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Implementation of an Automatic Interlock System to Eliminate Workplace Accident Risks in the Dolly Painting 2 Corridor Area Using the Value Engineering Method

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Abstract— *Workplace safety is a crucial aspect in manufacturing operations to ensure the continuity of production processes. The Dolly Corridor area in Painting Department 2 has been identified as having a high risk of accidents (High Risk) due to a level crossing between towing vehicle tracks and pedestrian paths. The walled environment creates a blind spot, increasing the potential for fatal collisions. This study aims to design an automatic safety system to effectively and efficiently eliminate these risks. The root cause analysis was performed using the Fishbone Diagram to map the dominant factors contributing to potential accidents. Solution design applied Value Engineering to find the best alternative system that is functional yet cost-efficient. The developed solution is the Smart Magnetic Lock System, which integrates infrared sensors, magnetic locks, and warning indicator lights. This system works by detecting the presence of passing towing vehicles and automatically locking the pedestrian access door to prevent workers from entering dangerous paths. Implementation results showed significant effectiveness in safety and cost efficiency. The High-Risk category in the Dolly Corridor area was reduced by 100% (from high-risk to zero risk). This system contributed to a 33.3% reduction in the total High Risk in Painting Department 2. The financial evaluation recorded a Net Quality Income (NQI) of IDR 106,283,322 per year, derived from the prevention of potential Lost Workday costs and savings from internal system construction. This innovation has been registered for Intellectual Property Rights (IPR) as a standard effort to create a safe working environment (zero accident).*

Keywords— *Auto Door Lock System, Fishbone Diagram, Occupational Safety and Health, Painting 2, Value Engineering.*

I. INTRODUCTION

Occupational health and safety (OHS) is a fundamental element in ensuring the sustainability of manufacturing industry operations. The International Labour Organization (ILO) estimates that around 2.78 million workers die annually from work-related accidents and diseases, with 374 million non-fatal work injuries occurring (International Labour Organization, 2019). The impact of work accidents is not only physically damaging to individuals but also leads to significant economic losses, amounting to about four percent of global GDP (International Labour Organization, 2019). Efforts to create a safe working environment align with the United Nations Sustainable Development Goals (SDGs), particularly Target 8.8, which focuses on protecting workers' rights and promoting safe and secure work environments for all workers (United Nations, 2023).

The Indonesian government consistently encourages the implementation of adaptive OHS culture in response to the digitalization era to protect workers. This commitment is reinforced by the Minister of Manpower, Ida Fauziyah, through the theme of National OHS Month 2022: "The Implementation of OHS Culture in Every Business Activity to Support Worker Protection in the Digitalization Era" (Ministry of Manpower of the Republic of Indonesia, 2022). PT Automotive Manufacturing, as part of the Astra International group, prioritizes employee safety in every business line to achieve sustainable growth (PT Astra International Tbk, 2023). The Painting Department 2 holds a major responsibility in ensuring that every production process runs accident-free (zero accident), in line with the company's vision of becoming a global manufacturer with a strong safety culture.

Field observations in Painting Department 2 identified significant hazards in the Dolly Corridor area. This area is crucial for the loading and unloading of hanging part components using towing vehicles. The work environment in this area has a high risk due to a level crossing between towing vehicle tracks and pedestrian paths. The walled corridor structure creates a blind spot where towing vehicle operators and pedestrians cannot see each other clearly.

The root cause analysis was conducted using the Fishbone Diagram (Ishikawa Diagram) to map the dominant factors causing the risks based on the 4M1E categories (Man, Machine, Method, Material, Environment) (Ishikawa, 1986). This analysis aligns with H.W. Heinrich's accident prevention theory, which emphasizes that accidents are the result of a chain of events, where unsafe acts and unsafe conditions are the main factors that can be prevented (Heinrich H.W., 1931). The analysis revealed that machine (Machine) and environmental (Environment) factors are the biggest contributors to potential hazards, especially concerning the absence of an automatic interlock system in the blind spot area.

The design of technical solutions required careful consideration between functionality and cost-efficiency. The Value Engineering approach was applied to evaluate various safety system alternatives to select the solution that provides the best functional value with the most efficient cost (Miles, 1972). This evaluation ensures that the innovation produced is not only effective in preventing accidents but also economically feasible for implementation by the company.

This research aims to design and implement an automatic interlock system in the Dolly Corridor area using the Value Engineering approach and Fishbone Diagram analysis to eliminate workplace accident risks entirely. The implementation of this system also aims to reduce the risk status of the area from High Risk to Zero Risk and improve operational efficiency by eliminating potential Lost Work Days due to workplace accidents in Painting Department 2.

II. Literature Review

Value Engineering (VE) is a method used to improve the value of a product or system by reducing costs without compromising its quality or functionality. This approach was first introduced by Lawrence D. Miles in 1947 while working at General Electric to address material shortages. Through the combination of creative ideas, he developed a methodology known as Value Analysis, which later evolved into Value Engineering (Miles, 1972). The main goal of VE is to separate essential elements from non-essential ones within a system, and to develop alternatives that meet functional needs at the lowest possible cost, while maintaining performance (Dell'Isola, 1997). Additionally, VE includes efforts to save costs while maintaining a balance between the cost, strength, and appearance of the project for optimal results (Zimmerman & Hart, 1982).

The organized team approach in Value Engineering focuses on analyzing the functions of products, systems, or processes to improve their value by identifying unnecessary costs (Sudiarsa et al., 2020). This systematic evaluation covers various activity components such as procurement and construction to reduce overall project costs (Kencana & Waty, 2021). In a broader context, VE is seen as a decision-making process based on a multidisciplinary, systematic, and structured approach to achieve the best value of a project (Miraj et al., 2019). However, the implementation of VE also needs to take into account potential barriers that may arise in the industry to ensure its effective application (Kalani et al., 2017).

The root causes of a problem or undesirable occurrence can be seen and systematically determined using the Fishbone Diagram, also known as the Ishikawa Diagram (Ishikawa, 1986). This diagram categorizes the causes into several main categories, such as Man, Machine, Material, Method, and Environment. This method allows teams to identify the relationships between different factors contributing to a specific problem, including quality control (Besterfield, 2009). In the context of workplace safety improvements, the Fishbone Diagram helps evaluate various causes of accidents, ranging from physical conditions at the worksite to human factors, making the solutions designed more targeted (Ishikawa, 1986). Based on the analysis in the work area, this diagram is effective in detecting specific causes such as the absence of an automatic locking system or warning indicators (Riley & Juran, 1999).

The combination of Value Engineering and Fishbone Diagram provides a holistic and systematic approach in analysis and process improvement. Value Engineering focuses on cost reduction and efficiency improvement without compromising quality, while the Fishbone Diagram offers an in-depth understanding of the main causes of problems (Besterfield, 2009). Integrating both methods ensures that companies can accurately identify problems and develop effective and cost-efficient solutions (Miraj et al., 2019). As a result, workplace safety quality can be improved, accident risks reduced, and work productivity can be maintained at an optimal level (Riley & Juran, 1999).

III. Research Methodology

This research approach is designed to address work safety issues systematically and measurably in an industrial environment. The root cause analysis method using the Fishbone Diagram is applied to break down the factors contributing to accidents, while the solution design utilizes the Value Engineering method. This research is carried out following a systematic flow, starting with problem identification, literature study, data collection, and ending with the final evaluation of implementation.

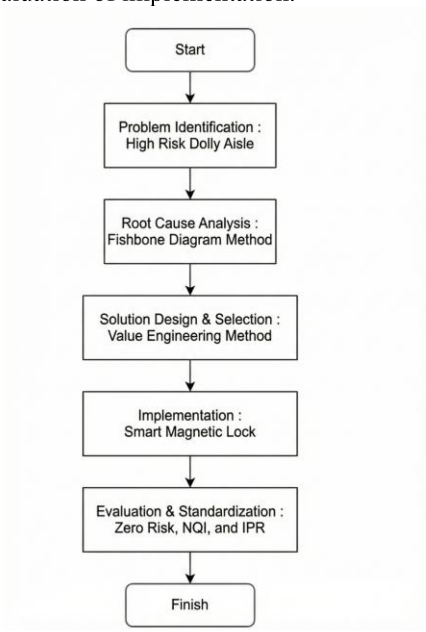

Figure 1. Research Methodology Flowchart.

A. Root Cause Analysis

The identification of the root causes of the problem is carried out using the Fishbone Diagram to map out the dominant factors contributing to the high accident risk in the Dolly Hall area. This analysis groups the causes into the 4M1E categories: Man, Machine, Method, Material, and Environment.

a. Human Factors (Man): Unsafe behavior, such as workers crossing the path when towing vehicles are passing, was identified as the main issue.
b. Machine Factors (Machine): The absence of an automatic locking system (interlock) and warning indicators at the pedestrian crossing doors was identified as a major equipment deficiency.
c. Method Factors (Method): The existing work procedure

allowing the towing path to directly intersect with the pedestrian path was reevaluated.

d. Environmental Factors (Environment): The physical conditions of the corridor, which are enclosed by walls, create blind spots that obstruct the view between the towing operator and pedestrians.

B. *Value Engineering*

Value Engineering is applied in this study to balance the required safety functions with the most optimal cost. The basic concept follows the relationship between value, function, and cost.

$$Value = \frac{Function}{Cost}$$

The research process breaks down three main aspects of Value Engineering and applies them through five systematic work stages.

IV. RESULTS AND DISCUSSION

A. *Determining the Theme and Initial Data*

The theme determination is based on factual data regarding work safety in the Painting 2 Department. Field observations show high activity in the Dolly Hall area, which is a critical path for both goods and pedestrian movement. Traffic frequency in the area is notably dense, with towing vehicles passing 30 times per shift and pedestrians crossing 84 times per shift. The existing conditions show a level crossing between the towing vehicle path carrying hanging parts and the pedestrian path. The closed corridor structure creates blind spots where the towing operator and pedestrians cannot clearly see each other.

The estimated cost of losses to the company in the event of a work accident (Lost Workday) is calculated based on the number of affected workers and the effective workdays. The loss calculation is as follows:

Daily Lost Workday Loss = 10 Workers × IDR 740,151
= IDR 7,401,510

Monthly Loss = 22 Days × IDR 740,151 = IDR 16,283,322

TABLE 1. Estimated Loss Due to Work Accidents (Lost Workday)

Component	Calculation	Number of Workers	Unit Cost (IDR)	Estimated Loss (IDR)
Daily Loss	10 workers × IDR 740,151	10	740,151	7,401,510
Monthly Loss	22 working days × IDR 740,151	-	740,151	16,283,322

Initial HIRADC (Hazard Identification Risk Assessment and Determining Control) data placed the Dolly Alley area at High Risk status with a severity score of 10, a probability of occurrence of 6, and a frequency of 4.

B. *Analysis of Conditions*

The next step is to perform a deeper analysis of the factors contributing to the high accident risk using the Fishbone Diagram. This analysis maps the root causes based on the 4M1E categories to identify the dominant factors that need improvement. The results of this analysis are presented in the Fishbone Diagram in Figure 2.

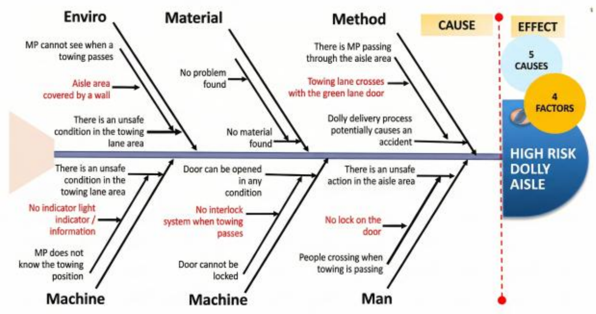

Figure 2. *Fishbone Diagram*

The details of the root cause analysis based on the diagram above are as follows: a) Man (Human): Unsafe behavior (unsafe action) was identified where employees often crossed the track when towing vehicles were passing. b) Machine (Machinery): The equipment currently does not have an automatic locking system (interlock system) that can hold the door when dangerous. The absence of indicator lights or warning information is also a major shortcoming in the machine aspect. c) Method: The applicable work procedure allows for a towing path that crosses directly with the green path door without an active safety mechanism. d) Environment: The physical condition of the corridor area, enclosed by permanent walls, causes obstructed visibility (blind spots), making the towing position invisible to pedestrians. Validation of the root cause was reinforced by collecting safety perception survey data from 10 employees who were actively working in the area. The survey results showed that 80% of participants stated that they could not determine the position or activity of the towing vehicle when they were about to cross the road. This lack of awareness was confirmed to be the result of limited visibility (blind spot) and the absence of early warning indicators at the access door. These actual data findings form the basis for validating that technical interventions in the Machine and Environment factors are necessary to help workers detect hazards.

C. *Planning for Improvements with Value Engineering*

The next step is to design a repair solution using the Value Engineering approach to select the most functionally effective and cost-efficient safety system. Three alternative solutions were evaluated to address the root causes identified. The investment costs for each alternative safety system were calculated in detail. The cost for the pneumatic system was estimated at Rp 20,083,488, with the main components being air cylinders and solenoid valves. The cost for the magnetic system only required a budget of Rp 6,358,188. A complete cost comparison analysis is presented in Table 2.

The magnetic system was determined to be the most cost-effective, saving 68% of the investment compared to the pneumatic system while maintaining the primary safety functionality, i.e., automatic locking of the door. The decision was made to implement the Smart Magnetic Lock System, which integrates an infrared sensor and indicator lights.

TABLE 2. Comparison of Investment Costs for Safety Solutions

No.	Component Description	Pneumatic System (IDR)	Magnetic System (IDR)
1	Air Hose (30 meters)	375,000	-
2	Air Cylinder (2 units)	2,832,300	-
3	Solenoid Valve (2 units)	2,406,000	-
4	Air Filter Regulator (2 units)	7,000,000	-
5	Limit Switch (2 units)	1,412,000	-
6	Magnetic Lock (2 units)	-	300,000
7	Contactor (4 units)	800,000	800,000
8	Photo Sensor (4 units)	3,180,188	3,180,188
9	Cables (100 meters)	1,700,000	1,700,000
10	Junction Box (1 unit)	300,000	300,000
11	Relay Timer (1 unit)	78,000	78,000
Total Investment		20,083,488	6,358,188
Cost Efficiency Percentage		-	68%

D. Making Improvements and Implementation

This stage covers the entire process from technical design to the execution of safety system installation in the field, as well as legal protection for the innovation. The automatic safety system is designed to address the main root causes of the problem, namely the absence of a locking mechanism in case of danger and the loss of visual information (blind spots). The basic concept of this improvement is to create an integrated interlock system that connects motion detection sensors with electromagnetic door locking mechanisms. The system is designed to ensure that the crossing access door locks automatically as soon as the sensor detects the arrival of a towing vehicle. This mechanism serves to forcibly separate physical interaction between humans and vehicles while still ensuring worker safety.

The main components of the system were selected based on technical specifications that support operational reliability in a factory environment. Component selection was carried out with precise technical calculations to ensure optimal performance. The sensor used is a Photo Sensor model E3Z R61, which has a fast response and is compatible with industrial electrical systems. For the lock, a 24 VDC induction magnet was selected, capable of withstanding a tensile load of up to 150 kg, strong enough to withstand the force of a pedestrian pushing against it.

TABLE 3. Main Components of the Safety System

Component Name	Primary Function	Technical Specifications
Photo Sensor	Detects the presence of towing vehicles	Infrared, precision detection range
Magnetic Lock	Automatically locks the door when activated	Strong holding power, Fail-safe design
Indicator Light	Provides visual warning signals (green, yellow, red)	24V, 0.48-Watt energy-efficient pilot light
Control Panel	Central logic control for the system	Includes Timer, Relay, Contactor

The system's logic is designed systematically, starting from object detection to the execution of door locking by magnets. This logic flow ensures that the system can distinguish between safe and dangerous conditions in real time without significant time lag. Input from the sensor will be processed by the controller to activate the timer and then trigger the door locking magnet automatically. Figure 2 shows a flowchart of the system that illustrates the sequence of operational logic.

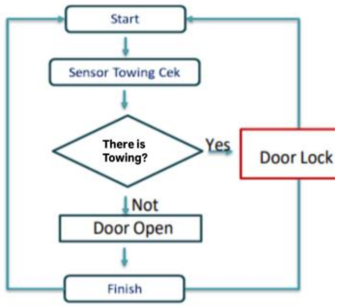

Figure 2. Automation System Flowchart.

The electrical design was developed to connect all input and output components into a centralized control panel. This circuit includes cable lines for sensors, power supplies, and magnetic actuators equipped with electrical current protection. Figure 3 shows the wiring diagram, which is the main guide in the control panel assembly process. This guide is crucial to ensure that there are no connection errors that could damage sensitive components.

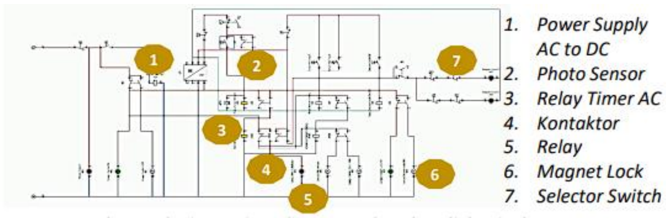

Figure 3. System Wiring Diagram.

The physical implementation process began with the fabrication of supports and installation of mechanical components in the work area. Sensor supports were installed at strategic points to ensure optimal detection range without obstruction from building structures. Magnetic iron plates were installed on door frames with sturdy construction to withstand heavy thrust loads. Figure 4 shows the results of the installation of the mechanical components of the sensors and magnets, which have been installed precisely in their respective positions.

Figure 4. Installation of Mechanical Sensor and Magnet.

The next stage focused on installing visual components and integrating the electrical system comprehensively. Indicator

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lights were installed at the top of the door so that they could be easily seen by pedestrians from a distance as an early warning sign. The installation of these indicators aimed to provide information on safe (green), caution (yellow), and danger (red) conditions to road users. Figure 5 shows the results of the installation of the three-color indicator lights, which are functioning properly.

Figure 5. Installation of Warning Indicator Lights.

The system was improved by adding a By-Pass System feature as a further risk mitigation measure. Anticipation of potential system failure was carried out using FMEA (Failure Mode and Effects Analysis). Risks such as power outages or sensor damage were mitigated by installing (Push Button Release Gate) on the inside and outside of the door. This button manually cuts off the power to the magnet, ensuring that workers are not trapped in the passageway (trap risk) during an emergency. The final step of this implementation is the registration of the innovation with the Directorate General of Intellectual Property. Figure 4.6 shows the Intellectual Property Rights (IPR) certificate that has been issued as valid proof of the originality of this work safety innovation.


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Kewarganegaraan: Indonesia
Pemegang Hak Cipta
Nama: AFIN YOLANTA YASTINDA PUTRA
Kewarganegaraan: Indonesia
Jenis Ciptaan: Kompilasi Ciptaan / Data
Judul Ciptaan: SMART MAGNETIC LOCK SYSTEM
a.n. MENTERI HUKUM DAN HAK ASASI MANUSIA
DIREKTUR JENDERAL KEKAYAAN INTELEKTUAL

Figure 6. Intellectual Property Certificate (IP).

E. Evaluation of Results

The evaluation was conducted after implementation to measure the effectiveness of improvements in reducing risk and overall financial benefits. The application of this system successfully eliminated all High Risk categories in the Dolly Lane area, reducing the risk status from high to zero (Zero Risk). This contribution also resulted in a 33.3% reduction in the total number of High Risk findings in the Painting 2 department. The initial conditions before the improvement showed a very high level of risk at various points in the work area. Historical data recorded three high-risk findings in the department and one specific risk in Lorong Dolly that was potentially fatal. Figure 7 shows a graph of the risk conditions before the intervention of the automatic safety system, where the graph bars show high incident rates.

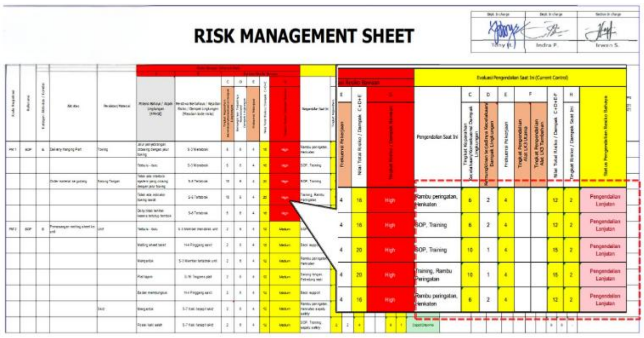

Figure 7. Risk Condition Before Improvement.

The implementation of the Smart Magnetic Lock system has had a dramatic impact on reducing risk after repairs. The evaluation graph shows that the risk figure in Dolly Corridor has dropped to zero, while the risk in the department has dropped to two cases. Figure 8 illustrates the achievement of a safe condition (Zero Risk) after the device was installed and fully operational, marked by a significant decrease in the graph.

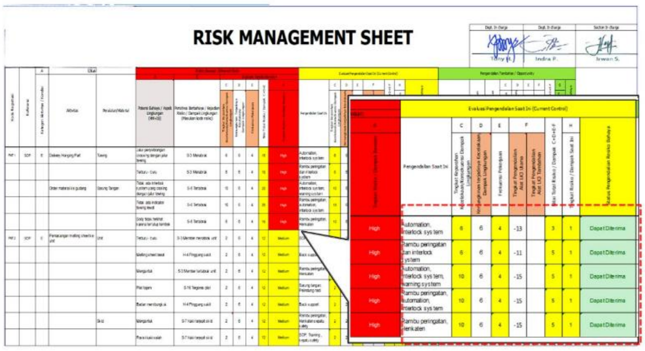

Figure 8. Risk Condition After Improvement.

The economic benefits or Net Quality Income (NQI) of this project are calculated based on savings in tool manufacturing costs (compared to vendors) and the elimination of potential losses due to workplace accidents. The total savings are calculated as follows: Manufacturing Cost Savings = IDR 90,000,000 (Vendor) - IDR 0 (In-house) = IDR 90,000,000 Prevention of Potential LWD = 1 Month x IDR 16,283. 322 = IDR 16,283,322 Total NQI = IDR 90,000,000 + IDR 16,283,322 = IDR 106,283,322 Table 4 presents a summary of the financial benefits obtained by the company from the results of this innovation.

The results of the study prove that modifying work processes through an automatic interlock system can create a safe working environment while providing significant cost efficiencies for the company. This innovation has been registered as intellectual

Havidz Vitto R., Jaka Aria, Bagas Nur Alief, M. Angga Adi L., and Yudi Prastyo, "Implementation of an Automatic Interlock System to Eliminate Workplace Accident Risks in the Dolly Painting 2 Corridor Area Using the Value Engineering Method," *International Research Journal of Advanced Engineering and Science*, Volume 11, Issue 1, pp. 78-83, 2026.

property rights (IPR) as a new standard for work safety at PT Automotive Manufacturing.

TABLE 4. Financial Evaluation (Net Quality Income)

No.	Category of Savings	Code	Savings Value (IDR)
1	System Construction Efficiency (In-house vs Vendor)	IDL	90,000,000
2	Prevention of Potential Lost Workdays (LWD)	DL	16,283,322
Total	**Net Quality Income (NQI)**		**106,283,322**

V. CONCLUSION AND RECOMMENDATIONS

A. Conclusion

This study successfully designed and implemented an automatic safety system called the Smart Magnetic Lock System to mitigate the risk of accidents in the Dolly Corridor area of the Painting 2 Department. Problem identification using the Fishbone Diagram method found that the main root cause of the high risk was the absence of a door locking mechanism in case of danger and limited visibility due to walls (blind spots). The technical solution was selected through a Value Engineering approach, which determined that an induction magnet-based system was the best option because it had a 68% lower investment cost than a pneumatic system while still providing optimal safety functions.

The implementation of this system has proven to be effective in separating physical interaction between towing vehicles and workers by automatically locking access doors when sensors detect danger. The impact of implementing this system has been significant in improving workplace safety performance and operational efficiency for the company. The accident risk level in the Dolly Corridor area was successfully reduced by 100% from the High-Risk category to Zero Risk after the installation of the equipment. This contribution also had a positive impact on reducing the total number of high-risk findings in the Painting 2 Department by 33.3%, from three cases to two cases. Work areas that were previously prone to accidents now have active protection that works in real-time without disrupting operational productivity.

Financial analysis shows that this innovation provides total cost savings (Net Quality Income) of IDR 106,283,322 per year. These savings come from the elimination of potential losses due to Lost Workdays and the cost efficiency of manufacturing tools in-house compared to using external vendors. The sustainability of this innovation is guaranteed through the issuance of a standard operating procedure with document number SOP/PNT2/AUTO/4/002 concerning Auto Gate Panel Operations, as well as legal recognition through an Intellectual Property Rights (IPR) certificate as a valid and original work safety standard.

B. Recommendations

The continued performance of the Smart Magnetic Lock system is highly dependent on consistent routine maintenance activities by management. A schedule of periodic maintenance or preventive maintenance must be implemented for vital components such as sensors and magnets to prevent a decline in performance due to dust or shocks. Checks on the emergency button or By-Pass System must also be carried out regularly to ensure that the backup safety mechanism is always ready for use in critical conditions. Refresher training for operators and pedestrians needs to be scheduled periodically to ensure that understanding of safety procedures in this new technological area is well maintained.

The application of this safety technology has great potential to be replicated in other work areas with similar risk characteristics in factories. Other departments that have intersections between industrial vehicles and pedestrians can adopt the Smart Magnetic Lock scheme as a new safety standard. Further research is recommended to develop system integration with Internet of Things technology to enable real-time monitoring of area conditions. The use of smart surveillance cameras can also be considered to digitally record unsafe behavior as material for more accurate safety evaluations in the future.

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