Safety and Health at Work 10 (2019) 327–335

Contents lists available at ScienceDirect

Safety and Health at Work

journal homepage: www.e-shaw.org

Original Article

Design and Development of an Ergonomic Trolley-Lifter for Sheet Metal Handling Task: A Preliminary Study

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ARTICLE INFO

Article history:
Received 15 September 2017
Received in revised form
6 May 2019
Accepted 15 June 2019
Available online 21 June 2019

Keywords:
Design
Ergonomics
Intervention
Material handling
Sheet metal

ABSTRACT

Background: There have been some concerns related to manual handling of large items in industry. Manual handling operations of large sheet metal may expose workers to risks related to efficiency as well as occupational safety and health. Large sheet metals are difficult to move and burdensome to lift/transfer, and handling the sharp sheet edges may result in contact stress and/or cut injuries on the workers.
Methods: Through observation, interview, and immersive simulation activities, a few problems related to current handling of sheet metals were identified. A sheet metal trolley-lifter was then designed and fabricated to address these issues. A pilot study on the use of the developed trolley-lifter for handling sheet metals was conducted to compare between the new and traditional handling methods.
Results: The pilot study of the trolley-lifter showed promising results in terms of improving the cycle time, manpower utilization, and working postures compared with the traditional handling method.
Conclusion: The trolley-lifter offers an alternative solution to automation and a mechanized assistive device by providing a simple mechanism to assist the handling of sheet metals effectively and safely.

1. Introduction

Over the last decades, industrial practitioners and academicians have paid a lot of attention to manual material handling (MMH) as it has substantial impact on work efficiency as well as occupational safety and health. The International Organization for Standardization defines MMH as an activity requiring the utilization of human effort to lift, lower, carry, move, or restrain an object [1]. The work efficiency in MMH can be referred as the ability of the task process and/or design of the mechanical aids to contribute to conservation of workers' energy, overall cost, and cycle time. As an example, a study revealed that inappropriate design of a mechanical aid results in changes of postures, leading to higher muscular loads during pushing activity [2]. One of the strategies to improve efficiency in MMH activities is to introduce assistive devices that can reduce exertion requirements and poor working postures. Repetitive forceful exertions and poor postures during MMH can strain the musculoskeletal system, fasten the rate of fatigue, increase the cycle time, and ultimately reduce the overall productivity. MMH activities have also been associated with occupational injuries such as low back pain and muscle sprain among industrial workers. In 2015, the United States Bureau of Labor Statistics reported 155,740 cases involving back injuries [3]. The injuries are likely to occur when workers perform the MMH tasks that exceeded their physical capacities [4]. A study pointed that workers' compensation claims associated with injuries due to MMH represent the single largest source of claims and costs [5].

Handling of large items is common in many industries; however, poor handling techniques can impact both efficiency and safety aspects. A manual handling guideline fromHave we correctly interpreted the following funding source(s) and country names you cited in your article: Universiti Teknikal Malaysia Melaka, Malaysia; International Islamic University Malaysia, Malaysia; UTeM seed money? Australia categorizes a material as a "large item" if weight of the load is equal or more than 25 kg and it has a dimension of 500 mm or more [6]. To make the large item handling activities more efficient and safer, mechanical aids are usually used to assist workers. Handling of large items such as sheet metals, as those in metal fabrication industries, can be performed by motorized and nonmotorized mechanical aids. The motorized mechanical aids

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2093-7911/$ – see front matter
https://doi.org/10.1016/j.shaw.2019.06.006

include forklift trucks, battery-operated trucks, pallet converters, and drum rotators. These motorized mechanical aids may impose a higher cost for purchasing and maintenance. In addition, they may require specific training and skilled workers for operation. Moreover, the size of motorized mechanical aids is bulky, which may affect the practicality especially in small workshops where working areas are limited. Thus, nonmotorized mechanical aids become an alternative owing to their propensity to be generally cheaper and smaller in size.

However, a previous study on trolleys pointed that the use of nonmotorized mechanical aids may be associated with low work efficiency such as loss of work hours [7]. This is due to the difficulty of handling the heavy nonmotorized equipment, which leads to a faster rate of fatigue. In addition, unsuitable nonmotorized mechanical aids may also pose safety and health issues when handling large and sharp items such as sheet metals. The sheet metals need to be balanced during transfer, and without a proper device, the workers may have to maintain physical contact on the sharp sheet edges for stabilization during the process. Manual handling of metals can also expose workers to strains and sprains owing to their sheer size and weight [8] as well as cuts and bruises owing to contact stress exposures. The study argued that restructuring or changing workplace conditions and reducing ergonomic stressors may help to improve efficiency and safety in work environments [7]. There have been a number of ergonomic studies involving nonmotorized mechanical aids, especially carts and trolleys, that have been conducted to achieve these aims [7,9–13]. To date, there are limited quantitative studies that looked into the effects of nonmotorized mechanical aid designs on both work efficiency (e.g., cycle time) and occupational safety and health (e.g., work posture) simultaneously.

The main purposes of this study are to design and develop a nonmotorized trolley-lifter prototype to improve work efficiency (i.e., cycle time and manpower utilization) and occupational safety and health (i.e., work posture and contact stress). The design and development processes used a participatory approach to identify issues and generate forward actions in the task of handling large sheet metals in a metal fabrication workshop. The participatory approach has been used in various industries as one of the methods used to implement safety-related changes in workplaces [14,15]. In the participatory approach, end users as one of the main stakeholders of the change process are actively engaged to take the role as one of the decision makers. Their involvement in the change process as end users provides valuable ground input, encourages empowerment and sense of ownership, and consequently promotes better acceptance of the change. Through active participation and communication with end users, the participatory approach can result in positive health impact [16–18].

The level of participatory engagement may vary [19] as end users may be engaged either in a limited role or more comprehensive roles as part of the team. In this study, a group of technicians in a metal fabrication workshop were engaged in more comprehensive participatory roles from problem identifications, concept generation, and fabrication of prototype stages. A high-fidelity prototype of a nonmotorized trolley-lifter was then tested to compare between the developed sheet trolley prototype and an existing mobile lift table used when handling large sheet metals in the workshop. This study offers some preliminary insights into an ergonomically designed sheet trolley to allow more efficient and safe handling of large sheet metals.

2. Methodology

There were three major stages involved in the design process, as summarized in Fig. 1. Stage 1 involves investigating the issues and problems at existing sheet metal handling processes. Stage 2 focuses on the design and development of a prototype of a nonmotorized trolley-lifter for a sheet metal handling task. Finally, in Stage 3, a pilot study was carried out to compare the effectiveness of the designed prototype against the current handling method.

2.1. Stage 1: Problem identification

The identification of issues and needs related to the sheet metal handling process was conducted through on-site interviews, observations, and work simulations (immersions) at a local fabrication workshop, involving three technicians responsible for the operation of sheet metal handling and the machine operations. All technicians have at least 5 years of work experiences in the workshop and are familiar with all tasks in the metal sheet work area.

Technicians were informed about the scope and constraints of the project. They were made aware that the project aims are to identify simple ergonomic issues and provide low-cost interventions to those issues. Each technician was engaged independently in the semistructured interview sessions and was asked to self-report body parts that experience musculoskeletal pain and discomfort (if any) as well as possible tasks that could potentially contribute to that experience. During the interview session, the technicians were encouraged to share any ergonomic issues that they may have and if they have feasible and practical ideas to explore as solutions. Actual tasks and activities identified during the interview sessions were then observed by the research team. Challenges and difficulties previously discussed were documented in this observation activity. In addition, the research team also simulated some of the work tasks to have first-hand experiences on the issues documented earlier by the technicians. A closing discussion was then conducted, where the research team and technicians actively collaborated to narrow down areas to mutually focus on, based on previously set upon scope and constraints of the study.

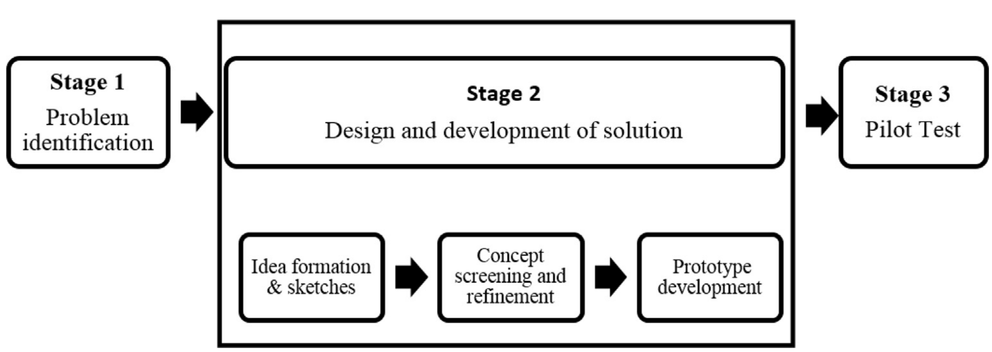


Fig. 1. The generic design process in this study.

2.2. Stage 2: Design and development of solution

a) Idea formation and sketches: Preliminary concepts were generated by the research team through discussions, reviews of the related literature, and brainstorming sessions. The concepts were generated from initial information and ideas gained from previous interactions with the technicians in Stage 1. Input from technicians was considered as the base in which all generated concepts were built upon.
b) Concept screening and refinement: The Pugh Controlled Convergence method [20] was used to screen the best initial concepts by the research team. The internally screened concepts were then further evaluated and reviewed by the technicians, before one conceptual design was selected. The technicians provided minor design inputs before finalization of the selected design concept.
c) Prototype. A functional prototype was built using mild steel bars and plates as well as galvanized iron pipes for the main body frame of the material handling device. The prototype was fabricated within the same metal fabrication workshop area owing to availability of tools and equipment. The technicians were actively engaged throughout the prototype fabrication process owing to their proximity with the research team.

2.3. Stage 3: Pilot test

The main concern raised by the technicians was mostly focused on the safety and health aspect on manual handling of the sheet metal. On the researchers' side, additional concern revolves around the efficacy of the proposed intervention. As such, an additional criterion was set by the research team that the nonmotorized trolley lifter must not introduce a significant productivity drop in the sheet metal handling task. The prototype of the nonmotorized trolley-lifter was pilot tested by the respective technicians from the fabrication workshop. Simulations of the sheet metal handling process involving 9 participants were conducted, and a video was recorded to assess the effectiveness of the new device. In these simulations, the sheet metals were carried from the storage location to machine before they were lifted and loaded on the machine. The simulations also involved the study of the current handling procedure to make comparison with the newly developed prototype. In this stage, the working postures during the sheet metal handling process were analyzed based on visual observations. In addition, the length of average cycle times required to transfer the materials from the storage location to machine was measured. The cycle time analysis was performed using three different sheet materials, and the handling process using each material was repeated five times.

Working posture assessment using Rapid Upper Limb Assessment (RULA) [21] and Rapid Entire Body Assessment (REBA) [22] was also conducted to assess workers' exposure to ergonomic risk factors associated with disorders while performing the sheet metal handling. RULA and REBA are both assessment methods that evaluate the loads on the musculoskeletal system of workers when the workers are exposed to risk factors such as poor postures, static muscle work, and force exertion. The scoring generates the level of an intervention act necessary to reduce the risk of injury associated with these risk factors. For instance, a RULA score of 1 or 2 indicates that the posture is acceptable as long as the work is not repeated or carried over an extensive period. On the other hand, a RULA score of 7 marks immediate investigation and changes are required. Similarly, a lower REBA score indicates lower risks as compared with the higher score level. For both RULA and REBA assessments, the simulation of the sheet metal handling process cycle was repeated three times involving different participants. Three different assessors with knowledge of RULA and REBA methods conducted assessments independently.

3. Results

3.1. Stage 1: Problem identification

In general, the findings from Stage 1 activities indicated that there is a need for an ergonomic and efficient supporting tool for the manual handling of sheet metals in the local fabrication workshop. Findings from interview sessions to all three technicians revealed that their main work-related discomfort and pain are primarily focused on their hands and palm areas. All of them attributed their discomfort and pain to a specific activity of manual handling of the sheet metal task as the main source. The discomfort was due to static and continuous holding of the heavy sheet metals. The technicians reported that the most common injuries during the handling process were cut injuries owing to sharp edges of the metals. Although gloves may provide protection, the current glove protects users only at the wrist level. Even while wearing gloves, the contact stress from the sheet edge is present owing to the sheer weight of the sheet metal to be handled. Subsequently, they expressed the need for a better handling procedure or handling device that provides minimal direct contact between the hands and the sheet metals.

The complete cycle of the existing transfer process of sheet metals was then observed on-site by the research team. The current procedure was found to be laborious as the technicians need to hold the sheet metal with their hands throughout the transfer process. The process also required two technicians to maintain continuous contact with the sheet metals during transfer from the storage location to machine. Fig. 2 illustrates how sheet metals are currently being stored in storage racks, the work postures when

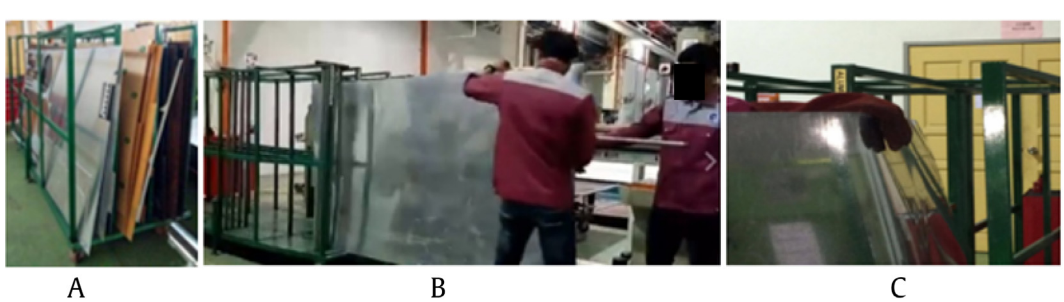


Fig. 2. Existing conditions at the sheet metal storage area: (A) The storage rack of sheet metals (left), (B) the posture during transfer of the sheet metal from the storage rack (middle), and (C) sharp edge contact during the transfer process (right).

pulling the sheet metals from the storage rack before laying it down on a transfer trolley, and the sharp edge contact between the technician's hand and the sheet metals during the transfer process. To further identify other issues, two team members from the research team participated in the work simulation of the sheet metal handling process. Issues identified from this activity were possible overexertion force during the sheet metal transfer process, awkward postures, and the time-consuming process.

It should be noted that although the technicians were encouraged to share any ergonomic issue that they may have in their daily work tasks, there seems to be a clear consensus from the technicians on their main problem, which is the sheet metal handling task. As such, the research team and technicians came to a mutual agreement to explore potential low-cost interventions to address this issue. Few initial ideas were brought up through discussion with the technicians, such as the layout rearrangement, changing standard operating procedures, and a design of a new trolley-lifter. It was found that the discussion naturally converges to a design of a new trolley-lifter that addresses specific needs of these technicians.

3.2. Stage 2: Design and development of a solution

The general design and development activities of the trolley-lifter followed the process described by Eppinger and Ulrich [23]. After identification of issues in Stage 1, each member in the research team was initially assigned to individually explore ideas before group discussion sessions to consolidate those ideas. Exploration of ideas includes references to a similar task from the literature and website reviews. In total, eleven preliminary concepts were generated by the research team after reviewing, vetting through, and merging potential ideas. It should be noted that all generated concepts were derived based on documented points from interview sessions with technicians, observation of the manual handling activity, and work simulation by the research team members.

Eleven generated concepts were then screened down to three most promising concepts using the Pugh Controlled Convergence method as described by Pugh [20]. The research team screened down the concepts based on a few criteria and constraints such as budget, available material, and tools and equipment in the facility, as well as complexity of the fabrication process. The screened three concepts underwent further internal conceptual refinements by the research team, before being shared with two shop technicians. The technicians reviewed the concepts, provided feedback, and, together with the research team, selected a final concept. Minor design inputs from the technicians' review session were integrated in the selected final concept.

The prototype fabrication process was conducted in the same fabrication workshop the technicians are working owing to tools and equipment access needed in the fabrication process. As the prototype fabrication process was within close proximity to the technicians, they were aware of the progress and were periodically involved to provide verbal inputs. A functional prototype, as shown in Fig. 3, was fabricated using materials such as galvanized iron, steel, and rubber. Metal Inert Gas welding was used to join the materials. The total cost of the materials to develop this prototype was around RM 450 (~USD 100).

The trolley-lifter prototype consisted of a rectangular support frame (74 cm × 100 cm), which is mounted on a wheeled base frame with triangular sides. The base frame with triangular sides is measured at 90 cm (width) x 40 cm (depth) x 100 cm (height). Two handles are attached at the back of the wheeled base frame to provide grip supports for pushing/pulling activities. The rectangular support frame sits at an inclined 70 degrees to hold sheet metals from falling during transfer. In addition, multiple roller balls were attached to the support frame to reduce the friction forces when pulling and sliding the sheet metals from the storage rack. All frames are made of squared hollow metal tubes.

The trolley-lifter prototype is specifically designed to transfer sheet metals from the storage rack to a laser cutting machine. Once

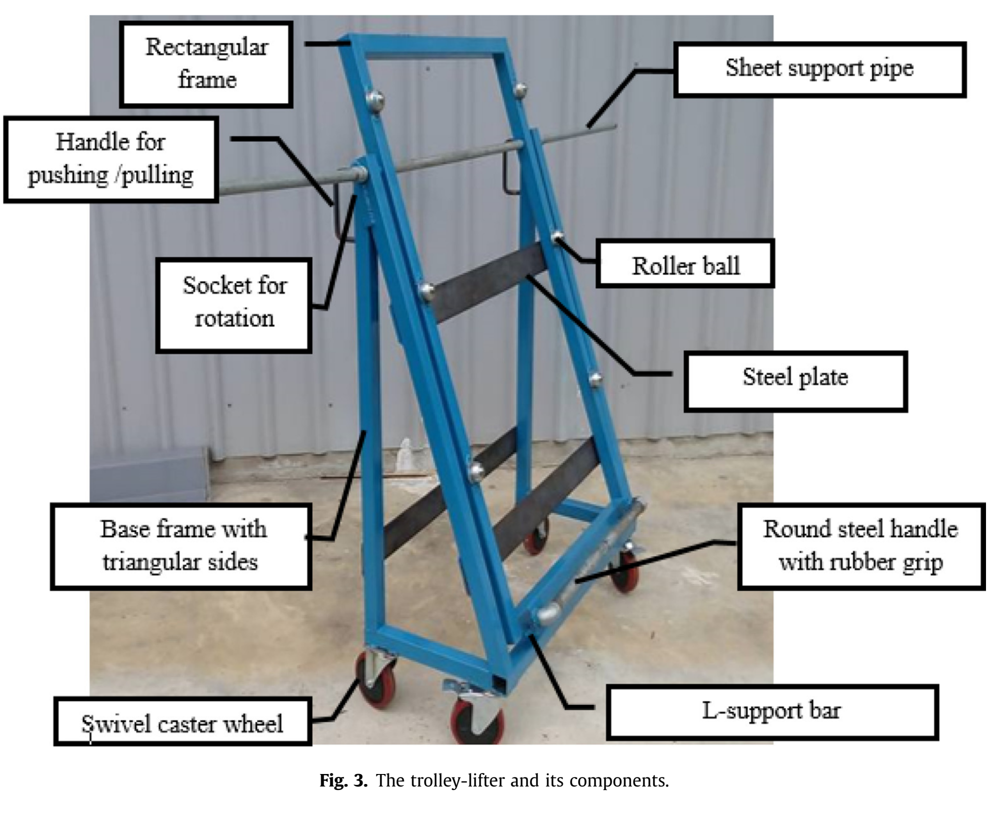


Fig. 3. The trolley-lifter and its components.

the sheet metals reached the machine, the mounted frame will be rotated on a socket hinge to lift the sheet metals from to a horizontal position to load the sheet metals onto the machine. The roller balls attached on the mounted frame help the sheet metals to easily slide onto the machine when the frame is raised at a higher angle than the horizontal position. The flat vertical surface leaning on the laser machine can provide stability during the transfer process. In addition, the swivel casters can also be locked to prevent the sheet on the trolley-lifter from moving when sliding the sheet metals onto the machine. Fig. 4 shows the trolley-lifter in its rotated position.

Although the design is similar to a few other commercially available panel carts tilting/pivoting top trolleys, adjustable carriers, and frame wagons [24–27], there were few distinct design features. An example of the differences is the roller balls attached on the frame so that the sheet can be glided over from the trolley to the laser cutting machine (to minimize lifting). The loading mechanism is also slightly different in that one side of the trolley is designed at a right angle and slightly above the laser cutting machine's height to lean over the machine for the purpose of providing external support during the tilting process. This improves the stability, as well as reduces the mechanical strain on the castor wheels, during the unloading process. It should be noted that the trolley-lifter is designed to be highly specific in this particular sheet metal transfer task in this metal fabrication workshop and may not work as well in other tasks and work setups.

3.3. Stage 3: Pilot test

A pilot test was conducted to analyze the efficiency and work postures while transferring the sheet metals from the storage rack to laser cutting machine. The following results show the comparison between the current method of sheet metal handling and using the developed trolley-lifter prototype.

Fig. 4. The trolley-lifter in rotated position.

3.3.1. Handling postures

Table 1 displays the visual comparison of the working posture using the current method and the developed trolley-lifter prototype. Overall, it can be seen that the prototype was able to minimize awkward postures and continuous physical contact with the sheet metals. With the new prototype, workers no longer need to bend their body to lift or hold the sheet metals during the transferring process, except during lifting the sheet metals to the machine level as described in Segment 3 (however, a proper lifting method was adopted to minimize the risks—Posture Segment 3, as shown in Table 1). As a result, continuous static holding of the sheet metals was able to be minimized. The observation categorizes the handling processes into four posture segments. A sample of each individual's worst posture in each posture segment was identified and mutually agreed upon through discussions among research team members.

3.3.2. Time analysis

The average time to transfer the sheet metal from the storage rack to laser cutting machine was measured to evaluate the efficiency of the trolley-lifter prototype. Table 2 shows the average time (and standard deviation) to transfer three different types of sheet metals from the storage rack to machine based on five recorded cycle times.

The result shows that the average times to transfer the sheet metals from the storage rack to machine were reduced at least by more than 34% (in all three types of materials being handled) with the use of the new trolley-lifter prototype. Transferring the lightest sheet metal (1 mm galvanized iron) shows the highest improvement by 47% in average transfer time. Therefore, the new trolley-lifter prototype is more efficient than the current method as it allows for easier and faster handling of the sheet metals. As a result, the use of the new trolley-lifter prototype can potentially increase the overall productivity of the sheet metal machining operation.

3.3.3. RULA and REBA

The RULA and REBA methods were used to evaluate the working posture while performing the complete transfer process of sheet metals from the storage rack to laser cutting machine. The entire RULA and REBA analysis is divided into four posture segments as previously reported in Handling postures. Each individual's worst posture in each posture segment was assessed by three assessors. The averaged RULA and REBA scores for the current method and the new method are tabulated in Tables 3–6, respectively. For the current method, the RULA and REBA assessment was conducted for each person involved in the handling process because it required two operators (designated as leader and follower) to handle the sheet metal. On the other hand, only a single user was assessed in the new method.

In this pilot test, it can be seen that the use of the new trolley-lifter prototype was able to reduce the RULA scores from 3–7 to 3–4 levels across all four posture segments. Scores of 3–4 imply that further investigation and changes may be needed, whereas scores of 5–6 show that investigation and changes are required soon. The highest score of 7 as appeared in Segment 1 (transfer from the storage rack to transport equipment) of the current procedure assessment indicates immediate changes are crucial for the involved work setup. Similarly, REBA scores reduce from 3–12 to 2–9 with the new trolley-lifter prototype. Segment 1 was seen to be rated as high risks with the traditional method, and the trolley-lifter usage reduced the REBA score rating level to low risk.

4. Discussion

The participatory approach adopted in the design process was found to be worthwhile to inform the design development process.

Table 1
Postures before and after the trolley-lifter implementation.

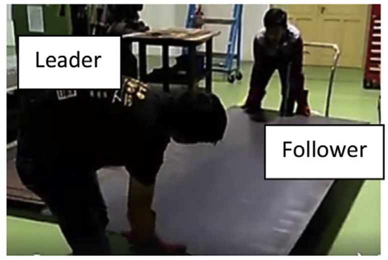
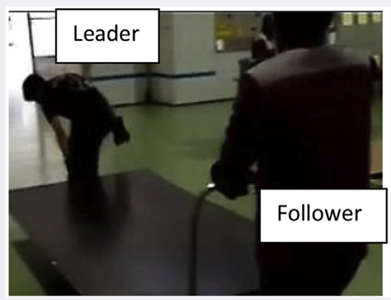
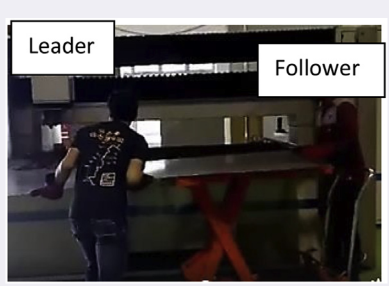
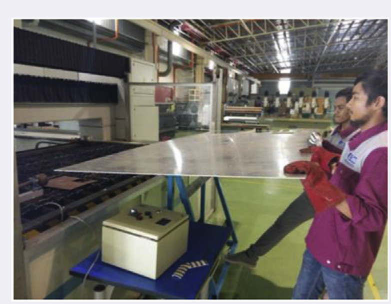
Posture segment	Before (current method)	After (with the trolley-lifter)
1 (transfer the sheet metal from the storage rack to handling device)	 Lift a sheet metal from the storage rack and place it on the lift table cart jack.	 Pull and slide the sheet metal from the storage rack and lean on the trolley-lifter.
2 (transport the sheet metal from the storage rack to laser cutting machine)	 The other end of the sheet metal needs to be supported manually (by a leader) while pushing.	 While gripping the handle, push/pull the trolley-lifter to machine.
3 (raise the sheet metal to the machine level)	 The worker must continue to support the other end of sheet metal while pumping the foot pedal.	 While practicing the correct squatting down posture, grip the handle and lift up.
4 (transfer the sheet metal from the handling device to machine)	 Lift the sheet metal and slide it onto the machine.	 Lift the sheet metal slightly higher than the machine table and push the sheet metal to slide in.

Table 2
Averaged cycle time (5 repetitions) to transfer sheet metals from the storage location to machine

Sheet materials handled	Average cycle time (sec) [standard deviation]		Average improvement
	Existing method	New method (using the prototype)	
6 mm aluminum	142 [14]	94 [15]	34%
3 mm aluminum	112 [12]	67 [4]	40%
1 mm galvanized iron	113 [4]	60 [3]	47%

Inputs from end users were helpful in determining the design direction by the research team. The participatory approach in designing ergonomic interventions has been reported in other studies [28–31] and has generally shown positive responses from their targeted end users. The participatory approach allows the research team to identify the issues to focus on the technicians themselves. Their comments and on-site demonstration of the tasks provide groundwork for the research team to generate preliminary concepts. Technicians' input was found to be helpful in the selection and fabrication processes of design concepts to be further developed. In the pilot test of the new trolley-lifter prototype, the trolley-lifter achieved its goal as an aiding tool for manual handling of sheet metals in improving productivity and safety. In terms of productivity, the prototype showed promises that it can be used to support the manual sheet metal handling task by reducing the cycle time. It was demonstrated that the trolley-lifter can be operated with one worker instead of the traditional operation that requires two workers. In term of safety, the new trolley-lifter generally promotes better work postures compared with the traditional method. In addition, the trolley-lifter also reduces the overall duration of physical contact with the sheet metal. These promising initial findings provide a good overview of the trolley-lifter's potential to improve the current manual sheet metal handling task.

At the beginning of the interview session, the shop technicians were made aware that the study has a limited budget and that the research team will not be purchasing new equipment for them. The focus of the study was set to revolve around low-cost interventions, especially focusing on simple mechanisms that can be fabricated in-house or off-the-shelf parts. As such, the study itself limits the potential solutions owing to the scope and financial constraints. The problem identification stage does involve technicians, albeit with a limited sample size. However, all three technicians were in consensus on the MMH task to be prioritized in this study. It should be noted that the research team encouraged the technicians to discuss other issues and did not provide limitations other than the financial and complexity constraints described at the beginning of the session.

Although the prototype is fully functional, the concept is still in the preliminary stage and may require multiple design iterations before being finalized. For example, although the trolley-lifter reduces RULA scores of Segment 3 (raise the sheet metal to the machine level) from 6 (investigation and changes are required soon) to 4 (further investigation and changes may be needed), the action level for the new trolley-lifter still requires additional investigation to further minimize potential risks to the operators. REBA scores also do not show much improvement for Segment 3, which indicate further improvement needs. As an example, further iteration of the trolley-lifter design may focus on further improvement of the posture during lifting activity in Segment 3. This may include designing handle extension or a spring mechanism to minimize poor back posture when raising the sheet metal to the machine level.

A pilot session was conducted using only three different types of sheet metals. There are other different sheet materials being handled by the technicians in the workshop, but those materials were not tested in this study. As such, efficiency of the trolley-lifter on other materials cannot be established. However, the three sheet materials tested were the most common materials handled, and the prototype shows initial promise on how productivity can potentially be improved with correct utilization of the proposed intervention. Another limitation is the limited sample size involved in the pilot test, as well as the limited workplace context in which the developed prototype is being tested. As such, further testing of the

Table 3
RULA scores (averaged from three assessors) of the current handling method

Trial	Participant (technician)	RULA scores by assessors			
		Posture segment			
		1: transfer the sheet metal from the storage rack to handling device	2: transport the sheet metal from the storage rack to laser cutting machine	3: raise the sheet metal to the machine level	4: transfer the sheet metal from the handling device to machine
1	Leader 1	6	4	5	6
	Follower 1	7	6	6	6
2	Leader 2	6	3	5	4
	Follower 2	5	3	5	4
3	Leader 3	6	3	5	4
	Follower 3	5	3	5	4

RULA final score of 1 or 2 = acceptable; 3 or 4 = investigate further; 5 or 6 = investigate further and change soon; 7 = investigate and change immediately.
RULA, Rapid Upper Limb Assessment.

Table 4
REBA scores (averaged from three assessors) of the current handling method

Trial	Participant (technician)	REBA scores by assessors			
		Posture segment			
		1: transfer the sheet metal from the storage rack to handling device	2: transport the sheet metal from the storage rack to laser cutting machine	3: raise the sheet metal to the machine level	4: transfer the sheet metal from the handling device to machine
1	Leader 1	11	12	9	6
	Follower 1	11	3	5	6
2	Leader 2	11	11	9	8
	Follower 2	11	3	5	8
3	Leader 3	11	9	9	6
	Follower 3	11	3	4	4

REBA final score of 1 = negligible risk; 2–3 = low risk, change may be needed; 4–7 = medium risk, further investigation, change soon; 8–10 = high risk, investigate and implement change; 11+ = very high risk, implement change.
REBA, Rapid Entire Body Assessment.

Table 5
RULA scores (averaged from three assessors) of the new handling method

Trial	Participant (technician)	RULA scores by assessors			
		Posture segment			
		1: transfer the sheet metal from the storage rack to handling device	2: transport the sheet metal from the storage rack to laser cutting machine	3: raise the sheet metal to the machine level	4: transfer the sheet metal from the handling device to machine
1	User 1	4	3	4	3
2	User 2	4	3	4	4
3	User 3	4	3	4	4

Note: RULA final score of 1 or 2 = acceptable; 3 or 4 = investigate further; 5 or 6 = investigate further and change soon; 7 = investigate and change immediately.
RULA, Rapid Upper Limb Assessment.

Table 6
REBA scores (averaged from three assessors) of the new handling method

Trial	Participant (technician)	REBA scores by assessors			
		Posture segment			
		1: transfer the sheet metal from the storage rack to handling device	2: transport the sheet metal from the storage rack to laser cutting machine	3: raise the sheet metal to the machine level	4: transfer the sheet metal from the handling device to machine
1	User 1	3	4	9	3
2	User 2	3	4	6	5
3	User 3	3	2	9	2

REBA final score of 1 = negligible risk; 2–3 = low risk, change may be needed; 4–7 = medium risk, further investigation, change soon; 8–10 = high risk, investigate and implement change; 11+ = very high risk, implement change.
REBA, Rapid Entire Body Assessment.

trolley-lifter may involve handling different types of materials, with a larger sample size of technicians and at different workplace contexts.

Although not specifically measured, the trolley-lifter prototype has the potential to reduce physical exertion on the operators. Informal discussion with end users revealed that female users were able to use the new trolley-lifter with ease. Future study may focus on perceived exertion and muscle activity to quantify the differences in exertion between the new and traditional methods. The initial success with the sheet metal handling task suggests the possibility of the trolley-lifter become the assisting equipment for other large item forms of material such as plywood, composite, glass, and so on. These large items may share the same manual handling challenges as the sheet metals in this study.

5. Conclusion

A nonmotorized trolley-lifter has been designed and developed in this study, based on the participatory inputs from end users. The actual working operation of the high-fidelity trolley-lifter prototype has been successfully simulated in manual handling of sheet metals and has shown some early promises to improve work efficiency and occupational safety and health conditions. Through repeated simulated tasks, the use of the developed prototype reduced cycle time (up to 47%) and manpower utilization (from two to one). The prototype also improved the safety components of manual handling activity by ensuring minimal physical contact with sharp edges on the sheet metal. Finally, the developed trolley-lifter allows for a better working posture (apparent reduction in RULA and REBA score ratings in certain task process segments) for transferring sheet metals and eliminates the need to provide manual contact/support to the heavy sheet metal throughout the transfer process.

Conflicts of interest

None of the authors have any financial interest or benefit to declare in any regard in relation to the study described in this manuscript.

Acknowledgments

The authors are grateful to the Malaysian Government, Universiti Teknikal Malaysia Melaka (UTeM), and International Islamic University Malaysia (IIUM) for the support to publish this manuscript. We would like to acknowledge Roslan Hassan, Tengku Ahmad Shauki, Lee Poh Yan, Zulaikah Sulaiman, and Nursyuhada Ismah for their contributions in this study. This study is partially funded by the UTeM seed money grant (PJP/2016/FKP-AMC/S01501).

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