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Enhancing Productivity in Smart Trowel Indoor Court Operations: A Systematic Ergonomic Evaluation through HIRARC, RULA, and CTA Assessments

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ABSTRACT

The major cement finishing steps are floating and trowelling. The prevailing ergonomic standards are not adequately met by the currently available walk-behind power trowels, exposing operators to postural hazards poor transportation and require excessive repetition, which consumes time and money. This research aims to detect work tasks hazard, postural risks and tasks process during power trowel transit and trowelling. In addition, this research examines the transportation process to provide smart power trowel enhancement. Finally, propose a better power trowel design. Interviews and observation revealed issues. The study evaluates ergonomics assessments method including Hazard Identification Risk Assessment and Risk Control (HIRARC), Rapid Upper Limb Assessment (RULA), Cognitive Task Analysis (CTA). The results of RULA score dropped from 7 to 3 in comparison to current trowel. By employing HIRARC, 5 risks factors and hazard have been identified in the current power trowel employment process. Enhanced blade configuration, design, and transport attributes alleviate the issues. The assessments indicate a 4° blade angle and 15 mm thickness, including a 2-ton bottle-jack that elevates a smart trowel in two strokes. This study decreased awkward posture, repetitive work, and intense exertion. The comparative evaluation of conventional and smart trowels unequivocally establishes the efficacy of ergonomic interventions in attenuating inherent risks and enhancing the holistic well-being of operators engaged in the transportation and trowelling processes.

Keywords: Identification Risk Assessment and Risk Control (HIRARC), Rapid Upper Limb Assessment (RULA), Cognitive Task Analysis (CTA), Indoor Sports Smart Trowel

1. POWER TROWELS AND ERGONOMICS ISSUES

The construction operation has undergone an upheaval, encouraging contractors to streamline processes to ensure optimum efficiency at low cost. Precision, accuracy, efficiency, and cycle time must be meticulously adjusted for the most effective outcomes. The industry has focused on educating personnel or automating procedures to improve expanding rates and quality in a competitive market. Since the construction sector accounts for 10–20% of the GDP in most nations and is the largest employment, its economic relevance is vital [1]. The industry's reliance on labour and repetitive activity emphasises its importance in national economic growth. Due to increased competition, a scarcity of experienced personnel, and technical advances, the construction sector is automating [1].

Research on automated concrete trowelling and finishing is needed to fulfil construction industry expectations. Malaysians finish wet concrete with hand and walk-behind trowels [2]. More industrialised nations choose self-propelled riding trowels with one to three revolving rotors for

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automated trowelling. Ride-on power trowels are efficient but typically neglect operator comfort and safety. Current power trowels' design inefficiencies require repetitive effort, wasting time and labour. Innovative machinery changes to improve operator comfort and safety, work quality, and efficiency are needed to address these difficulties [3,14].

The current trowelling process of transporting and operating the power trowel involves awkward posture, repetition of work, and forceful exertion which can lead to posture injuries. Ergonomic potential risks, safety, and comfort issues need to be studied to understand the problem. The existing transferring and transporting method of heavy immobile power trowels involves multiple tools to aid the transporting process. The additional steps required are time and labour-intensive. The process needs to be studied to identify the minimum time and portability of the process [4]. The current trowelling operation involves repetition of work while working with cement and concrete. The design structure of the blade has been identified as the main problem of inefficiencies in the process [3,4].

The study's primary objectives focusing on the identification and mitigation of ergonomic posture risks associated with the carrying and trowelling process of a walk-behind power trowel. The research employs the Rapid Upper Limb Assessment (RULA) method to systematically analyse and identify potential ergonomic challenges in the execution of these tasks. Concurrently, safety concerns are addressed through the application of Risk Assessment and Risk Control (HIRARC) methodologies. The study also aims to assess the current transportation procedure through cognitive task analysis, with a specific focus on identifying opportunities for improvement. Recommendations for enhancement include the potential removal of certain procedural steps and the incorporation of supportive features or tools to facilitate and optimize the efficiency of the carrying and trowelling work. Through these objectives, the research endeavours to contribute valuable insights and practical solutions to enhance both ergonomic considerations and safety measures in the context of walk-behind power trowel operations.

2. CONCRETE TROWELLING PROCESS AND CHALLENGES

The finishing process in concrete construction involves several crucial phases, namely screeding, floating, and trowelling [3,4,15]. Screeding, or the cutting of excess concrete to achieve the desired surface grade, employs a straightedge in manual methods or a vibratory screed when coupled with vibrators. The goal is to create a levelled surface with a slight surcharge of concrete to fill in low places. Following screeding, consolidation, and bull floating are conducted before excess water accumulates on the surface. Floating, the subsequent phase, involves the use of a bull float or darby to remove high and low spots and embed large aggregate particles. Edging follows, compacting concrete next to shapes, joints, and insulation areas, making it more resilient. The final phase, trowelling, creates a flat, rough, and dense surface. It is crucial to avoid premature trowelling, as it can lead to surface defects, while additional trowelling enhances smoothness, density, and wear resistance [4].

Figure 1: Concrete Trowelling Process Operators

In the proposed process, the study focuses on floating and trowelling, aligning with the limitations and scope. While screeding is crucial, it is often carried out using specialized machinery. The

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selected process corresponds with the predominant function of existing power trowels available in the market, which are designed specifically for floating and trowelling concrete surfaces. The emphasis on these phases is aligned with the practical nature of the construction process and the machinery's design and functionality.

In conclusion, the study delves into the intricacies of the finishing process, emphasizing the importance of screeding, floating, and trowelling in achieving a desired concrete surface. The proposed focus on floating and trowelling aligns with the existing market trends and the practical considerations of the construction industry, particularly in the use of power trowels. This research aims to contribute valuable insights into optimizing these critical phases for enhanced efficiency and quality in concrete finishing.

3. HAZARD IDENTIFICATION RISK ASSESSMENT AND RISK CONTROL (HIRARC), RAPID UPPER LIMB ASSESSMENT (RULA) AND COGNITIVE TASK ANALYSIS (CTA) FOR POWER TROWELS

3.1 Hazard Identification Risk Assessment and Risk Control (HIRARC)

Ergonomic risk factors encompass elements such as awkward posture, sustained activity, repeated motion, static posture, friction, contact stress, and environmental factors. Two prominent safety assessments, Workplace Ergonomic Risk Assessment (WERA) and Hazard Identification, Risk Assessment and Risk Control (HIRARC), are highlighted for their relevance to the research. WERA is an analytical tool designed for rapid job screening, focusing on six risk factors during physical tasks, including stance, repetition, force, friction, touch tension, and task duration [5]. The assessment involves scoring tasks based on the risk factors, providing insights into the need for alternative countermeasures. It proves valuable during the production phase, facilitating alterations before mass production and requiring minimal resources for implementation. HIRARC, on the other hand, serves as a foundational risk management tool, involving hazard identification, risk assessment, and risk control. It is integral to planning and managing company operations, providing a structured approach to identify and mitigate current and future hazards. The risk matrix in HIRARC aids decision-making by calculating risk based on likelihood and severity, guiding corrective actions to mitigate or eliminate identified risks [6]. This comprehensive safety assessment contributes to improved work practices and safety measures in the workplace. The outcomes of the risk assessment provided in the risk matrix are important for decision-making on risk management. This equation can be used to calculate the risk:

$$\text{"Risk " ("R")" = Likelihood " ("L")" × Severity (S)"} \quad (1)$$

The effectiveness of ergonomic safety assessments lies in their ability to identify and mitigate potential risks associated with work activities. WERA's focus on specific risk factors provides a targeted approach for rapid job screening, enabling timely interventions. HIRARC, with its systematic hazard identification and risk assessment process, serves as a foundational tool for risk management, contributing to positive changes in work practices [7]. The risk matrix in HIRARC enhances decision-making by quantifying risks, leading to informed corrective actions. Both assessments contribute to fostering a safer work environment by addressing ergonomic risk factors and facilitating the implementation of countermeasures to enhance worker safety and well-being.

3.2 Ergonomics Postural Assessment

In the pursuit of obtaining new insights for the research, various assessments are crucial, and this subchapter delves into the comprehensive realm of ergonomic posture assessment methods. Postural assessment serves as a pivotal tool for scrutinizing work activities, offering valuable insights into the risk of musculoskeletal injuries associated with different postures. Various

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assessments vary in the body parts evaluated and the specific work activities under focus. Notably, the assessment approach contributes to the design process by identifying potential ergonomic alterations throughout different stages of the product life cycle. Among the notable postural assessment methods discussed are the Ovaco Working Analysing System (OWAS), Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA), and Novel Ergonomic Postural Assessment Method (NERPA) [8,9]. Each method offers distinctive features, such as OWAS's classification of 28 body postures and RULA's real-time ergonomic evaluation of manual activities. REBA stands out as a cost-effective method requiring minimal resources, while NERPA, a modified version of RULA, introduces a 3D modelling tool to enhance posture evaluation and identify ergonomic danger postures more effectively [10].

The selected postural assessment methods play a crucial role in the ergonomic evaluation of concrete finishing tasks, such as floating and trowelling. The methodologies discussed offer a nuanced understanding of the impact of body postures on the risk of musculoskeletal injuries, enabling researchers to make informed decisions for optimizing work conditions and minimizing ergonomic risks. By employing these assessments, the study aims to enhance the design of the concrete finishing process by identifying potential ergonomic changes and fostering a safer and more efficient working environment.

3.3 Work Task Analysis Assessment

Task analysis is a crucial practice in understanding how individuals perform tasks and achieve their objectives by studying their actions in motion. It goes beyond intuition and speculation, providing a methodical approach to comprehending user tasks and refining research directions. Task analysis is particularly valuable for recognizing essential activities, determining content scope, and gaining insights into user behaviour [11]. Among the various types of task analysis, two predominant approaches are Cognitive Task Analysis (CTA) and Hierarchical Task Analysis (HTA). CTA delves into the cognitive processes underlying task success, incorporating insights on awareness, thinking processes, and objective frameworks. It utilizes interview and observation techniques to gather detailed accounts of both overt actions and latent cognitive processes. The five-step process involves collecting primary knowledge, identifying knowledge representations, applying focused elicitation methods, analysing, and verifying acquired data, and formatting results for the intended application [12].

In contrast, HTA is a formal and analytical method for explaining task success by breaking down tasks into main goals and sub-goals. This approach provides a comprehensive understanding of user activities and their relationships, allowing for exploration of alternative paths to task completion. HTA focuses on three fundamental principles: main goals, sub-goals, and the relationship between them. The steps involved in HTA include identifying primary task goals, delineating detailed steps to accomplish the task, and identifying optimizations for those steps [13]. Both CTA and HTA contribute valuable insights into user behaviour and task performance, offering systematic approaches to inform research and design decisions.

4. RESULTS AND DISCUSSION

This chapter presents the findings of the research conducted, which involved various methods such as interviews and observations to collect essential data for ergonomic assessments using Hazard Identification, Risk Assessment, and Risk Control (HIRARC), Rapid Upper Limb Assessment (RULA), and Cognitive Task Analysis (CTA) method. The focus was on the walk-behind power trowel, given its prevalence compared to the ride-on power trowel. RULA and HIRARC assessments were employed to identify ergonomic risks associated with the transportation and trowelling processes of the walk-behind power trowel. Concurrently, CTA was conducted to comprehensively understand the tasks involved in transporting the walk-behind power trowel to the worksite. The results aim to provide insights into ergonomic considerations

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and risk factors associated with the use of the walk-behind power trowel, contributing valuable information for further analysis and potential improvements in the design and operation of such equipment.

4.1 Current Walk-Behind Power Trowel HIRARC Results

The Hazard Identification, Risk Assessment, and Risk Control (HIRARC) process were applied to analyse various work activities associated with the operation of the walk-behind power trowel. The first step involved identifying and scrutinizing the steps from the initial transporting process to the final brooming process. Among the identified work activities, changing the type of blade emerged as a significant hazard, particularly the risk of improperly mounted blades causing injuries due to their sharp edges. The hazard's severity was deemed high, leading to the recommendation of designing a multipurpose blade to eliminate the need for frequent changes. The second activity, lifting the power trowel, highlighted hazards related to the weight of the equipment and awkward lifting postures, with a recommended risk control of designing a proper handle and reducing the overall weight. Steering the power trowel, the third activity, revealed hazards associated with extended exposure to awkward handling postures, proposing the design of a power trowel prioritizing operator comfort as a risk control measure. Additionally, maintaining the power trowel in place and trowelling large-scale slabs presented risks of direct vibration exposure, suggesting the need for alternative handling methods and improved blade configurations to reduce exposure time, respectively.

Table 4.1 shows the findings that emphasize the importance of addressing design considerations and introducing ergonomic features to mitigate risks and improve overall operational safety for current walk-behind power trowel.

Table 2 shows some examples of the indicators that can be used to assist in determining the score. This just the indicators and may not be applicable for certain situation. **Respondents' response** and **opinion** should be the **main indicator** as they are the one that feel the intensity of the activity being performed.

Table 1: Current HIRARC of Walk-Behind Power Trowel

Process: Transporting and utilizing the walk-behind power trowel								
Hazard identification				Risk analysis				Risk Control
No	Work Activity	Hazard	Effect	Existing Control	L	S	Risk	Recommendation
1	Changing the type of blade	Improperly mounted sharp-edged blades	Sharp-edged blades may cause major and minor injuries	Multiple fastening points for a single blade	4	5	20	Eliminate the need to change blades by designing a multipurpose blade.
2	Lifting the power trowel at the guard ring	The large weight of the power trowel and the awkward lifting posture	Muscle fatigue and injuries to the muscles and joints	Lifting the power trowel with a crane	3	3	9	Design a proper handle specified for lifting / reduce the weight of the machine
3	Steering the power trowel by exerting force to the handle	Extended awkward handling posture	Muscle fatigue and injuries to the muscles and joints	Not available	3	3	9	Design a power trowel catering to the comfort of the operator

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4	Maintaining the power trowel in place by gripping the handle	Direct vibration extendedly exposed to the operator	Carpal tunnel disease and white finger disease	Not available	4	3	12	Purpose a different method to handling the power trowel

Table 2: Improvements made to improvised hazards of existing Walk-Behind Power Trowel.

No.	Work Activity	Hazard	Effect	Recommendations	Improvements made
1	Changing the type of blade	Improperly mounted sharp-edged blades	Sharp-edged blades may cause major and minor injuries	Eliminate the need to change blades by designing a multipurpose blade.	Smart trowel designed with multi-purpose combination blade.
2	Lifting the power trowel at the guard ring	The large weight of the power trowel and the awkward lifting posture	Muscle fatigue and injuries to the muscles and joints	Design a proper handle specified for lifting / reducing the weight of the machine	Smart trowel designed with two hydraulic handles. Smart trowel fabricated from lightweight metal alloy.
3	Steering the power trowel by exerting force to the handle	Extended awkward handling posture	Muscle fatigue and injuries to the muscles and joints	Design a power trowel catering to the comfort of the operator	The smart trowel is remotely controlled eliminating manual control.
4	Maintaining the power trowel in place by gripping the handle	Direct vibration extendedly exposed to the operator	Carpal tunnel disease and white finger disease	Purpose a different method to handling the power trowel	The smart trowel is remotely controlled eliminating manual control.
5	Trowelling a large-scale slab for a long period	Extended exposure to vibration and extended awkward posture	Muscle injuries and carpal tunnel disease.	Suggest a better blade configuration to reduce the number of passes	The smart trowel is designed with two rotating blade configurations containing eight blades.

4.2 Rapid Upper Limb Assessment (RULA) Results of Existing Walk-Behind Power Trowel.

The Rapid Upper Limb Assessment (RULA) was systematically employed by analysing video footage depicting the operator's activities, both in transporting the walk-behind power trowel onto the construction site and during its utilization for the trowelling process. Two critical postures were considered for assessment: the first pertained to the operator's posture during the transportation of the trowel machine onto the working site, and the second focused on the operator's posture while engaging in the trowelling process using the walk-behind power trowel. Notably, the method of transportation was assessed without the aid of wheel support, reflecting the prevalent manual labour approach adopted by many construction companies. In meticulous detail, screenshots were captured to precisely measure the angles of limb movements, utilizing a protractor on the computer screen. The process involved hoisting the walk-behind power trowel by two or more workers from a transport vehicle onto the working surface, with the power trowel held at the guard ring. Multiple screenshots from video recordings were strategically taken to offer diverse angles for a comprehensive observation of each limb's movement.

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Figure 2: Worker lifting a walk-behind power trowel for RULA.

Figure 3: Lower arm position during transporting process for RULA.

Figure 4: Neck position of a worker during lift process for RULA

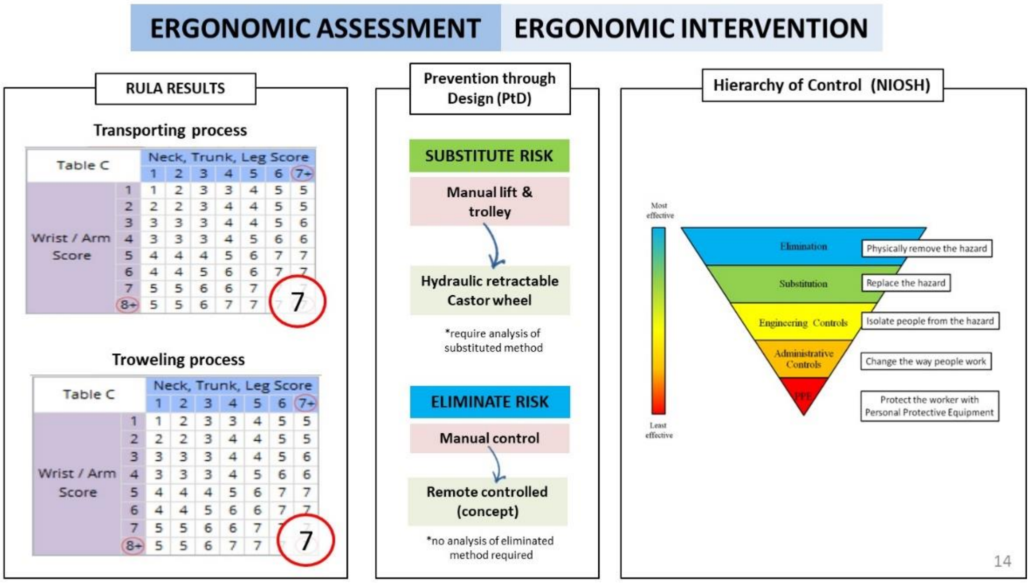

Figure 5: RULA Results for existing walk-behind power trowel.

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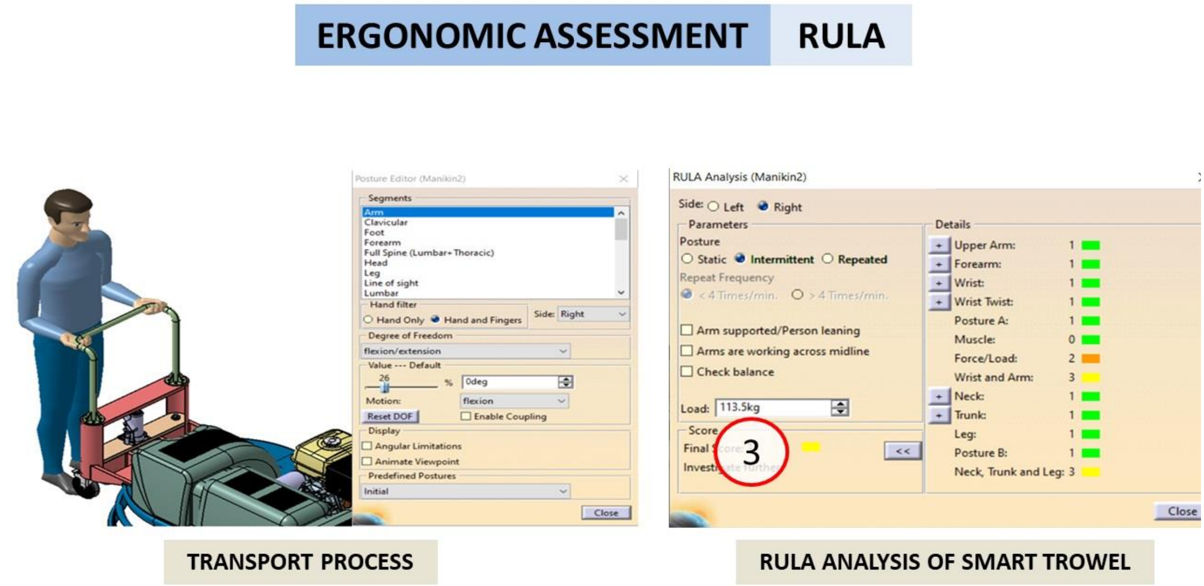

Figure 6: RULA Results for enhanced smart trowel.

The RULA assessment, based on video and observation analysis, provides valuable insights into the ergonomic considerations and potential musculoskeletal stress faced by operators during the transportation and usage of the walk-behind power trowel. By examining specific postures and limb movements, the assessment contributes to identifying areas where ergonomic improvements can be implemented to enhance operator well-being and reduce the risk of musculoskeletal disorders in the construction industry.

4.3 Cognitive-Task Analysis (CTA) of Transporting Process of Existing Power Trowel Results

The Cognitive Task Analysis (CTA) depicted in Figure 7 was conducted through a combination of interviews and observations, focusing on the task of transporting a walk-behind power trowel using a trolley. The analysis is particularly relevant to the prevalent use of walk-behind power trowels in Malaysia compared to ride-on alternatives. Given the challenge of transporting power trowels to specific indoor work areas where trucks may not reach precisely, workers employ alternative means such as trolleys or manual lifting. For this analysis, the chosen mode of transport is a trolley. The CTA aims to comprehensively visualize the sequential steps involved in this transportation process, considering both overt and covert actions.

The task analysis initiates with the worker inspecting the blade condition, necessitating blade replacement if required, a process demanding coordinated effort due to the weight of the power trowel. Subsequent steps involve checking and prepping the power trowel with sufficient fuel, followed by preparing a trolley for transportation. Lifting the power trowel onto the trolley involves the collective effort of two workers. Once on the trolley, one worker pushes it to the work area, where the power trowel is lifted once again onto the starting position of the concrete slab. The process concludes when the power trowel reaches the designated job site. While the use of a trolley facilitates transportation, it requires forethought, as workers need to bring their trolleys to the site, and the heavy-duty nature of these trolleys presents an additional challenge for the workers in transporting both the power trowel and the trolley to the working area.

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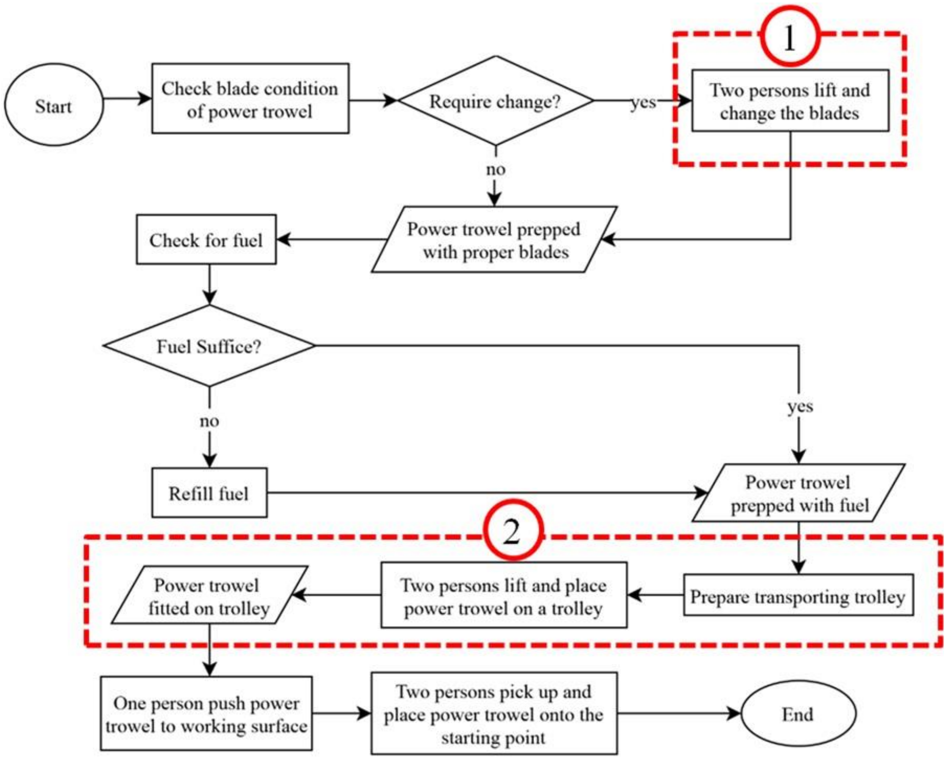

Figure 7: CTA of existing transporting process.

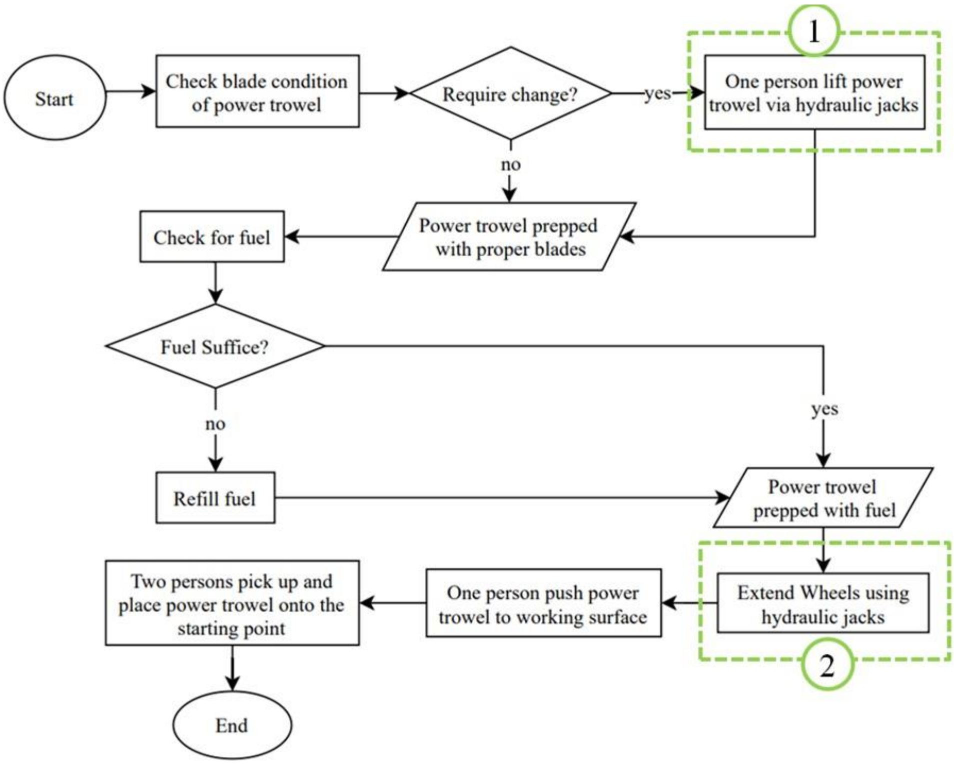

Figure 8: CTA of enhanced smart trowel transporting process.

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5. CONCLUSION

The study commenced with a comprehensive assessment, beginning with the Rapid Upper Limb Assessment (RULA) for both the operator's posture during the transportation and trowelling processes. Notably, both postures received the maximum RULA score, signifying a severe risk to the operator. Subsequently, the Hazard Identification, Risk Assessment, and Risk Control (HIRARC) further validated the presence of hazardous conditions in both the transportation and trowelling activities with the conventional power trowel. The Cognitive Task Analysis (CTA) was deployed to scrutinize the existing power trowel, identifying potential hazards, and justifying the need for ergonomic interventions based on the hierarchy of control. Following this, the RULA and CTA were replicated on the smart trowel to substantiate the improvements achieved through the ergonomic interventions.

The findings revealed a significant risk reduction with the smart trowel compared to its conventional counterpart. By systematically integrating HIRARC, RULA, and CTA methodologies, the study successfully identified critical ergonomic challenges and implemented interventions to enhance the work tasks, safety and usability of power trowels. The comparative analysis between the existing and smart trowels demonstrated the effectiveness of ergonomic interventions in mitigating risks and improving overall operator well-being during the transportation and trowelling processes.

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