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Risk Management in Industry 4.0 Maintenance: Identifying and Addressing Hazards

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Abstract - *This research investigates hazards and risks specific to maintenance activities in Industry 4.0. It includes firsthand observations from an industry visit, identifying potential hazards using the Hazard Identification and Risk Assessment (HIRA) methodology. The research emphasizes the importance of a comprehensive safety approach for Industry 4.0, providing practical control measures and recommendations to mitigate maintenance-related risks. The outcomes highlight the transformative potential of Industry 4.0 and offer valuable guidance to stakeholders, policymakers, and practitioners. Implementing the research's recommendations enables organizations to navigate Industry 4.0 confidently, fostering a safe and efficient future.*

Key Words: Industry 4.0, HIRA, Maintenance

1.INTRODUCTION

The construction industry in India is experiencing rapid growth, driven by urbanization and infrastructure development. It is projected to reach a market value of $1.4 trillion by 2025. The demand for residential construction is also increasing, with a need for 25 million mid-range and affordable housing units by 2030. India has allocated a substantial budget for infrastructure development under the National Infrastructure Pipeline, focusing on renewable energy, roads, highways, urban infrastructure, and railways. Initiatives like the Smart City Mission and the PMAY-U program are promoting modernized urban planning and construction technologies.

However, this growth comes at a cost, as the construction industry has a concerning safety record. Accidents result in hundreds of fatalities among workers each year, with the construction sector accounting for a significant portion of these deaths. The AEC industry, which encompasses architecture, engineering, and construction, plays a broader role in designing, planning, managing, and maintaining built environments. It involves various professionals, including architects, engineers, construction managers, and tradespeople, who collaborate to create functional, safe, and aesthetically pleasing structures. Quality control, safety, and effective project management are essential aspects of both the construction and AEC industries.

The construction industry in India is booming due to urbanization and infrastructure projects, but worker safety remains a significant concern. The AEC industry plays a more comprehensive role in creating and managing built environments, emphasizing design, planning, and efficient project execution.

Industry 4.0, also known as the fourth industrial revolution, involves the integration of advanced technologies, such as the Internet of Things (IoT), big data, and cloud computing, into various sectors, including manufacturing. Construction 4.0 aligns with Industry 4.0 and implements similar technologies within the construction industry to enhance efficiency and innovation. The Industrial Revolution has evolved through several stages: 1.0 relied on human effort and steam-powered machines, 2.0 introduced electricity and more efficient machines, and 3.0 saw the rise of automation and electronics in production. Industry 4.0, the fourth revolution, focuses on Cyber-Physical Systems and leverages cutting-edge technologies to enable real-time data analysis and intelligent decision-making in manufacturing processes. The goal of Industry 4.0 is to integrate these technologies across all industrial sectors, leading to enhanced business performance and improved quality of life for workers. By embracing innovative techniques, companies can achieve flexibility, efficiency, and intelligence while reducing human effort and risks associated with tasks.

Safety is a critical consideration in both manufacturing and construction industries. The introduction of new technologies in Industry 3.0 increased the need for safety and security measures, which remain relevant in Industry 4.0. In the construction industry, safety considerations must permeate all phases of operations, and adherence to protocols and regulations is crucial to mitigate risks and protect workers and the public. The evolution of industrialization has led to improved workplace environments and better engagement between employers and employees in addressing health and safety issues. Advanced tools, risk management standards, and safer devices contribute to monitoring and controlling the work environment effectively. While challenges persist, Industry 4.0 offers the potential for further advancements in safety and efficiency across various industries.

The research highlights how Industry 4.0 is revolutionizing maintenance practices for businesses. It highlights the following key points:

- Predictive Maintenance (PdM): Industry 4.0 enables organizations to implement predictive maintenance, which allows them to foresee equipment failures and take proactive preventive actions. Smart sensors play a crucial role in detecting anomalies and notifying technicians for timely intervention.
- Proving the Value of Maintenance: Data analytics and comprehensive metrics enable organizations to showcase the tangible impact of maintenance practices on their bottom line. Shifting from a reactive to a proactive mindset rewards effective maintenance strategies and continuous improvement.
- Building a Solid Foundation: Organizations need to establish a well-built preventive maintenance program with essential steps, providing a roadmap for successful integration with Industry 4.0 and minimizing challenges during the transition.
- Focus on Data Collection: Good-quality data is crucial for leveraging Industry 4.0 effectively. Detailed, consistent, and digital asset data, including maintenance activities, naming conventions, and key performance indicators (KPIs), should be prioritized.
- Creating a Reliability Culture: A successful implementation of Industry 4.0 relies on fostering a reliability culture that embraces change and continuous improvement. This involves establishing guiding principles, formal processes, open communication, and recognizing adaptability and innovation.
- Starting Small with Predictive Maintenance: Organizations can begin with condition-based maintenance (CBM) as a stepping stone towards full-fledged predictive maintenance. Starting small allows learning, building expertise, and gaining confidence in the power of predictive maintenance

Research gap identified in the literature review is investigating the role and impact of Industry 4.0 technologies on maintenance processes in industrial facilities, with a specific focus on the effectiveness and sustainability of digital technologies in enhancing maintenance practices.

2. FACILITY MANAGEMENT

To establish the groundwork for the research by stating the problem, the author collected data and observations from the Facilities management (FM) of a MNC. located in Bengaluru, Karnataka. This activity offered firsthand experience of actual working conditions and a practical understanding of a theoretical concept related to the field of integrated facility management. Several noteworthy advantages of adopting such quantitative data collection approach include:

- • An opportunity to connect with leaders, professionals, entrepreneurs, policymakers, and corporate individuals who generously share their knowledge, insights, and experiences.
- • To witness and engage with actual facility management sites, machinery, systems, and interact with highly skilled and experienced staff.
- • To gain insights into the company's policies concerning production, quality control, and service management.
- • To unlock numerous possibilities for corporate training enhancing one's employability prospects.
- • To comprehend the collaborative efforts of managers, engineers, employees and other staff in achieving common objectives, presenting valuable management lessons.
- • To recognize the importance of safety in facility management and make informed decisions about future work areas such as facility maintenance, equipment handling, signaling, and safety protocols.

During the industry visit, an industry embracing Industry 4.0 technologies, I had the opportunity to witness a wide range of activities and advanced equipment in action. The visit provided valuable insights into the company's commitment to technological excellence and overall maintenance and management of their facilities. Company's impressive array of equipment included Vacuum Circuit Breaker Panels, Diesel Generators (1, 2, and 3), Lifts (Pl3, Pl4, and Pl5), and Uninterruptible Power Supply Panels. These state-of-the-art technologies exemplify their dedication to adopting Industry 4.0 principles, ensuring efficient and reliable power supply and distribution. The implementation of Sliding Doors, Sequencing Batch Reactors (SBR) Unit, Flow Switches, Solar Fencing Zones, and Solar Power Fencing Zones demonstrated Honeywell's focus on sustainability and energy efficiency, utilizing renewable energy sources to reduce environmental impact. Moreover, It was observed that meticulous attention to facility maintenance and cleanliness, evident through activities such as Reception Cobweb Cleaning, Carpet Shampooing Machine Service, Water Pond Deep Cleaning, and Floor Deep-Cleaning & Shampooing. These initiatives indicate Honeywell's dedication to maintaining a safe and pleasant working environment for its employees. The company also showcased their commitment to employee well-being with the provision of Grr & Lrr Rest Rooms, ensuring comfort and relaxation during breaks. Additionally, I noticed a seamless integration of technology and civil work within the facility, along with well-designed Signage Boards and Signage Markings, indicating efficient wayfinding and facility management. Furthermore, the company emphasized pest control activities, illustrating their attention to maintaining hygiene and cleanliness in their operational spaces. Overall, the visit to the industry provided a comprehensive understanding of their progressive approach to Industry 4.0, sustainable practices, and their unwavering commitment to maintaining a technologically advanced, safe, and environmentally conscious working environment. The experience reaffirmed the importance of adopting cutting-edge technologies and best practices to stay ahead in today's competitive industrial landscape.

3. METHODOLOGY

The research employs a specific methodology aimed at implementing task-specific control measures to effectively reduce or eliminate hazards identified during metro construction projects. The methodology utilizes the data collection and its analysis followed by Hazard Identification and Risk Assessment with Controls (HIRAC) method to thoroughly analyze potential hazards across various maintenance activities.

Hazard Identification, Risk Assessment, and Control (HIRAC) is a methodical and proactive process employed to ensure the safety and well-being of individuals within a workplace by effectively managing potential occupational and health hazards. The primary aim of HIRAC is to identify potential risks, evaluate their severity and likelihood, and implement appropriate measures to minimize or eliminate these risks. The initial step in HIRAC involves identifying hazards, where a thorough analysis of the workplace is conducted to recognize any conditions, activities, or substances that may pose harm to employees or other stakeholders. Hazards encompass a broad spectrum, ranging from physical dangers to chemical, ergonomic, and psychological factors. Following hazard identification, the Risk Assessment stage ensues. During this step, the severity and likelihood of each identified hazard are assessed to determine the level of risk it presents. Risks are categorized as high, medium, or low, allowing organizations to prioritize and address the most critical issues first.

Subsequently, the Control Implementation phase is initiated, wherein measures are devised and applied to mitigate or eliminate the identified hazards. These control measures may take the form of engineering modifications, administrative protocols, or the implementation of personal protective equipment (PPE) requirements. Continuous monitoring and evaluation are integral throughout the HIRAC process to ensure the effectiveness of implemented controls. Regular reviews of the workplace and its processes are essential to identify emerging hazards, reassess risks, and make necessary adjustments to control measures. Compliance with HIRAC principles is not only essential for employee safety but is also a legal obligation in many jurisdictions. By adhering to safety and health legislation and employing HIRAC, organizations demonstrate their commitment to employee well-being, reduce workplace accidents and injuries, enhance productivity, and avoid potential legal liabilities.

3.1 Hazard Identification

Hazard identification is the process of detecting potential risks and dangers within a workplace or work practice. Understanding the nature of hazards is crucial for a comprehensive hazard identification process. These hazards can be categorized into various types, including physical, biological, chemical, and psychosocial, all of which are commonly found in workplaces. Performing a thorough hazard identification requires significant effort and can be time-consuming. Consequently, periodic hazard identification may be necessary to ensure its effectiveness. One effective approach is to divide the workplace into distinct zones, enabling the identification and prioritization of high-priority areas based on hazardous elements like equipment, substances, processes, or environmental conditions. To achieve accurate hazard identification, it is essential to gather insights and opinions from domain experts who possess ample knowledge and are familiar with the work procedures, such as workers and supervisors.

3.2 Risk Assessment

Risk assessment involves estimating the level of risk associated with identified hazards and determining whether the level of risk is acceptable for the given work context. This assessment is conducted based on evaluating the "likelihood" and "consequence" of potential hazardous events occurring. For tasks with high-risk potential, appropriate measures must be implemented to reduce the risk to an acceptable level, ensuring a safe working environment. The identified hazards are listed and ranked based on their level of consequences and likelihood. Consequences refer to the severity of the potential impact or harm caused by the risk, while likelihood denotes the probability of the risk occurring. Mathematically, the risk level is calculated by multiplying the likelihood (L) and severity (S).

$$\text{Risk Level} = L \times S$$

Table -1: Rating scale for assessing the probability of an event taking place

Level	Descriptor	Example detailed description
1	Rare	May occur only in exceptional circumstances
2	Unlikely	Limited potential of occuring
3	Possible	Potential to occur some time
4	Likely	Will probably occur in most circumstances
5	Almost Certain	Is expected to occur in many circumstances

Table -2: Rating scale for assessing the severity of an event taking place

Level	Descriptor	Example detailed description
1	Insignificant	Hazard Identified, Near Hit with no injury
2	Minor	First Aid Treatment, 1-2 days lost time injury
3	Moderate	Medical treatment, >3 days lost time injury
4	Major	Extensive injuries such as permanent disability/ amputations and/or resuscitation
5	Catastrophic	Single / Multiple Fatalities

Table -3: Risk Matrix

Likelihood		1 (A)	2 (B)	3 (C)	4 (D)	5 (E)
Severity		Rare	Unlikely	Possible	Likely	Almost Certain
5	Catastrophic	5	10	15	20	25
4	Major	4	8	12	16	20
3	Moderate	3	6	9	12	15
2	Minor	2	4	6	8	10
1	Insignificant	1	2	3	4	5

The risk matrix is a valuable tool used for evaluating and prioritizing potential risks in various contexts, such as projects or organizations. It involves assessing each risk based on its likelihood and severity, and then plotting them in the appropriate cells on the matrix. This visual representation helps identify high-priority risks with significant consequences and enables the allocation of resources accordingly. To further enhance its usability, risks are often categorized into different levels, distinguished by distinct colors, making it easier for decision-makers to grasp the importance of each risk and take appropriate actions to manage them effectively.

"The severity of risk, as indicated by the risk relative score, directly influences the level of necessary intervention. A high risk relative score demands immediate and decisive action to mitigate potential hazards. When confronted with an intermediate risk score, adequate preparation is essential to effectively manage and control the associated risks. Conversely, situations marked by a low risk relative score are considered acceptable and tolerable, requiring less urgent attention."

Table -3: Description of actions corresponding to different risk levels

Priority for Control Implementation All hazards and risks must be controlled, risk level provides a 'priority for action'.	
Severe	**Unacceptable level of risk – Cease activity immediately.** Other action and control measures must be implemented and the extreme risk reduced to ALARP before work can commence. **Re-assess risk after any new control is implemented.**
Moderate	Other action and control measures should be considered to reduce the risk to ALARP. Ensure all existing measures are monitored for adequacy. **Re-assess risk after any new control is implemented.**
Low	Other action and control measures may not be necessary but consider making all risk ALARP. Monitor all existing controls for adequacy. **Re-assess risk after any new control is implemented.**
When determining appropriate hazard / risk control measures apply the ALARP principle: Reduce the level of risk to As Low As Reasonably Practicable.	

3.3 Risk Management

In this research, risk control measures were established by carefully assessing the identified hazards and implementing a combination of engineering controls, administrative controls, and personal protective equipment (PPEs). It is essential to adhere to a well-defined hierarchy of risk control measures for effective risk management, ensuring the safety and well-being of individuals involved in the process.

The hierarchy of risk control measures is of utmost importance in ensuring the adoption of the most efficient strategies to manage hazards. This hierarchy outlines a preferred sequence for addressing risks:

- Elimination: The most effective approach is to entirely remove the hazard from the workplace. This may entail substituting hazardous materials with safer alternatives or redesigning processes to eliminate potential dangers altogether.
- Substitution: If complete elimination is not feasible, substitution involves replacing hazardous materials or practices with less risky alternatives.
- Engineering Controls: As previously mentioned, engineering controls involve modifying the work environment or equipment to minimize the risk of exposure to hazards.
- Administrative Controls: When engineering controls are inadequate, administrative controls are implemented to limit exposure and enhance safe work practices.
- Personal Protective Equipment (PPEs): PPEs serve as a final line of defense, protecting individuals from remaining risks after all other control measures have been put in place.

4. RESULT

The Hazard Identification, Risk Assessment, and Control method is a thorough and extensive approach used to ensure safety and health in a worksite. Hence, this research focuses on applying the Hazard Identification, Risk Assessment, and Control method to the observed maintenance activities.

The assessment results for these activities are shown in Figure 1, where a total of 134 hazards were identified across different sub-tasks. The identified potential hazards for all the observed activities are listed in Table Below. The Hazard Identification, Risk Assessment, and Control (HIRAC) method were applied to these sub-tasks following the methodology discussed earlier.

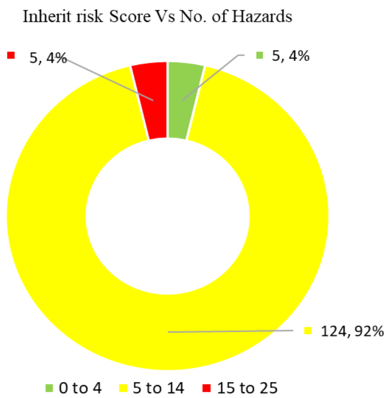

Fig -1 Distribution of determined inherit risk scores

Figure 1 represents the distribution of hazards based on their corresponding risk scores. Each hazard is assigned a risk score based on its potential severity and likelihood of occurrence. The risk scores are grouped into three ranges, and the table shows the number of hazards falling into each range.

Table -4: Hazard Identification & Risk Assessment Worksheet

S.No	Process / Activity / Work Area	Risk Category	Hazard / Aspect (The source of the risk)	Unwanted Event (Risk & Consequence)	Inherent		Inherent Risk Score	Control(s) (Hierarchy of Control)	Residual		Residual Risk Score
					(S)	(L)			(S)	(L)	
1	Vacuum Circuit Breaker Panel Maintenance	Electrical Hazard	Electric Shock due to exposed live parts	Injury or Fatality	5	3	15	1. Engineering Controls: Proper insulation and guarding. 2. Administrative Controls: Lockout-Tagout procedures. 3. PPE: Insulated gloves, safety glasses.	2	2	4
2	Vacuum Circuit Breaker Panel Maintenance	Fire Hazard	Electrical overheating	Fire leading to property damage or injury	4	3	12	1. Regular thermal scanning and maintenance. 2. Fire-resistant barriers. 3. Fire extinguishers.	3	2	6
3	Vacuum Circuit Breaker Panel Maintenance	Chemical Hazard	Exposure to hazardous insulating fluids	Chemical burns or respiratory problems	3	2	6	1. Use of proper Personal Protective Equipment (PPE). 2. Proper handling and storage of fluids. 3. Emergency response procedures.	2	1	2
4	Vacuum Circuit Breaker Panel Maintenance	Mechanical Hazard	Pinch points or moving parts	Crush injuries or amputations	4	4	16	1. Machine guarding. 2. Lockout-Tagout procedures. 3. Proper training.	2	2	4
5	Vacuum Circuit Breaker Panel Maintenance	Fall Hazard	Working at heights	Fall leading to injuries or fatalities	4	3	12	1. Fall protection equipment (harnesses, lanyards). 2. Proper scaffolding and platforms. 3. Proper training.	3	2	6
6	Diesel Generator Maintenance	Mechanical	Moving engine parts	Worker's hand caught in machinery	3	2	6	Engineering Controls	2	1	2
7	Diesel Generator Maintenance	Electrical	Electric shock	Electrician exposed to live wire	4	3	12	Lockout/Tagout Procedures	2	1	2
8	Diesel Generator Maintenance	Fire	Fuel leak	Fire due to fuel ignition	4	2	8	Regular Inspection & Maintenance	1	1	1
9	Diesel Generator Maintenance	Noise	High noise levels	Hearing loss to maintenance crew	2	4	8	PPE - Ear Protection	1	2	2
10	Diesel Generator Maintenance	Chemical	Diesel fumes	Inhalation of toxic fumes	3	3	9	Adequate Ventilation	1	1	1
11	Elevator lift activity	Mechanical	Elevator entrapment	People trapped inside the elevator, panic, suffocation	4	3	12	Regular maintenance and inspection of lift components	2	1	2
12	Elevator lift activity	Mechanical	Elevator door malfunction	People caught between closing doors	3	2	6	Door sensors and safety mechanisms installation	1	1	1
13	Elevator lift activity	Electrical	Power surge	Electrical shock, damage to electronic components	3	3	9	Surge protectors, grounding systems	1	1	1
14	Elevator lift activity	Electrical	Motor failure	Elevator stuck, occupants stranded	3	2	6	Regular motor maintenance and backup power supply installation	1	1	1
15	Elevator lift activity	Operational	Incorrect weight distribution	Overloading the elevator, increased risk of malfunction	2	3	6	Clearly displayed weight capacity and monitoring systems	1	1	1
16	Elevator lift activity	Operational	Failure to stop at the correct floor	Tripping hazards, delayed response of the elevator	2	2	4	Regular calibration and maintenance of floor sensors	1	1	1
17	Elevator lift activity	Human	Inadequate user training	Incorrect use of controls, causing operational errors	2	3	6	Comprehensive user training and clear instructional signage	1	2	2

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					(S)	(L)			(S)	(L)	
18	Elevator lift activity	Human	Lack of maintenance personnel training	Incorrect maintenance practices, missed issues	3	3	9	Training and certification for maintenance personnel	2	2	4
19	Elevator lift activity	Environmental	Flood or water ingress	Electrical hazards, elevator malfunction	4	2	8	Proper water sealing and drainage systems	2	1	2
20	Elevator lift activity	Environmental	Earthquake or structural instability	Elevator damage or collapse, occupants trapped	5	1	5	Earthquake-resistant building design and structural integrity assessments	4	1	4
21	Elevator lift activity	Mechanical	Malfunction of lift mechanisms	Elevator stall with occupants inside	4	3	12	Regular maintenance and inspection of lift components	2	1	2
22	Elevator lift activity	Electrical	Power failure	People trapped in the elevator	3	2	6	Backup power supply installation	1	1	1
23	Elevator lift activity	Operational	Improper operation	Misalignment leading to jerky motion	2	4	8	Staff training and certification	2	2	4
24	Elevator lift activity	Human	User negligence	Entrapment or fall accidents	3	4	12	Clear safety guidelines for users	2	2	4
25	Elevator lift activity	Environmental	Fire hazard	Elevator damage and smoke inhalation	4	2	8	Smoke detectors and fire extinguishers installation	3	1	3
26	Elevator Control Cabinet Maintenance	Electrical Hazard	Electrical Wiring Exposure	Electric Shock, Burns, Injury, or Fatality	5	4	20	Proper Electrical Isolation and Lockout/Tagout	2	2	4
27	Elevator Control Cabinet Maintenance	Mechanical Hazard	Moving Parts	Crushing or Pinching Injuries	4	3	12	Machine Guarding	2	2	4
28	Elevator Control Cabinet Maintenance	Fire Hazard	Electrical Overheating	Fire and Property Damage	3	2	6	Regular Inspection and Maintenance	2	1	2
29	Elevator Control Cabinet Maintenance	Chemical Hazard	Chemical Exposure	Skin Irritation, Respiratory Issues	2	1	2	Proper PPE Usage	1	1	1
30	Elevator Control Cabinet Maintenance	Ergonomic Hazard	Awkward Posture	Musculoskeletal Disorders	3	3	9	Training on Proper Lifting Techniques	1	2	2
31	UPS Panel Maintenance	Physical	Electric Shock	Electrical shock to maintenance personnel resulting in injury or death.	5	4	20	Ensure isolation procedures are followed, use proper PPE.	2	1	2
32	UPS Panel Maintenance	Fire	Short Circuit / Overheating	Fire outbreak damaging equipment and causing injury.	4	3	12	Regular thermal scanning, proper ventilation around the panel.	2	2	4
33	UPS Panel Maintenance	Chemical	Acid / Corrosive Chemicals	Contact with corrosive substances causing skin or eye injuries.	3	2	6	Proper labeling, use of appropriate PPE, and safe handling practices.	2	1	2
34	UPS Panel Maintenance	Ergonomic	Improper Lifting Techniques	Muscular strain or back injuries during lifting.	3	3	9	Training on proper lifting techniques and using lifting aids.	2	1	2
35	UPS Panel Maintenance	Fire	Electrical Fire	Fire outbreak damaging equipment and causing injury.	4	3	12	Regular inspection and maintenance of electrical components.	2	2	4

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					(S)	(L)			(S)	(L)	
36	UPS Panel Maintenance	Chemical	Battery Acid Exposure	Contact with battery acid leading to chemical burns.	4	2	8	Use of appropriate PPE (acid-resistant gloves, goggles, etc.).	2	1	2
37	UPS Panel Maintenance	Fire	Overloading of Circuit	Circuit overloading causing fire and equipment damage.	4	3	12	Implement load monitoring and power distribution checks.	2	2	4
38	UPS Panel Maintenance	Physical	Falling Objects	Objects falling from heights during maintenance.	3	2	6	Secure tools and equipment, use safety harnesses.	2	1	2
39	UPS Panel Maintenance	Fire	Overheating Batteries	Batteries overheating and catching fire.	4	3	12	Regular temperature monitoring, thermal protection.	2	2	4
40	UPS Panel Maintenance	Biological	Rodents and Vermin Infestation	Contamination and damage to electrical components.	3	2	6	Regular pest control measures, sealing entry points.	1	1	1
41	Sliding Door Maintenance	Mechanical	Inadequate Lubrication	Sliding door jams, difficult to open/close	3	4	12	Regular Lubrication and Inspection	2	2	4
42	Sliding Door Maintenance	Operational	Faulty Lock and Handle	Difficulty in securing the door, potential unauthorized access	2	3	6	Regular Inspection and Maintenance	2	1	2
43	Sliding Door Maintenance	Slip/Trip	Wet Floor due to Cleaning	Slip and fall accidents	2	3	6	Use Wet Floor Signs, Adequate Drying	1	1	1
44	Sliding Door Maintenance	Chemical	Improper Cleaning Agents	Skin Irritation or Chemical Exposure	3	2	6	Use Appropriate Cleaning Agents	1	2	2
45	Sequencing Batch Reactors (SBR) Unit	Cleaning and Inspection - Mechanical	Moving machinery parts	Entanglement and crush injuries	4	3	12	Engineering controls	3	1	3
46	Sequencing Batch Reactors (SBR) Unit	Chemical Handling	Handling corrosive chemicals	Skin contact and chemical burns	3	2	6	PPE (Personal Protective Equipment)	2	2	4
47	Sequencing Batch Reactors (SBR) Unit	Confined Space Entry - Physical	Limited space and poor air quality	Asphyxiation and loss of consciousness	5	2	10	Permit to Work System	3	1	3
48	Sequencing Batch Reactors (SBR) Unit	Electrical	Exposed wires and electrical shocks	Electric shock and burns	3	4	12	Lockout-Tagout (LOTO)	2	2	4
49	Sequencing Batch Reactors (SBR) Unit	Noise Exposure - Physical	High noise levels	Hearing loss and tinnitus	2	3	6	Hearing Protection	1	1	1
50	Sequencing Batch Reactors (SBR) Unit	Manual Lifting - Ergonomic	Lifting heavy loads	Musculoskeletal injuries	3	3	9	Mechanical Lifting Aids	2	1	2
51	Sequencing Batch Reactors (SBR) Unit	Fire and Explosion	Combustible materials	Fire outbreak and property damage	4	2	8	Fire Suppression System	2	1	2
52	Sequencing Batch Reactors (SBR) Unit	Slips, Trips, and Falls - Physical	Slippery surfaces	Slip, trip, and fall injuries	2	4	8	Good Housekeeping	1	1	1
53	Sequencing Batch Reactors (SBR) Unit	Confined Space Entry - Physical	Toxic gas accumulation	Poisoning and respiratory problems	4	2	8	Ventilation and Gas Monitoring	2	1	2
54	Sequencing Batch Reactors (SBR) Unit	Hot Work (Welding, Cutting) - Fire	Heat and sparks	Fire outbreak and burns	3	3	9	Fire Blankets and Extinguishers	2	1	2
55	Flow Switch Maintenance	Physical	Electrical shock	Electrocution	4	3	12	Isolation of Power Source	2	1	2

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					(S)	(L)			(S)	(L)	
56	Flow Switch Maintenance	Physical	Mechanical injury	Crushed fingers/hand	3	4	12	Use of Proper PPE	1	2	2
57	Flow Switch Maintenance	Chemical	Corrosive chemicals exposure	Skin irritation / chemical burns	2	2	4	Use of Chemical Resistant Gloves	1	1	1
58	Flow Switch Maintenance	Ergonomic	Awkward posture	Musculoskeletal disorders	3	3	9	Ergonomic Workstation Design	1	1	1
59	Flow Switch Maintenance	Biological	Exposure to harmful microorganisms	Infections	2	2	4	Use of Personal Protective Gear	1	1	1
60	Solar Fencing Maintenance	Physical	Electrocution from exposed wiring	Major electric shock or fatality	5	4	20	Insulate live wires	3	2	6
61	Solar Fencing Maintenance	Chemical	Exposure to hazardous cleaning agents	Moderate chemical burns	3	3	9	Provide PPE (gloves, goggles)	2	2	4
62	Solar Fencing Maintenance	Ergonomic	Improper lifting techniques	Musculoskeletal injuries	2	4	8	Training on proper lifting	2	2	4
63	Solar Fencing Maintenance	Biological	Bites/stings from insects or animals	Allergic reactions or infections	3	3	9	Use insect repellents	2	2	4
64	Solar Fencing Maintenance	Psychosocial	Work-related stress and fatigue	Reduced work efficiency	2	3	6	Workload distribution	1	2	2
65	Replacement of Light Bulbs	Electrical	Electric shock	Electric shock leading to injury	4	3	12	Use insulated gloves and tools	2	1	2
66	Cleaning Light Fixtures	Fall	Working at height	Fall from height leading to injury	3	4	12	Use fall protection equipment	2	2	4
67	Testing Electrical Connections	Electrical	Short circuit	Fire hazard	4	2	8	Regular maintenance and testing	2	1	2
68	Working in Low Light	Ergonomic	Poor visibility	Strain or trip hazards	2	4	8	Improve lighting conditions	1	1	1
69	Working at Height with Scissor Lift	Fall Hazard	Uneven ground or surface	Fall from height resulting in serious injury or fatality	4	3	12	Ensure scissor lift operators are trained and certified	3	2	6
70	Working at Height with Scissor Lift	Electrical	Contact with live wires or equipment	Electric shock leading to injury or fatality	4	2	8	Ensure proper lockout-tagout procedures are followed	2	1	2
71	Using Tools and Equipment	Mechanical	Improper use of tools or equipment	Hand or finger injuries or equipment malfunction	3	3	9	Provide proper training on tool usage and maintenance	2	1	2
72	Working near other Personnel	Collision	Collisions with other personnel	Minor injuries or disruptions	2	3	6	Implement clear communication and safe work zones	1	1	1
73	Working near other Personnel	Struck-By	Struck by falling objects or equipment	Head injuries or severe trauma	4	2	8	Use barricades and hard hats, store materials properly	2	1	2
74	Working near Traffic	Traffic	Proximity to moving vehicles or machinery	Vehicle collision with workers or equipment	4	3	12	Set up barriers, warning signs, and traffic control measures	2	2	4
75	Use of Scissor Lift	Tip-Over	Scissor lift tipping over	Serious injuries or fatalities due to tip-over	4	2	8	Ensure proper weight distribution and level ground	2	1	2
76	Use of Scissor Lift	Entrapment	Entrapment between lift components	Crush injuries or asphyxiation	4	2	8	Use lift with safety features like pinch-point guards	2	1	2
77	Working in Adverse Weather	Weather	Adverse weather conditions	Slips, falls, or visibility issues due to weather conditions	3	3	9	Monitor weather conditions and suspend work if necessary	2	2	4
78	Manual Handling of Equipment	Ergonomic	Improper lifting and handling techniques	Musculoskeletal injuries or strains	3	2	6	Provide training on proper lifting techniques	2	1	2

S.No	Process / Activity / Work Area	Risk Category	Hazard / Aspect (The source of the risk)	Unwanted Event (Risk & Consequence)	Inherent		Inherent Risk Score	Control(s) (Hierarchy of Control)	Residual		Residual Risk Score
					(S)	(L)			(S)	(L)	
79	Storm Motor Maintenance	Mechanical	Lack of Lockout-Tagout Procedure	Serious injury to maintenance personnel due to unexpected startup	4	3	12	Implement Lockout-Tagout Procedures	2	1	2
80	Storm Motor Maintenance	Electrical	Electric Shock	Electrocution of maintenance personnel	4	2	8	Ensure Lockout-Tagout & PPE Usage	3	2	6
81	Storm Motor Maintenance	Chemical	Exposure to Hazardous Chemicals	Chemical burns or respiratory issues	3	3	9	Use appropriate PPE	2	1	2
82	Storm Motor Maintenance	Ergonomic	Improper Lifting Techniques	Musculoskeletal injuries	2	4	8	Training on proper lifting techniques	1	3	3
83	Storm Motor Maintenance	Fire	Ignition Sources	Fire outbreak and property damage	3	2	6	Fire prevention measures	2	2	4
84	Storm Motor Maintenance	Working at Height	Fall from height	Fatal or serious injuries	5	2	10	Fall protection equipment	3	1	3
85	Storm Motor Maintenance	Confined Space	Toxic Atmosphere	Asphyxiation or poisoning	4	1	4	Ventilation and Permit Systems	2	1	2
86	Storm Motor Maintenance	Noise	High Noise Levels	Hearing loss and damage	3	3	9	Use hearing protection	2	2	4
87	Storm Motor Maintenance	Fire	Inadequate Fire Exits	Trapped in the event of fire	3	2	6	Ensure clear and accessible exits	1	1	1
88	Storm Motor Maintenance	Chemical	Chemical Spills	Environmental contamination	3	3	9	Spill containment and cleanup	1	2	2
89	Diesel Engine maintenance	Mechanical	Moving engine parts	Crushing or trapping fingers	3	4	12	Engineering controls	2	2	4
90	Diesel Engine maintenance	Chemical	Diesel fuel exposure	Inhalation of toxic fumes	3	3	9	Personal protective equipment	1	2	2
91	Diesel Engine maintenance	Electrical	Electrical shock	Electrocution	4	2	8	Lockout/Tagout procedures	2	1	2
92	Diesel Engine maintenance	Fire	Fuel leak or spill	Fire or explosion	4	3	12	Fire safety training	2	1	2
93	Diesel Engine maintenance	Ergonomic	Awkward postures	Musculoskeletal disorders	2	3	6	Proper ergonomics	1	1	1
94	Diesel Engine maintenance	Noise	High noise levels	Hearing damage	2	4	8	Hearing protection	1	2	2
95	Diesel Engine maintenance	Slip/Trip/Fall	Oily/greasy surfaces	Slip, trip, or fall	3	3	9	Non-slip floor coatings	1	1	1
96	Cleaning the restroom floor	Slips/Trips	Wet and slippery floor	Slip and fall injuries	3	4	12	Use slip-resistant mats	2	2	4
97	Handling cleaning chemicals	Chemical	Exposure to cleaning chemicals	Skin irritation or chemical burns	2	3	6	Use personal protective equipment (gloves, goggles)	1	2	2
98	Ladder use for high cleaning	Falling	Falling from the ladder	Broken bones or head injuries	4	3	12	Use stable and properly maintained ladder	2	2	4
99	Handling restroom waste	Biological	Exposure to biohazards	Risk of infection	3	2	6	Use appropriate PPE; provide disposal guidelines	1	1	1
100	Wall Repair	Physical	Falling objects from height	Worker hit by falling tiles	3	3	9	Install scaffolding and guardrails	1	1	1
101	Tiles Repair	Chemical	Hazardous fumes during tile cutting	Inhalation of toxic fumes	2	4	8	Use proper ventilation	1	2	2
102	Wall Repair	Ergonomic	Manual lifting of heavy tiles	Musculoskeletal injuries	3	4	12	Use mechanical lifters	2	2	4
103	Tiles Repair	Physical	Slips, trips, and falls	Worker slips on wet tiles	2	3	6	Keep work area dry and clean	1	1	1
104	Wall Repair	Biological	Mold growth due to water seepage	Allergic reactions and respiratory issues	2	3	6	Repair water leaks and improve ventilation	1	1	1
105	Carpet Shampooing Machine	Mechanical	Moving parts	Entrapment of body parts in the machine	4	3	12	Ensure machine guards are in place and functional	3	2	6

S.No	Process / Activity / Work Area	Risk Category	Hazard / Aspect (The source of the risk)	Unwanted Event (Risk & Consequence)	Inherent		Inherent Risk Score	Control(s) (Hierarchy of Control)	Residual		Residual Risk Score
					(S)	(L)			(S)	(L)	
106	Carpet Shampooing Machine	Chemical	Cleaning chemicals	Skin irritation or chemical burns	3	4	12	Provide and use appropriate PPE (gloves, goggles)	2	2	4
107	Carpet Shampooing Machine	Electrical	Electrical components	Electric shock or short-circuit	4	2	8	Regular inspection and maintenance of electrical parts	2	1	2
108	Handling Chemical Containers	Manual Handling	Heavy lifting and carrying	Musculoskeletal injuries due to improper lifting	3	3	9	Provide training on proper lifting techniques	2	1	2
109	Slippery Floors	Slip / Trip	Wet floors	Slip and fall accidents	3	3	9	Regularly clean spills and put up warning signs	2	1	2
110	Reception Cobweb Cleaning	Physical	Slips, Trips, and Falls	Fall from a ladder, Injury	3	4	12	Use of fall protection equipment	2	1	2
111	Reception Cobweb Cleaning	Chemical	Inhalation of Cleaning Chemicals	Respiratory Irritation, Poisoning	3	2	6	Use of PPE, Adequate Ventilation	2	1	2
112	Reception Cobweb Cleaning	Biological	Exposure to Mold	Allergic Reaction, Respiratory Issues	2	3	6	Use of PPE, Proper Ventilation	1	1	1
113	Reception Cobweb Cleaning	Ergonomic	Poor Lifting Technique	Musculoskeletal Injury	2	3	6	Manual Handling Training	1	1	1
114	Reception Cobweb Cleaning	Physical	Eye Injuries from Debris	Eye Irritation, Corneal Abrasion	2	4	8	Use of Eye Protection	1	2	2
115	Water Pond Deep Cleaning	Physical	Slips, Trips, and Falls	Workers may slip and fall	3	3	9	Provide anti-slip footwear and warning signs	2	2	4
116	Water Pond Deep Cleaning	Chemical	Exposure to Toxic Chemicals	Health issues due to chemical exposure	4	2	8	Use appropriate PPE, provide adequate ventilation	2	1	2
117	Water Pond Deep Cleaning	Biological	Vector-Borne Diseases	Workers getting infected with diseases	3	3	9	Administer vaccines, use insect repellents	2	1	2
118	Water Pond Deep Cleaning	Physical	Drowning Hazards	Workers falling into deep water	5	2	10	Implement barricades, provide life jackets	3	1	3
119	Water Pond Deep Cleaning	Physical	Confined Space Hazards	Workers trapped in confined spaces	4	3	12	Follow confined space entry procedures, provide gas monitors	2	1	2
120	Water Pond Deep Cleaning	Ergonomic	Musculoskeletal Disorders	Strain or injuries from lifting	3	4	12	Use lifting equipment, provide training on proper lifting techniques	2	2	4
121	Water Pond Deep Cleaning	Physical	Electrical Hazards	Electrocution or electrical burns	4	3	12	Ensure proper grounding, use insulated tools	2	1	2
122	Water Pond Deep Cleaning	Physical	Falling Objects	Workers hit by falling debris	4	3	12	Wear hard hats, use safety netting	2	1	2
123	Water Pond Deep Cleaning	Chemical	Inhalation of Hazardous Fumes	Respiratory issues due to fume exposure	3	3	9	Use respirators, ensure proper ventilation	2	1	2
124	Water Pond Deep Cleaning	Psychological	Stress and Fatigue	Reduced concentration and decision-making ability	2	4	8	Implement work-rest schedules, provide psychological support	1	1	1
125	Pest Control Activities	Health	Exposure to toxic chemicals	Chemical poisoning	4	3	12	PPE - Gloves, Respirators	2	2	4
126	Pest Control Activities	Safety	Slippery surfaces	Slips and falls	3	4	12	Non-slip flooring	1	2	2
127	Pest Control Activities	Operational	Machinery breakdown	Work disruption	2	3	6	Regular maintenance	1	1	1
128	Pest Control Activities	Health	Bites or stings from insects	Allergic reaction	3	3	9	PPE - Protective clothing	1	2	2
129	Pest Control Activities	Health	Pesticide residues on food	Food poisoning	4	2	8	Proper storage and handling	1	1	1
130	Pest Control Activities	Safety	Chemical spillage	Environmental contamination	3	2	6	Secure transportation	1	1	1

S.No	Process / Activity / Work Area	Risk Category	Hazard / Aspect (The source of the risk)	Unwanted Event (Risk & Consequence)	Inherent		Inherent Risk Score	Control(s) (Hierarchy of Control)	Residual		Residual Risk Score
					(S)	(L)			(S)	(L)	
131	Pest Control Activities	Health	Inhalation of toxic fumes	Respiratory issues	3	3	9	Proper ventilation	2	1	2
132	Pest Control Activities	Human	Lack of knowledge and skills	Incorrect pesticide application	3	4	12	Training and certification	2	2	4
133	Pest Control Activities	Environmental	Wind carries chemicals off-target	Harm to non-target organisms	2	4	8	Weather monitoring	1	2	2
134	Pest Control Activities	Environmental	Improper disposal practices	Water and soil contamination	4	2	8	Proper disposal procedures	1	1	1

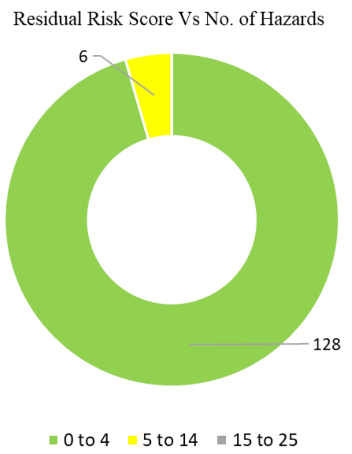

Fig -2 Distribution of determined residual risk scores

The table provided above presents a list of hazards along with their associated risk scores, which are calculated based on probability and severity assessments. These hazards are ranked in descending order of risk, with the highest risk score at the top. Topping the list is the hazard related to Vacuum Circuit Breaker Panel Maintenance, posing a significant risk of electric shock due to exposed live parts, potentially resulting in injury or even fatality. Following closely are the hazards associated with Solar Fencing Maintenance, Elevator Control Cabinet Maintenance, and UPS Panel Maintenance, all sharing the same risk score, indicating considerable danger. These hazards involve threats such as electrocution, burns, and other severe injuries. To ensure a safe working environment, it is imperative that these top-ranked hazards receive immediate attention and appropriate measures are implemented, including engineering controls, administrative procedures, and the use of personal protective equipment, to effectively mitigate the risks and safeguard the well-being of maintenance personnel and others involved.

The proposed control measures aim to minimize the risk associated with the top-ranked hazards:

1. Hazard: Vacuum Circuit Breaker Panel Maintenance (Electric Shock due to exposed live parts)

- Conduct Regular Maintenance Inspections: Implement a schedule for regular inspections and maintenance of circuit breaker panels to identify and address any potential issues before they become hazards.
- Provide Safety Barriers: Install physical barriers around the circuit breaker panel to prevent unauthorized access and accidental contact with live parts.
- Use Voltage Detectors: Equip maintenance personnel with voltage detectors to verify the absence of electrical energy before commencing work on the panel.
- Implement Restricted Access: Restrict access to the maintenance area to authorized personnel only, and ensure that they have received appropriate training and certifications.

2. Hazard: Solar Fencing Maintenance (Electrocution from exposed wiring)

- Install Warning Signs: Clearly mark the areas around the solar fencing with warning signs indicating the presence of high voltage to raise awareness among personnel and the public.
- Safe Work Permits: Require a documented safe work permit system for maintenance tasks on the solar fencing to ensure proper procedures are followed, and risks are adequately assessed before work begins.
- Conduct Regular Inspections: Regularly inspect the solar fencing system to identify damaged or exposed wiring and promptly repair or replace any faulty components.
- Provide Lockable Enclosures: Enclose the solar fencing system in lockable enclosures to prevent unauthorized access and tampering.

3. Hazard: Elevator Control Cabinet Maintenance (Electrical Wiring Exposure)

- Implement Double Verification: Ensure that maintenance activities involving elevator control cabinets require two qualified personnel to confirm that electrical isolation and lockout/tagout procedures have been accurately followed.
- Use Non-Conductive Tools: Require the use of non-conductive tools during maintenance tasks to minimize the risk of accidental contact with live wiring.

- Provide Training: Conduct specialized training for maintenance personnel on elevator systems, emphasizing electrical safety protocols and procedures.
- Emergency Procedures: Establish clear emergency response procedures in case of electrical incidents during maintenance, including immediate shutdown and medical assistance protocols.

4. Hazard: UPS Panel Maintenance (Electric Shock)

- Perform Risk Assessments: Conduct comprehensive risk assessments before performing maintenance on UPS panels to identify potential hazards and implement appropriate controls.
- Provide Voltage Indicators: Equip maintenance personnel with voltage indicators to verify the status of the UPS system before starting any work.
- Safe Handling of Batteries: If the UPS system includes batteries, ensure that maintenance personnel are trained in safe battery handling and wear appropriate protective gear.
- Establish Safe Work Zones: Establish and clearly mark safe work zones around the UPS panel to prevent unauthorized access and keep personnel at a safe distance during maintenance.

By incorporating these additional control measures, organizations can enhance their safety protocols and better protect maintenance personnel from the identified hazards. Regular training, risk assessments, and continuous improvement of safety procedures will contribute to maintaining a safer work environment. Addressing these top-ranked hazards with the appropriate control measures is essential to reduce the risk of accidents, injuries, or fatalities. By implementing these measures, organizations can create a safer working environment and protect maintenance personnel from potential harm while performing their duties. Regular training and safety protocols enforcement will also contribute to the effectiveness of these control measures.

5. CONCLUSION

In conclusion, this research paper presents a comprehensive and enlightening exploration of the hazards and risks associated with Industry 4.0 technology, with a specific focus on maintenance and service activities observed during an industry visit. The visit provided invaluable firsthand insights into the practical challenges and potential dangers that arise in real-world implementations of Industry 4.0. Utilizing the observations made during the industry visit as a foundation, the research rigorously applied the Hazard Identification and Risk Assessment (HIRA) methodology to systematically identify and analyze the various hazards encountered. This detailed hazard analysis allowed for a deep understanding of the safety implications of Industry 4.0 technologies and processes, shedding light on potential areas of concern that must be addressed to ensure the well-being of personnel and the smooth functioning of operations.

The outcomes of this research underscore the transformative potential of Industry 4.0, which promises increased efficiency, productivity, and technological advancements. However, it also emphasizes the need for a holistic approach to safety. The hazards identified serve as crucial touchpoints for organizations and industries seeking to embrace Industry 4.0 while preserving the safety and well-being of their workforce. The proposed control measures and recommendations outlined in this study provide practical and effective strategies to mitigate identified risks. By adopting these measures, industries can establish robust safety protocols, ensuring a secure and sustainable Industry 4.0 ecosystem that fosters innovation and growth without compromising on the safety of personnel. As Industry 4.0 continues to shape the future of various sectors, the findings from this research serve as a guiding compass for stakeholders, policymakers, and practitioners alike. Implementing the insights gained from this study will be pivotal in navigating the evolving landscape of Industry 4.0 with confidence, prioritizing safety, and building resilient frameworks that foster progress and well-being hand in hand. Through proactive risk management and adherence to best safety practices, Industry 4.0 can truly unleash its transformative potential and create a safer and more prosperous future for all.

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