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HUMAN FACTORS ENGINEERING FOR MITIGATING INDUSTRIAL HYGIENE HAZARDS IN MALAYSIAN LABORATORIES AND MANUFACTURING ENVIRONMENTS

Zafirah Zakaria[1], Tey Yu Xuan[1], Mimi H. Hassim *[1,2]

[1] UTM-MPRC Institute for Oil and Gas/Safety and Health Research Group, Universiti Teknologi Malaysia, Johor Bahru, Malaysia
[2] Institut Kebisingan dan Getaran (IKG), Universiti Teknologi Malaysia, Kuala Lumpur, Malaysia

Corresponding author: mimi@cheme.utm.my

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Abstract

This study explores the integration of human factors engineering (HFE) into industrial hazard mitigation, with a focus on ergonomic adjustment, noise reduction, and chemical exposure. The study took place in the Fluid Dynamic Laboratory, Universiti Teknologi Malaysia, and an industrial environment (Company X). Mixed methods were used, which included observational surveys and statistical analysis before and after the intervention. For the ergonomic risks, Rapid Upper Limb Assessment (RULA) was used. The result showed a reduction in the high-risk score from 7 to 3 after the redesign of the workstation. For noise exposure, the initially recorded 80 dB(A) was reduced to approximately 69.5 dB(A) after the implementation of personal protective equipment using the OSHA correction method. The HIRARC framework was used for the identification of chemical hazard risks associated with exposure to corrosive materials during electrodeposition. The overall result demonstrated that the customised HFE intervention was efficient in mitigating risk and eventually improving worker safety and performance. The application of HFE concepts is advised to be implemented in both educational and industrial settings to improve the occupational health and safety in general.

Keywords: Human Factors Engineering; Industrial Hazard Mitigation; Ergonomics; Noise Control; Chemical Safety.

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1.0 INTRODUCTION

The integration of human factors engineering (HFE) in addressing industrial hygiene hazards is essential in enhancing workplace safety and health standards. This study digs deeply into this integration, with a particular focus on ergonomic risks, noise pollution, and chemical exposures in industrial settings. The urgency for such an integration is underlined by alarming global statistics. The International Labour Organisation [1] claims that workplace accidents and diseases cause over 2.3 million deaths each year, which exceeds 6,000 deaths per day. This number comes from the fact that there are about 340 million work-related accidents and 160 million work-related illnesses each year. In a more specific sense, dangerous chemicals cause an estimated 651,279 deaths per year.

In Malaysia, the Social Security Organisation (SOCSO), or PERKESO, is the important body that preserves the welfare of employees. It was established under the Employees' Social Security Act 1969. PERKESO provides financial assistance and support for work-related accidents, diseases, or disabilities. It also administers the Employment Insurance System (EIS), which aids workers who have lost their jobs. In 2022, PERKESO reported about 64,168 accident case reports, with 35,015 cases related to industrial and workplace accidents, including 864 fatalities [2]. On the other hand, the Department of Occupational Safety and Health (DOSH) under the Ministry of Human Resources complements the SOCSO's social protection role by enforcement through the Occupational Safety and Health Act (OSHA) 1994. By conducting inspections, developing regulations, and promoting training, the enforcement will guarantee the safety, health, and welfare of workers associated with occupational activities.

Human Factor (HF) studies, as defined by ICAO and Scerbo [3, 4], focus on optimizing human performance, health, safety, and habitability in various environments, emphasizing the interaction of humans with their living and working conditions, machines, and procedures. The Fukushima Daiichi nuclear disaster in 2011, primarily attributed to human factors such as overconfidence, complacency, and inadequate safety culture, exemplifies the disastrous consequences of ignoring these elements in safety management [5].

There is a significant connection between human factors and industrial hygiene hazards. Humans are not only the victims of workplace hazards but also the instigators. The idea of human factors engineering encourages the systems design to be compatible with the ergonomic, cognitive, and emotional capabilities. From an industrial hygiene point of view, the design's development is bound to prevent or minimise exposure to hazardous conditions and extend to how workers recognise, react to, and manage risk. Poor ergonomic workstation design leads to musculoskeletal disorders (MSDs). Moreover, an inadequate communication system is the root cause of delayed responses to chemical leaks. Therefore, HFE integration, which includes psychology, physiology, engineering, and design, improves the barrier by optimising human and system interactions. This enhanced the usage of protective equipment, clarified the hazard communication, and reduced the probability of human error under stress or fatigue. The integration is important, as even the most advanced systems could fail if their usability is not in line with human limitations and behaviours.

Ergonomics became an independent discipline in the 20th century. HFE also evolved alongside it. This evolution marked a significant step in understanding human-artefact interactions. This multidisciplinary field encompasses scientific, engineering, design, technological, and management principles. This leads to the arising systems that are compatible with human capabilities and limitations and, the same time focus on safety, productivity, and well-being. A growing public health concern, musculoskeletal disorders (MSDs), have seen a steady rise in cases reported by SOCSO from 2005 to 2014 [6]. HFE's role in designing ergonomic tools and workstations to reduce the physical demands of tasks demonstrates its potential in addressing such health concerns [7]. From 2019 to 2023, the MSD-related claims continued as one of the top occupational diseases, according to SOCSO's annual report [8]. These claims are mostly from workers in the manufacturing, logistics, and healthcare fields. Due to the continuous cases, it encourages more research and audits, which result in the cause, such as poor posture, repetitive motions, and prolonged static positions. This leads to upper limb disorders and lower back pain.

Existing research in HFE and industrial hygiene did not comprehensively combine ergonomic, noise, and chemical hazard issues specifically in both controlled conditions and real industry environments. Typically, researchers evaluate these hazards individually without considering their combined impact on worker wellness. Moreover, the previous research did not assess the HFE-driven solution practically. This research suggests a holistic and field-validated approach for this problem.

This study actively contributes to the advancement of workplace safety by applying HFE principles to develop, implement, and evaluate interventions aimed at mitigating ergonomic risks, controlling noise pollution, and minimising chemical exposures. This research was chosen to be performed at a controlled laboratory and a real industry setting to prove this study scientifically and practically. Laboratory settings deliver accuracy in terms of measurement and simulation under controlled conditions, while Company X is a suitable choice due to its high cases of MSD and noise-related complaints. This procedure is aligned with the objective of this study, which is to assess the effectiveness of integrated HFE-based interventions for workplace hazard reduction and improving healthy working environments.

Through the application of a robust HFE framework, the research provides unique solutions to ergonomic issues, noise reduction strategies, and chemical safety protocols. The results showed how well this intervention works, setting a guideline for the practical application of HFE in improving occupational health and eventually forming a safer, more responsive environment for workers.

In conclusion, there is a need for effective safety communication and a positive safety culture because occupational accidents and diseases have caused millions of deaths annually. Adopting HFE as a multidisciplinary approach to design a system that is compatible with humans aims to significantly reduce the risk of hazardous chemical exposure and noise pollution. With this study, adverse health effects will be reduced, promoting workplace safety and well-being.

2.0 METHODOLOGY

This study uses a quasi-experimental, field-based design that has two parts, which are observational and interventional. This took place in a controlled academic lab, where the ergonomic and safety interventions were tested, and in a real industrial setting (Company X) to carry out the assessment and implementation. The Human Factors Engineering (HFE)-based solution was measured before and after the intervention to test the applicability. For six months, data that are relevant to industrial hygiene and occupational risk assessment were gathered.

This research adopts a systematic and sequential approach, depicted in Figure 1 of the thesis, encompassing problem identification, formulation of research questions, data collection, analysis, and reporting. The study begins with a thorough literature review covering areas like industrial hygiene, forming the foundation for identifying research gaps.

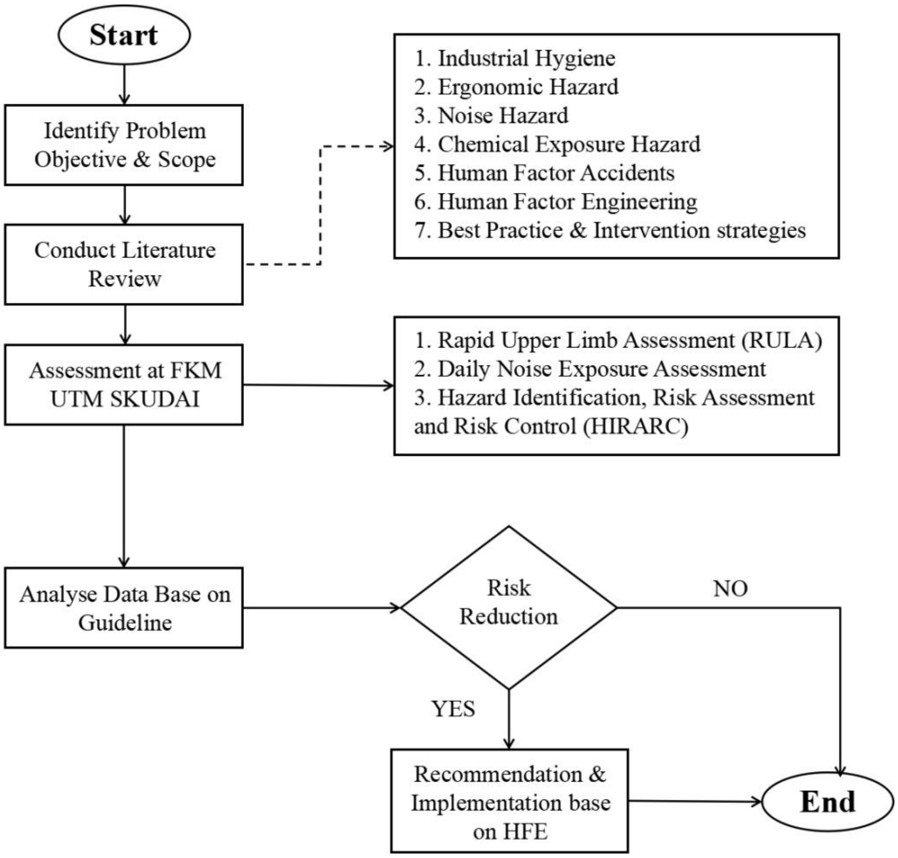

Figure 1. Flow chart of overall research design

Participants were selected by purposeful sampling with the criteria that they are exposed to relevant hazards. The three individuals selected for the study are Operator A, Student B, and Student C. The noise assessment was evaluated by lab students in the Fluid Dynamics Laboratory. The chemical hazard assessment specified the hazardous process in the Materials Engineering Laboratory with no direct individual participation.

The methodology of this study integrates multiple assessment tools and strategies. The Rapid Upper Limb Assessment (RULA) evaluates ergonomic risks, focusing on upper limb postures and movements. Daily Noise Exposure Assessment follows Health and Safety Executive guidelines to quantify workplace noise levels. The Hazard Identification, Risk Assessment, and Risk Control (HIRARC) method identifies and assesses chemical hazards as per DOSH guidelines. The study also employs the Prevention Through Design (PtD) concept, integrating Human Factors Engineering principles to develop risk mitigation strategies for ergonomic, noise, and chemical hazards. This comprehensive approach ensures a thorough analysis and effective mitigation of industrial hygiene hazards.

2.1 Ergonomic Hazard Assessment

The RULA score, as depicted in Figure 2 and Table 1, is derived through a series of systematic evaluations, resulting in a final score that dictates the urgency of intervention required to mitigate ergonomic risks [9]. A single qualified researcher who had received a formal course in ergonomic risk evaluation conducted the RULA assessment. The rater did calibration exercises using a standard RULA posture example before conducting the assessment to ensure the consistency and accuracy. The inter-rater reliability was not measured, but the standardised RULA rules and scoring were maintained throughout.

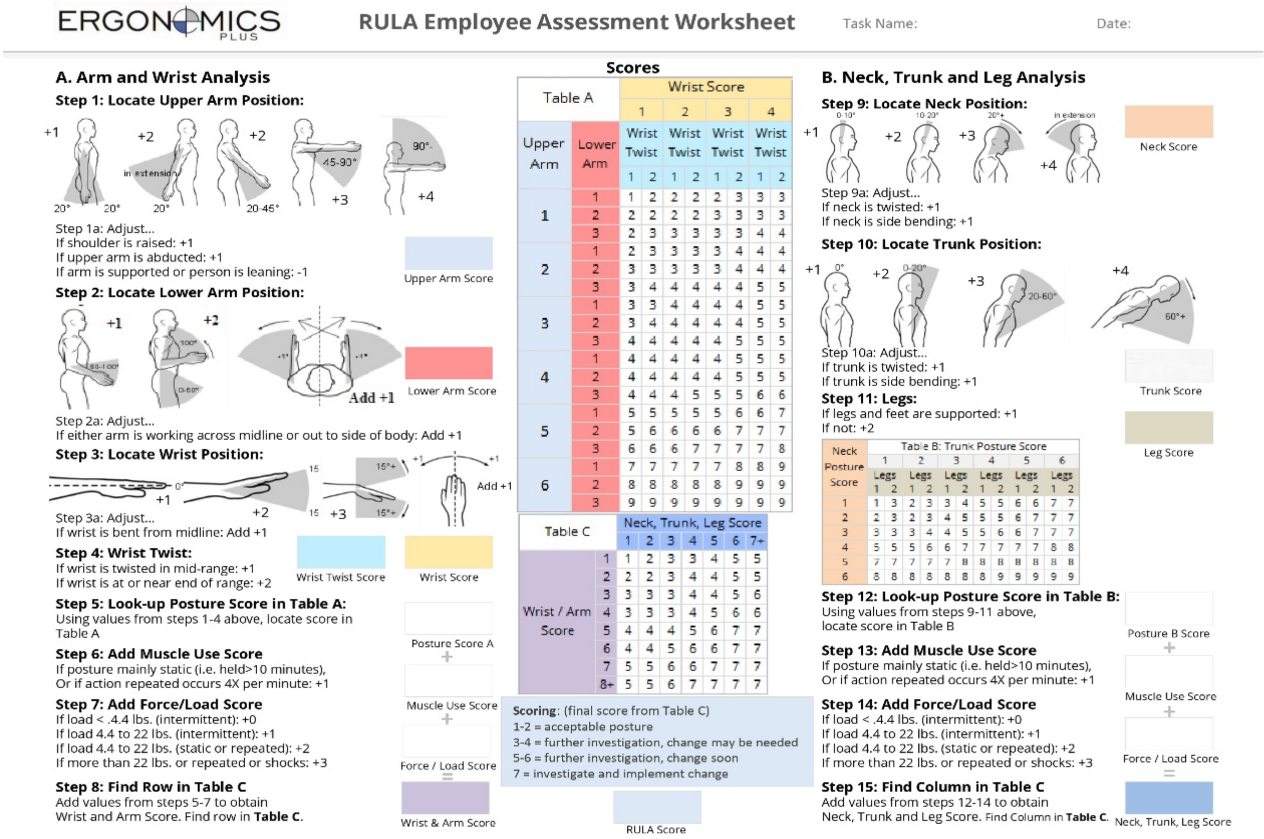

Figure 2. Standard format for RULA [9]

Table 1. Required Actions Based on RULA Final Score

Total final score	Action
1-2	Acceptable posture
3-4	Further investigation, change may be needed
5-6	Further investigation, change soon
7	Investigate and implement change

2.2 Noise Hazard Assessment

The Daily Noise Exposure Assessment uses a quantitative analysis to determine the workers exposure to noise levels. The assessment was conducted using a Type 2 Sound Level Meter (Model: Extech 407732) that met IEC 61672-1 standards. Before and after each measurement, a 94 dB acoustic calibrator at 1 kHz was used to ensure the accuracy. During typical job activities, measurements were taken at ear level. Each reading took approximately 10 minutes, and multiple readings were taken during an 8-hour work shift to identify how exposure levels have changed. Environmental conditions such as room temperature and humidity were recorded while background noise levels were kept below 50 dB to maintain data reliability.

Equation (1) defines the Exposure Point (EP) approach used in this assessment. It finds the EP by looking at the length of time of exposure and the equivalent continuous A-weighted sound pressure level (LAeq) [10]. Equation (2) shows how to use the EP to determine the daily personal noise exposure level (LEP,d). This gives a standard way to check if hearing conservation measures are needed.

$$EP = 100\frac{T_e}{T_o}10^{\left(\frac{L_{Aeq,T_e}-85}{10}\right)} \quad (1)$$

$$L_{EP,d} = 85 + 10\log_{10}\left(\frac{EP}{100}\right) \quad (2)$$

2.3 Chemical Hazard Assessment

HIRARC is a method to manage risks that includes classification of work activities, identification of possible hazards, risk assessment, and implementation of control measures. This study uses HIRARC to assess the etching process in the Materials Engineering Laboratory, which used ferric chloride ($FeCl_3$). Ferric chloride is a corrosive chemical that can enter your body through inhalation, absorption by skin, or getting into your eyes, especially when handling without proper ventilation and inappropriate protective equipment.

Table 2. Risk Matrix, HIRARC [11]

		Severity (S)				
		1	2	3	4	5
Likelihood (L)	5	Medium 5	Medium 10	High 15	High 20	High 25
	4	Medium 4	Medium 8	Medium 12	High 16	High 20
	3	Low 3	Medium 6	Medium 9	Medium 12	High 15
	2	Low 2	Low 4	Medium 6	Medium 8	Medium 10
	1	Low 1	Low 2	Low 3	Low 4	Medium 5

During the risk assessment phase, possible events were given a score from 1 to 5 based on likelihood and severity [11]. A common 5×5 colour-coded risk matrix was used to reflect the combined risk ratings [Table 2]. This risk matrix can be used to determine the risk score and eventually determine the risk of chemical exposure. Therefore, protective and administrative control can be planned for control measures.

2.4 Prevention Through Design

After the evaluative measures conducted through RULA, noise exposure assessment, and HIRARC, the research will pivot to a prescriptive stage. In this stage, informed by the Prevention Through Design (PtD) paradigm, recommendations will be systematically derived to integrate Human Factors Engineering (HFE) into the redesign of workplace systems and environments. The aim is to proactively curtail ergonomic, auditory, and chemical risks. This will involve a strategic redesign of workstations, the incorporation of materials to dampen noise, and the selection of less hazardous chemicals. This methodology underscores a commitment to bolstering worker welfare and safety by embedding HFE into the design process, thereby enhancing the congruence between human capabilities and systems [12].

3.0 RESULTS AND DISCUSSION

In the following section, we elucidate the empirical results derived from a series of targeted assessments designed to address ergonomic, noise, and chemical hazards within industrial settings. The assessments were judiciously carried out in diverse environments, each chosen to shed light on specific HFE considerations.

Ergonomic Assessment: We detail the methodology and findings from the ergonomic evaluations conducted in the Fluid Mechanics Lab and Company X. These assessments involved participants such as Students B and C from the lab and Operator A from Company X, with a focus on revealing ergonomic challenges and offering remedial measures. Students B and C were chosen because they faced different exposure to ergonomic risk during laboratory tasks. Student B performed manual tasks that included awkward positions such as stooping and bending regularly. On the other hand, Student C conducted activities with little ergonomic strain. The purpose of comparing regular activities is to highlight the significant ergonomic hazards present in the different tasks.

Noise Assessment: This part of the results discusses the noise assessments for two specific tasks. The section provides an analysis of the noise exposure levels encountered and the subsequent recommendations for noise control measures to ensure auditory health and safety.

Chemical Hazard Assessment: We then present the outcomes of the chemical hazard evaluation conducted during the electrodeposition process of Zn-Cu onto steel cords within the Materials Engineering Laboratory. The assessment critically examines the hazards involved and discusses the efficacy of the existing control measures.

Each subsection is crafted to not only present a quantitative account of the findings but also to interpret these results within the broader context of HFE application in industrial hygiene. The aim is to offer a clear, data-driven narrative that underscores the potential of HFE interventions in enhancing workplace safety.

3.1 Evaluation and Mitigating Ergonomic Hazard

The study's findings, highlighted in Table 3, reveal critical ergonomic issues at the workstations of Operator A, Student B, and Student C, as indicated by their RULA scores. The high scores of Operator A and Student B necessitate immediate ergonomic intervention to mitigate the risk of musculoskeletal disorders. On the contrary, the lower score of Student C implies a more ergonomically sound workstation. These results, displayed in Table 3, underscore the importance of ergonomic design in preventing work-related health issues and enhancing productivity and job satisfaction, supporting findings from previous studies [13, 14, 15, 16].

Table 3. Total RULA score

Person	Posture Score A	Posture Score B	Total RULA Score
Operator A	7	6	7
Student B	5	6	7
Student C	4	3	3

The RULA assessment at Company X identified significant ergonomic risks in the product feeding workstation. Although job rotation strategies were implemented, the risk remained due to basic design issues, which is the manual feeding process that required operators to bend, twist, and reach repeatedly. This is because the conveyor height is fixed; furthermore, there is no automatic handling. Addressing this, the study proposes a redesigned conveyor system. This new design, showcased in Figures 3 and 4, involves a reconfigured Conveyor A, split into A1 and A2, and Conveyor B. Refer to Figure 5; A1's vertical movement allows alignment with B for product transfer, while its lower position directs products to A2 for buffering. This automated system is meant to reduce the physical handling and pressure on the operator's body from excessive bending, awkward reaching, and repetitive lifting during the product feeding process. The introduction of height-adjustable conveyors and automatic transfers between sections will minimise the physical work as well as promote ergonomic working posture. This procedure demonstrates a proactive approach for managing ergonomic risks.

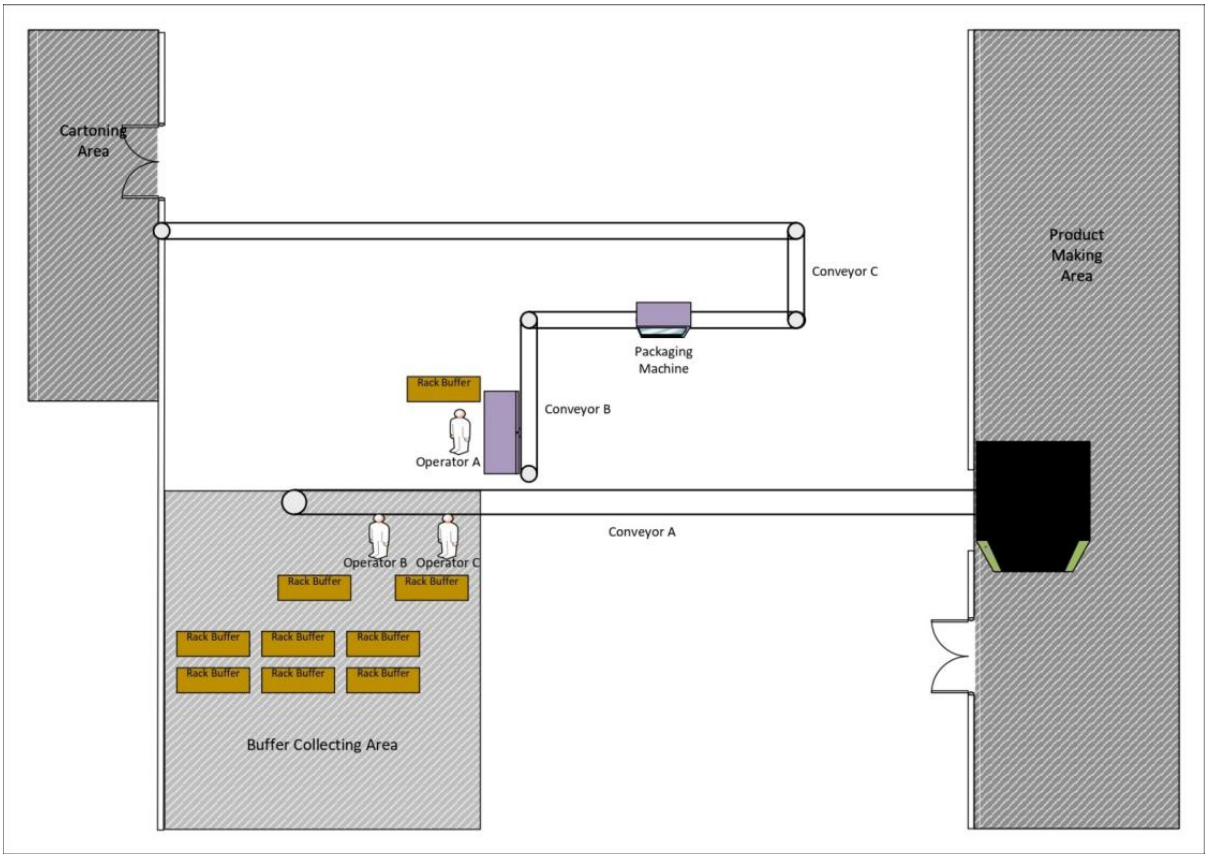

Figure 3. Layout of the current process flow

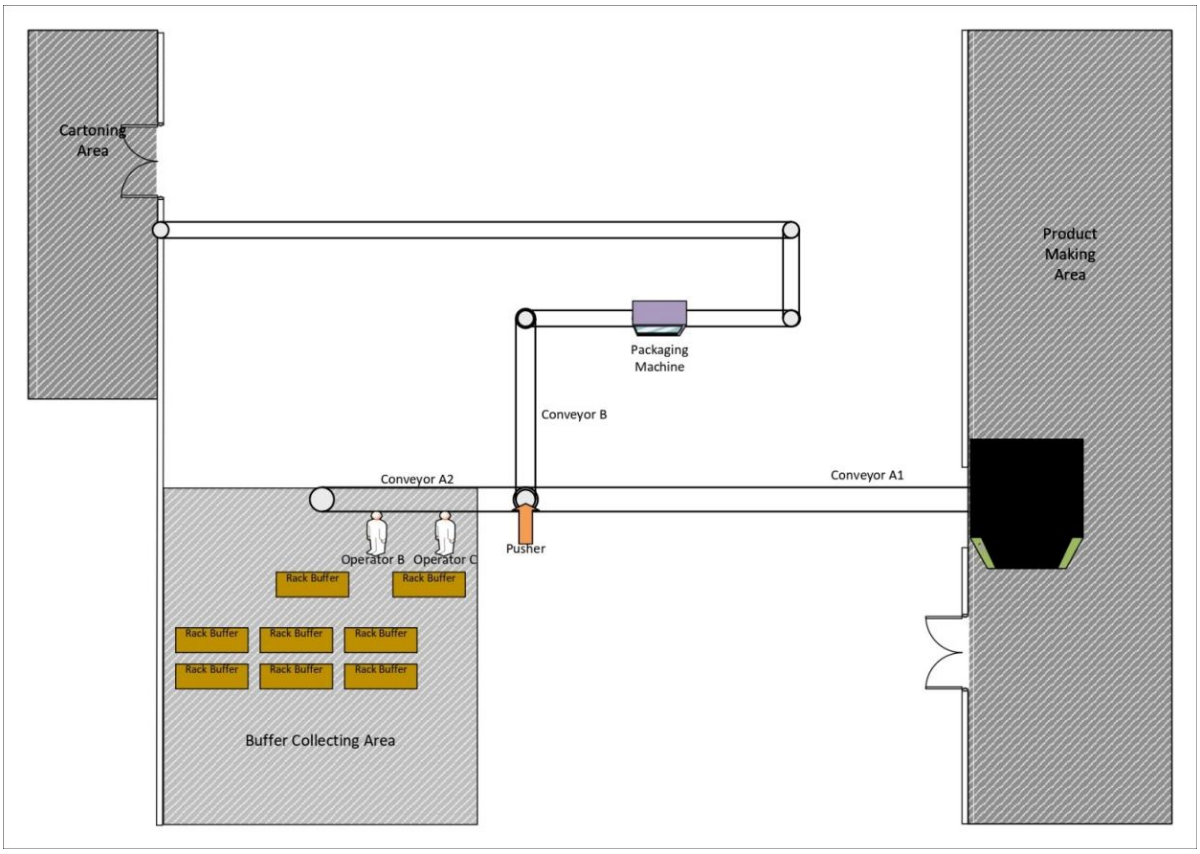

Figure 4. Redesigned Conveyor System Flow Layout

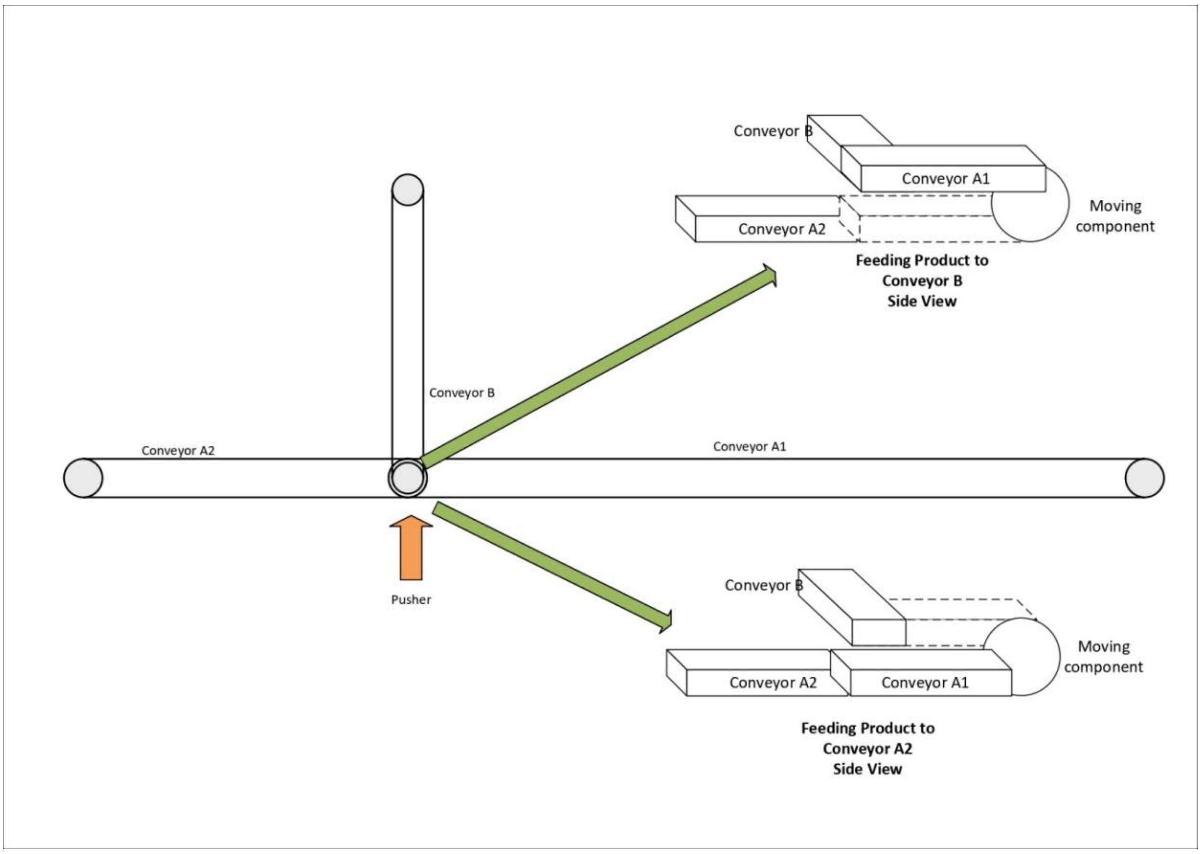

Figure 5. Conveyor Design

The redesign of Company X's conveyor system, incorporating a Programmable Logic Controller (PLC), effectively eliminates the need for manual handling of products by the feeder operator. This automation not only streamlines the workflow but also aligns with the hierarchy of control principles. Engineering controls (redesigning equipment and automating processes) are prioritised over less effective measures, like personal protective equipment (PPE) and administrative controls. By redesign, the ergonomic hazards associated with manual product feeding have been reduced. This change demonstrates a strong commitment to improving occupational health and safety in the workplace.

The ergonomic challenge faced by Student B in measuring water levels was addressed innovatively with the implementation of an Arduino-based water level sensor. This sensor, strategically placed in the tank, transmits water level data via a wired connection to a display board, appropriately positioned to eliminate the need for stooping or bending. This solution not only reduces the ergonomic risks associated with the task but also improves efficiency and accuracy in water level measurement. The integration of this technology, as discussed by Seffah et al. [17], showcases how ergonomic interventions in educational settings can enhance both physical well-being and operational efficiency.

3.2 Evaluation and Mitigating Noise Hazard

In the Fluid Dynamics Laboratory's noise hazard assessment, the focus is on the noise generated by a compressor used in an airflow and pressure measurement experiment. The compressor produced intermittent noise, mostly occurring during pressure build-up and air release phases. Even though it was not continuous, the bursts of noise were frequent and intense enough to contribute to considerable daily noise exposure. The ambient background noise level in the laboratory was maintained below 50 dB(A) during the assessment. The aim is to ensure that the value to be measured is accurately read from the compressor noise rather than environmental interference. Noise measurements for each task were taken multiple times during operations.The mean noise levels with standard deviation are presented in Table 4. For example, tasks such as controlling the valve and recording pressure drop data reach a noise level of 80 dB(A), with a daily exposure of 68.84 dB(A).

Table 4. Noise level for each task performed.

Task name	Mean Noise level ± SD (dB(A))	Daily exposure time		Points per Hour	Daily exposure, L EP,d (dB(A))
		Hr	Min		
Adjust Air Flow Valve	80.2 ± 1.5	0	45	2	68.84
Record Data	79.6 ± 1.5	0	45	2	68.84

In the study, earmuffs with a Noise Reduction Rating (NRR) of 28 dB were used as a protective measure against a noise level of 80 dB(A). The effective noise exposure level to the students' ears was significantly reduced when the earmuffs were worn correctly. The NRR was estimated using the OSHA method. 7 dB is subtracted from the NRR, and then the result is divided by 2. For earmuffs with an NRR of 28 dB, the estimated protection value is (28 – 7) ÷ 2 = 10.5 dB. Therefore, the compressor noise level of 80 dB(A) was effectively reduced to approximately 69.5 dB(A) at the ear, keeping exposure within acceptable limits.

The correct and consistent use of earmuffs is important so that they offer the intended level of protection against noise. For this study, when involving the compressor, the student wore earmuffs for 45 minutes. Technically, earmuffs were comfortable for short-term use; however, some students reported some discomfort for longer usage as heat and pressure accumulated around the ears. While earmuffs are an effective defence against hearing loss, it is imperative to acknowledge that high levels of environmental noise can have broader health implications. These can include increased stress levels and reduced concentration, which are particularly important to manage within educational settings [18]. Monitoring these non-auditory effects of noise is essential for the overall well-being of individuals exposed to noisy environments.

For subsequent research and practical applications, it is recommended to investigate the use of sound-dampening materials and architectural designs to mitigate noise in laboratory settings. Future strategies should also consider the optimal scheduling of high-noise activities to minimise auditory impact on the surrounding population. Ongoing monitoring of noise levels is essential to ensure they stay within established safety parameters. These proactive steps are crucial for preserving hearing and enhancing the acoustic environment in educational and industrial settings.

3.3 Evaluation and Mitigating Chemical Hazard

This section elaborates on the chemical hazard assessment for the electrodeposition of Cu-Zn on steel cords, conducted via the HIRARC method at the Materials Engineering Laboratory. It focuses on identifying and evaluating the chemical hazards inherent in the process, based on task observations and theoretical analysis. Although other hazards such as physical and electrical were present, they were not examined in this study. During the electrodeposition activity, a local exhaust ventilation (LEV) system was in place and functioning. However, quantitative air quality monitoring was not performed, and the risk evaluation was conducted based on material safety data sheets (MSDS), standard chemical handling practices, and observed task procedures. The emphasis is on chemical risks, underlining the need for effective hazard management and mitigation in the lab setting. The findings from this assessment are crucial for providing recommendations that ensure safety and regulatory compliance during the electrodeposition procedure.

In evaluating chemical hazards during electrodeposition, it's essential to analyse the specific chemicals involved and their potential risks. Table 4.11 in the study extensively details these chemicals, such as sulphuric acid and sodium hydroxide, which are notable for their corrosive properties and associated health hazards. The implementation of robust safety measures and protocols is paramount. These measures are vital for ensuring safe chemical handling and adhering to industrial hygiene and safety guidelines and underline the need for thorough risk mitigation strategies in such processes.

Table 5. Chemicals use in the electrodeposition of Zn-Cu to Steel Cords

Chemicals	Hazard
Sulfuric Acid (H_2SO_4)	Corrosive; severe burns; harmful if inhaled
Sodium Hydroxide (NaOH)	Caustic; severe burns; harmful if inhaled/swallowed
Copper Sulfate Pentahydrate ($CuSO_4{\cdot}5H_2O$)	Skin/eye irritation; harmful if swallowed; environmental hazard
Zinc Sulfate Heptahydrate ($ZnSO_4{\cdot}7H_2O$)	Respiratory irritation; similar to copper sulfate
Potassium Sodium Tartrate Tetrahydrate ($C_4H_4KNaO_6{\cdot}4H_2O$)	Mild irritant
Bismuth Sulfate ($Bi_2(SO_4)_3$)	Toxic if ingested/inhaled/absorbed; skin risk
Sodium Metasilicate (Na_2SiO_3)	Irritant to skin, eyes, mucous membranes
Sodium Phosphate (Na_3PO_4)	Mildly irritating to skin/eyes; digestive discomfort if ingested

In developing comprehensive risk mitigation strategies for electrodeposition processes, the study advocates a multi-faceted approach:

Substitution Principle: Prioritising the replacement of hazardous chemicals with safer alternatives without compromising process efficiency. This approach is supported by research demonstrating successful applications of alternative chemicals in electrodeposition processes [19].

Process Modification: Introducing automated dispensing systems can significantly reduce human contact with chemicals, thus lowering exposure risks. This involves precise mechanical handling and transfer of chemicals in enclosed systems to prevent the escape of fumes [20, 21].

Closed-System Transfer Devices (CSTDs): Implementing CSTDs is essential for safely handling hazardous chemicals, as evidenced by their effectiveness in limiting occupational exposure to dangerous compounds in medicals [22].

Administrative Controls: Developing and enforcing strict protocols for chemical handling, storage, and disposal is critical. These protocols should be supplemented with comprehensive training sessions for personnel, ensuring awareness and understanding of risks and the correct use of PPE such as chemical-resistant gloves, lab coats, safety goggles, and face shields.

Advancements in PPE: Leveraging the latest developments in material science, the use of multi-layered protective gloves (e.g., EN 374-compliant for chemical resistance), chemically resistant clothing(e.g., EN 13034 for limited chemical splash protection), and full-face respirators with appropriate filters (e.g., EN 136 for respirator facepieces) should become standard practice to provide better protection against chemical penetration.

4.0 CONCLUSION

In conclusion, this research indicated that human factors engineering (HFE) enhances the industrial hygiene hazard mitigation. This finding is supported by pre- and post-intervention assessment. Using RULA and noise exposure levels, the implementation of HFE-based proves significant improvement. This confirms the effectiveness of these interventions. The integration of ergonomic redesign, hearing measures, and chemical risk assessment between real and simulation provides a data-driven approach to hazard control. The importance of integrated safety management was highlighted, which is to align environmental and occupational risk with human-centered design. For future research, the long-term effectiveness of these interventions can be explored in more sectors and worker populations. Moreover, there is bright potential for enhancement of hazard identification and control using Artificial Intelligence (AI) and the Internet of Things (IoT). An example could be AI-driven ergonomic analysis that enables real-time detection of posture or predicts risk. Additionally, IoT-based sensor networks can perform continuous noise monitoring, air quality monitoring, and chemical exposure monitoring. With these responsive and predictive safety systems tools, more proactive risk management will be achieved. With these innovations, combined with HFE principles, there could be a trigger for the full potential to increase workplace safety by making systems smarter, more adaptive, and aligned to human capabilities.

Acknowledgements

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