

Electro-Mechanical Safety System for High-Speed Automated Zones to Enhance Safety during Unscheduled Maintenance

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Abstract: *An important factor in the expansion and advancement of the Indian economy is the automobile sector. Over the past three years, the production of passenger cars has grown at an average pace of 19%. To meet the demands for output, the automobile industry operates continually at maximum capacity. The non-routine nature of maintenance tasks presents a significant challenge. Employee confidence in safety is undermined by potential risks such as interlock malfunction, safety system failure, circumventing controls, inadequate coordination, and incorrect risk assessments. The maintenance risk associated with automated stations in the automobile manufacturing sector is examined in this article. A new electromechanical method to enhance safety has been established in factory premises, developed, and tested to improve the safety system's dependability and the elimination of the potential for PLC safety logic circumventing providing workers with more confidence to operate without worrying about the consequences of safety system failing.*

Keywords: Automated Stations, Automobile industry, Maintenance risk, PLC program safety interlock circumventing

1. Introduction

Manufacturers utilize high-speed machinery and sophisticated automation to meet the demands of expanding cost-effective manufacturing [4].

Enormous accidents are reported every year in Indian Manufacturing industries and the similar trends are observed during maintenance operations performed in those industries [1], [2]. Technologies that can carry out machine activities without human involvement are referred to as automation. Production process simplification is greatly aided by autonomously programmed PLC programmable devices, SCADA (Supervisory Control and Data Acquisition), and industrial robots [12]. Automation has advanced to the point that every piece of machinery is networked and operates with coordinated actions. In the automobile sector, robots are essential to the highly automated car body welding process. Fully automatic systems are perfect for repeated jobs requiring little to no human interaction. Spot welding is very popular for attaching thin metal sheets in the production of automobile bodies. By taking the place of people in dangerous welding jobs, robots have greatly increased safety. They can also work nonstop, increasing production capacity. Contemporary robotic systems possess the ability to execute complex and repetitive operations with precision, weld within tenths of a millimeter, and adjust to novel tasks without the need for reprogramming. Despite the enormous growth in production automation, autonomous equipment maintenance has not kept up, the need for human involvement to bridge the gap in maintenance is still a requirement even with highly automated stations. Maintenance personnel in automated stations are under pressure to resolve issues as soon as possible when technology malfunctions. The dependability of the safety system and the removal of the possibility for PLC circumvention provide employees with greater confidence to work without fear of failure. Organization of the paper is as follows, the first section presents the objectives and introduction at the beginning of the section. The second section describes the safety technologies in automated stations. The next section details the maintenance methods followed by maintenance personnel. Section four describes the proposed model. Section five concludes the work.

2. Safety In High-Speed Automated Zones of Automobile Industry

The spotwelding operations within automotive manufacturing facilities may be executed with complete automation. This process encompasses significant intricacies in the production workflow, necessitating the integration of welding apparatus, robotic systems, and operational stations. It comprises perpetually interconnected subsystems facilitated by synchronized robotic entities. The interactions among these interlinked subsystems are orchestrated through advanced algorithms. Within automated production lines, a zone is delineated as a collection of interrelated subsystems operating within a controlled gated environment. More than ten robotic units are interconnected within a designated zone. Interruptions during the operational timeline are regarded as critical. Robotic spot welding in the automotive industry has replaced traditional welding to accommodate the trend of increased output. Any stoppage in the robotic welding process is likely to result in errors, which lower the quality of the weld. Research was done on error proofing techniques to reduce these failures. Periodic health inspection of equipment reduces failures of machine. To guarantee the product's quality, maintenance personnel steps in and fix any problems with automated welding stations. In welding stations, safety sensors, fixture sensors, and robot teaching sensors require routine maintenance [3] Human engagement within these automated stations presents substantial risks for both production and maintenance personnel. To ensure uninterrupted production, such interventions are unavoidable. The following critical scenarios are frequently observed within the automated welding stations.

2.1 Production Scenarios

- The welding tip changing procedure must be executed after every twelve welding cycles.
- Preventive and corrective maintenance must be conducted as required
- Systematic quality assessments must be performed as an integral component of routine evaluations.
- 3S Shine, recognized as a pivotal element during intervals of respite, manifests as an essential procedural requirement.

The continuity of the paint and assembly process will be impacted by any manufacturing disruption. The production output signs off in units per hour will be impacted by any halt in the welding shop. Buffer stock cannot be kept for more than an hour due to adaptable restrictions. The key element in increasing plant efficiency is the reduction and optimization of Work in Progress levels [7]. In the manufacturing industry, stocks are regarded as important financial resources. The

profitability is impacted by waiting stocks in line. Therefore, in this area of interest, attempts are made to manage costs effectively [10]. The alternative solutions that were identified can be classified into two distinct categories: those reliant on human intervention and those dependent on machinery. In the context of machine dependence, programming robots for critical operations serves as a substitute, thereby extending cycle time to offset the need for repair robots. Conversely, in scenarios that necessitate human dependence, the involvement of personnel is imperative for the operation of robotic repair systems. A notable decline in both quality and production has been identified as the primary risk factor in both categories. Under these conditions, users employ electronic methods to circumvent the safety mechanisms of the Programmable Logic Controller (PLC) to gain access to the subsystems by evading the designated access route of the automated station. Individuals participating in this operation face considerable hazards because of such actions. These conditions often lead to significant incidents and near-miss occurrences. The establishment of a cost-efficient production framework will be facilitated by the collaboration between teams. However, this partnership poses a risk as safety devices may be compromised for the sake of shared objectives [9]. A ten-year survey shows that mishaps in the situations are more severe than typical safety hazards. Frequent training and disciplinary measures are effective to improve human behavior, but they cannot prevent similar dangerous situations from occurring or ensure that employees will behave differently. An impenetrable mechanism that stops electronic gated station circumvention is required to prevent such scenarios. The psychological issues that maintenance personnels encounter when automation of any form is implemented are studied by researchers. Anxiety and inadequate training were also addressed. However, no research was done on how the personnels behaved when they had to use the PLC program to finish the task. Personnels' level of severity, the foolproof mechanism that keeps users from evading automated stations will be covered in this paper.

Safety instrumentation systems are employed in industries to safeguard process plants through interlocks and emergency shutdowns. Engineered and regulated circumventing are used to test and maintain these systems. When circumventing is neglected and left unmanaged during maintenance and operation, there is a possibility of safety risks. More than administrative controls, a logic solver based on a programmable logic controller should be used by the Safety Instrumented System (SIS) to monitor the disabling of sensors via digital communications [6]. In automobile industries, parameters of the automated process can be effectively controlled by standard PLCs, which are utilized in traditional automated systems. Safety PLCs are equipped with redundant circuits that anticipate any internal system failure. With SIL, it may be integrated into the system. Safety PLC's complex diagnostic features necessitate regular monitoring to guarantee the proper operation of hardware and software systems, which are then linked to automated safety features (sensors, actuators). Through an integrated safety mechanism that recognizes software and electronic failures, it guarantees the system's functional

safety. Hardware failures, software mistakes, communication errors, I/O faults, improper wiring, and undervoltage situations are common reasons why a safety PLC enters a fault state. Upgrading all the safety components and PLC in the system is a complex task if safety PLC is integrated into a traditional system. Relays and actuators are part of the additional control circuit that requires modification that increases expensive and time-consuming. The Safety PLC's higher cost and complexity make it less viable to integrate into legacy systems.

3. Maintenance Safety Standard Operating Procedure

3.1. Planned Maintenance

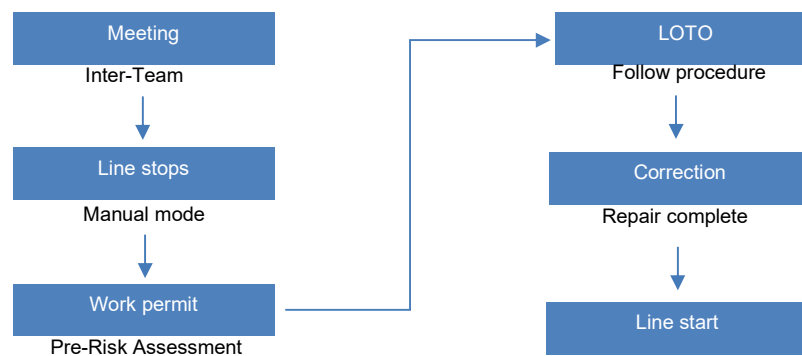


Figure 1. Flowchart for planned maintenance activity

During planned maintenance tasks, appropriate meetings involving coordinating teams including Production, Quality, and Maintenance is held. The automated station will be set to manual mode. A safety work permit will be issued by the safety team after a pre-risk assessment and control implementation. The LOTO procedure will be utilized to prevent the machine from inadvertently starting up when personnel are present. After the repairs are complete, the safety team confirms and close the safety work permit issue. The line will reopen after the coordinating teams have been properly notified. The safety steward assigned to the job will ensure conditions, and the safety officer on patrol will ensure compliance for essential work.

3.2 Un Planned Maintenance

Production and maintenance personnel communicate one-on-one during unplanned maintenance tasks. Stations that are automated will be in auto mode. Safety team approval and risk assessment is skipped. PLC program is circum-

vented around safety systems at the gate. On completion of activity PLC program and safety interlocks are brought back to ideal state.

The following procedure is used when performing unplanned maintenance activities:

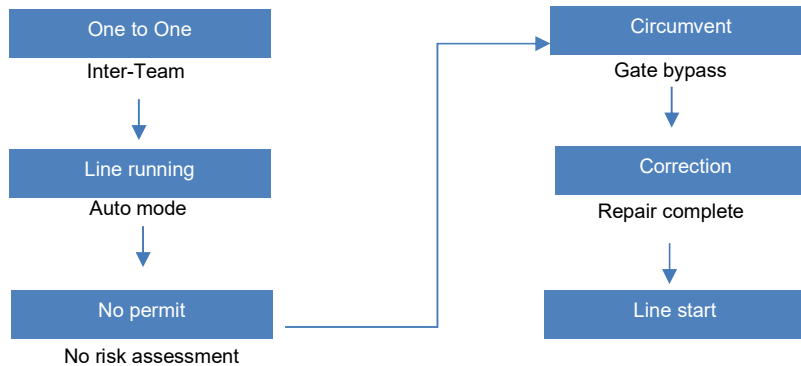


Figure 2. Flowchart for unplanned maintenance activity to ensure safety

3.3 Risk in the procedure mentioned above

- Unaware of the condition being circumvented, the intervening individual might become trapped in the moving equipment.
- After detecting movement, sensors and actuators may act.
- It is possible to activate the operation without knowing the person inside

4. Electro-Mechanical Safety System

4.1 Automated zone mapping

A study on maintenance practice brings out the following scenarios during entry into automated stations.

- Green zone - Safe operating practice was followed the line was stopped.
- Yellow zone - Equipment removed for maintenance, line running.
- Red zone - Line operating, gate circumvented, rectification made while the system is operational

The zone classification in AutoZone entry based on the risk factor versus time as displayed in Figure 3. The Manufacturing process line is stopped in the green zone for repair purposes. Safe working procedures are followed, and a safety work permit is raised. There is a 25% risk factor in this area. In this area, accidents are uncommon. The necessary amount of time was allotted to finish the maintenance task. Inadequate training, faulty equipment, low skill levels, and trips and falls are the main causes of accidents in this area. The injury's severity is insignificant. Physical barriers limit human intervention even while the line is in the yellow zone.

Red Zone: Quick Troubleshooting Methods are generally followed across industries with highspeed automation and running with maximum capacity, the methods are given below.

- Alarm Reset + Cycle Start
- Stand by changeover + Cycle Start
- Online Correction without interfering with safety interlocks
- Online Correction + Safety system override

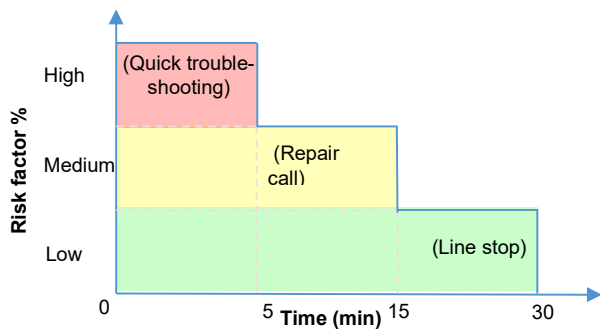


Figure 3. Zone Classification of AutoZone jobs

Table 1. Safety Device Status During Circumvented Scenario

Condition	Safety Device	Signal Status	
		Circumvent	PLC
No Circumvent	0	X	0
	1	X	1

Circumvent	1/0	✓	1
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Safety device is ON/OFF -> PLC Signal is always ON Periodically, machines in certain areas are called for maintenance, which is performed from outside the automated zone along with a person inside automated zone. Injuries could occur because of the personnels' inability to coordinate. The red zone is extremely important and more prone to mishaps. Line will be operating in the automated station and the gate will be bypassed in this area. It takes five minutes to get the PLC in enabled mode by getting around the gate entrance. Major mishaps and close calls are caused by unintentional start-ups that occur while a maintenance or production personnel is inside the station. This was primarily done to fulfil production goals, minimize maintenance downtime, and avoid overconfidence. Based on historical data, this was done. The state of the communication signal in each circumstance is described in Table 1. The safety device and PLC will have a robust communication signal if the system is not circumvented. Even if the gate is in an enabled or disabled state, the PLC will be in an enabled state when the system is being circumvented. This mimics the red zone scenario. When manufacturing is fully automated and operating in three shifts, line interruptions are most frequent.

4.2. Risk Analysis

Risk is characterized by adverse events, uncertainties, and the gravity of the consequences [11]. The risk management techniques are divided into three groups. A risk-informed strategy is one that avoids, reduces, or transfers risk. Redundancy, safety factor addition, and substitution are precautionary measures used in the development of safety equipment. Receiving input from indications and the precursors of important events is highly valued. Discussion method reduces scepticism and increases credibility. Combining these strategies comes up with a solution. The seriousness of the crisis and the danger it poses to the system must be considered, though. Risk scores are values that explains the severity of the risk and helps in finding ways to manage the risks. It helps in identifying the hazards and evaluating the risk They are derived considering the severity of the injury, probability of occurrence of the incident and the present control available in the activity identified. Risk is prioritized based on the criteria we have derived considering past impacts and existing culture. Scenarios identified with high-risk score need to be taken seriously and fool proof controls need to be implemented. Controls identified and established should be reliable to prevent any kind of tampering in undesirable circumstances. Various risk management strategies are employed to demonstrate the significant challenges in the organizations. Risk assessment is required for any planned maintenance or retooling operations in an automated station. There are different risk factors depending on how important the operation is. Time is the most crucial factor in determining the degree of risk.

Although there are goals for any activity besides routine production, nobody is coerced into performing the work in a dangerous manner. To control the work and ensure that it is finished without interfering with the manufacturing process, targets are set. Risk factors are characterized as Low, Medium and High with respect to time. Risk factor is low if we take the required time for repair and follow the procedure. Hazards in this space can be eliminated or substituted and the severity of the injury is minimal. Risk is medium, if we complete with some restrictions. Hazards in this space will result in permanent or temporary disablement and can be controlled through engineering controls.

It is High, if we override the safe operating procedure, circumvent the safety devices and do it in line operational condition. Here, grievous injuries or fatal may occur due to failure of safety devices to do its intended function. Various steps have been taken to prevent such act. But changes happened in the PLC programs due to intentional intervention or due to unintentionally environmental factors remain unnoticed. This poses a high risk to the person who enters the station believing it to be a safer zone.

Table 2. Risk Assessment of maintenance Scenario

Scenario	Sev	Poc	Pc	Score
Line stop	1	1	1	1
Repair call2	2	2	2	8
Trouble shooting	3	3	3	27
Sev – Severity, Poc – Probability of occurrence, Pc – Present Control				

In Table 2 Risk control table, troubleshooting has the highest score possessing the highest severity followed by the highest probability of occurrence with ineffective controls.

Table 3. Risk Guidance based on past scenario

#	Sev	Poc	Pc
1	First aid injury	1 year	Eliminate/ Substitute
2	Temporary/ Permanent/ Disablement	6 months	Engineering controls
3	Fatal/ Serious injury	Multiple times a day	No control/ Effective controls
Risk score = Sev x Poc x Pc			

Table 3 describes the guidelines used for the risk score evaluation. Hence, to prevent worst case scenarios which results in business interruptions, there is a need to develop a system which cannot be superseded under any circumstances. A re-

liable fail-safe system needs to be developed which will prevent unsafe act which circumvent the safety system

4.3 Electro-mechanical Robus Safety Control System

As illustrated in Figure 4, the current system still functions even if the PLC program safety interlock is circumvented at Gate 01. Regardless of whether the safety devices are connected or not, the equipment will continue to function. In the event of an interruption, all robots will continue to work, assuming that safety devices are protecting the gates and that the line will be cut off. This scenario possesses a substantial risk to personnel approaching the automated zones through Gate G01. Therefore, if operator unintentionally start the line during an unplanned maintenance or quick troubleshooting scenario where safety logic in the PLC program is circumvented, it could cause serious risk to all personnel inside the automated station.

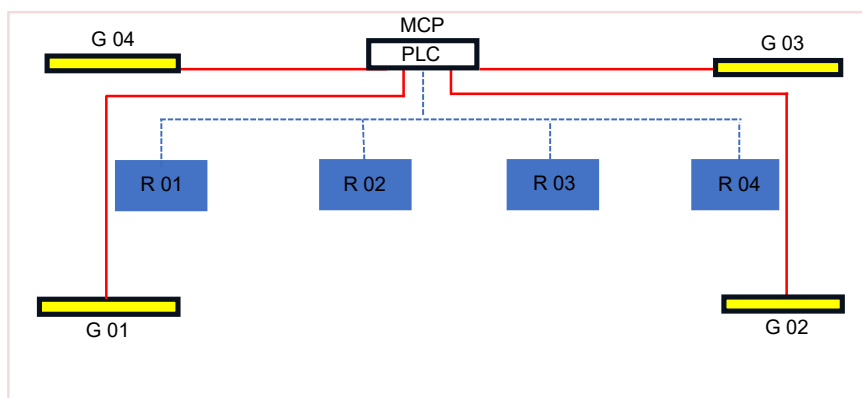


Figure 4. Existing High Speed Automated Zone and safety control system to prevent personnel entry during operation

To control similar scenario a system is developed by connecting the safety Input signal from multiple relay control, connected to the PLC program to timestamp personnel entering and exiting the high-speed automated system for routine or non-routine works, tracking duration of the safety system open status.

The information assists in determining the facts in anomalies, even if it does not prevent, warn, or stop people from evading the safety systems. With the information gathered from the PLC program, correlations of events that occur can be tracked, verify the personnels entered and the reason for intervention when an

unusual event occurs during the course. This provides with a reasonable understanding of the events and a forward-looking lead for unsafe incident inquiry. Since safety guards interlocked with PLC programs do not fulfil the purpose intended in the workplace as they are vulnerable to temporary disablement and circumventing. A redundant design is necessary to ensure that program modifications that change the safety features cannot be accessed in order to resolve this problem in the developed model for the current system. To reduce the likelihood of alterations by maintenance personnel and PLC programmers, safety controls and operating controls must be kept apart [8].

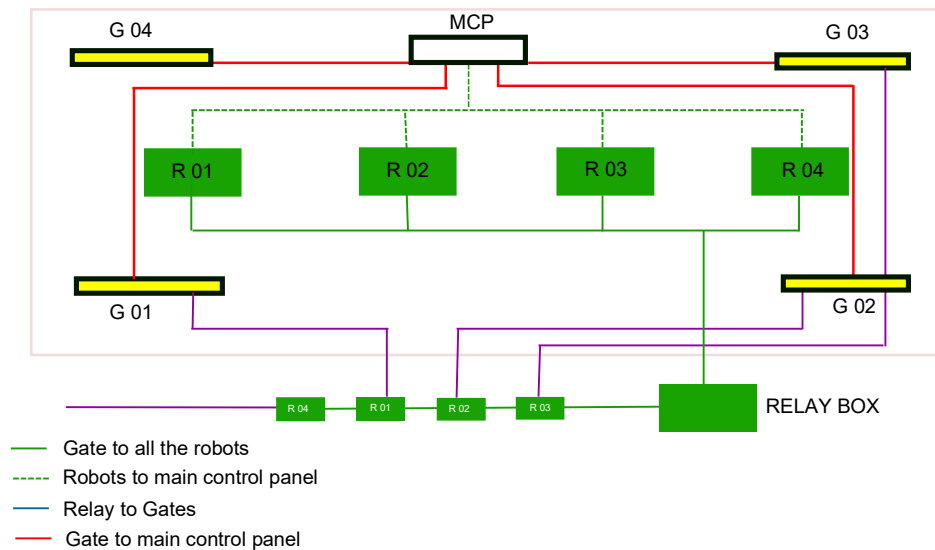


Figure 5. Proposed Electro-mechanical Robust Safety Control System

The proposed electro-mechanical system as in Figure 5. The automated station's gates serve as the primary entrance to the robot zone. Each robot and gate are linked to the main control panel, four relays and one master relay are housed in an outdoor relay box. Within the relay box, relays R01, R02, R03, and R04 are connected to each other and to the corresponding gates G01, G02, G03, and G04. All robots inside the enclosed area are connected from the master relay. Following the installation of this new electro-mechanical system, the integrity of the automated station will not be jeopardized by any PLC program software circumvention. because every gate is connected to the relays, and the relays are connected to the master relay. Each robot is connected to a master relay. As a result, even if we get around the PLC program that offers a dependable safety system during rapid troubleshooting scenarios, all the robots will stop once the safety

mechanism in the gate is physically removed, providing a reliable safety system during quick troubleshooting scenarios

Conclusion

According to trial run results, this new electro-mechanical model gives maintenance staff great confidence since it prevents PLC program safety logic circumvention during rapid troubleshooting scenarios. The welding shop's solution, that is now a part of the system, can be horizontally implemented at any high-speed automated system or at similar industry more quickly and affordably.

The study is constrained, however, in that if the gate's security mechanism is intentionally evaded, the security of the individual entering in front of the automated station cannot be ensured. Although such an act is not justified and would be considered a flagrant violation of safety regulations, it is still feasible and can be done on purpose. Further research is needed on the factors that motivate such behaviour as well as specially designed controls that prohibit and monitor misconduct that leads to detrimental conditions.

Declarations

All authors declare that they have no conflicts of interest.

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