths of 2 meters and 3 meters.
2. Black 4.5 mm Conduit Pipe for wrapping USB cables.

CONCLUSION

With the optimization of real-time monitoring of operational data at PT Putra Perkasa Abadi at the Adaro Indonesia job site through installing Smart Monitoring devices, it is hoped that operational activities will be more effective and efficient. This technology allows real-time monitoring of the Tower Lamp through the OFA dashboard, making it easy to access location data, fuel level, and engine status, thereby reducing time and the potential for manual data input errors. This implementation also improves efficiency and safety by speeding up the data collection process, reducing incidents during refueling, and lowering the intensity of workers' physical interaction with the Tower Lamp. In addition, checking the Tower Lamp becomes smoother and more efficient, minimizing wasted time and allowing for seamless unit transitions. Other advantages include real-time reporting capabilities, better monitoring, reduced operational time and costs, and improved data accuracy, making it easier for field supervisors and head office to provide quick improvement instructions. Switching from paper forms to digital devices supports data input efficiency and more sustainable work practices. In contrast, digital validation reduces HM validation time by operational supervisors, allowing units to operate earlier and improving overall time efficiency.

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