Ergonomics and Manual Handling Workplace Improvement: A Case Study of Firefighter at Pagoh

Salwa Mahmood, Siti Hana Nasir, Norashid Mamat, Ismail Abdul Rahman, and Noorul Azreen Azis

Abstract Firefighter are constantly at risk since they are directly exposed to various physical factors, harmful chemicals and mental stress during rescue and fire-fighting. In fire extinguishing, unstable posture is one of the possible hazardous factors and contribute to high ergonomic risk factor. Due to manual handling and lack of proper standard operation procedure, firefighter are at risk of developing musculoskeletal disorders problem such as awkward postures. This paper identify ergonomics risk factor that may cause harm to firefighter during rolling of fire hose. This study was conducted in Pagoh fire station. In order to achieve those aims, observational method was used by applying Ergonomic Risk Assessment (ERA).The Failure Mode and Effect Analysis (FMEA) method is used by calculating the severity, occurrence and failure detection which has rating score from one (1) to ten (10). Then, the risk priority number (RPN) was calculated to get the highest priority number which led to identification of ergonomic risk factor. A set of questionnaire was distributed to 20 firefighter located at Pagoh fire station for analyzing the ergonomic risk factor and compared to the FMEA result. The result of the analysis shows 56% of the respondent experienced awkward posture during handling of fire hose. The result of the questionnaire was compared to the highest RPN value from FMEA to obtain the solution on ergonomic workplace improvement at Pagoh fire station. In addition, a new tool that is expected to improve the ergonomic and manual handling of firefighter was proposed.

Keywords Ergonomic risk factors · Manual material handling · Firefighter hose handling

S. Mahmood (✉) · S. H. Nasir
Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, KM 1 Jalan Panchor, 84600 Pagoh, Muar, Johor, Malaysia
e-mail: msalwa@uthm.edu.my

N. Mamat
Balai Bomba Dan Penyelamat Pagoh, Jalan Muar–Labis, 84600 Muar, Johor, Malaysia

I. Abdul Rahman · N. A. Azis
Ergonomics Excellence Centre, National Institute of Occupational Safety and Health (NIOSH), No. 10, Jalan Persiaran Teknologi, Taman Teknologi Johor, 81400 Senai, Johor, Malaysia

M. H. A. Hassan et al. (eds.), *Human-Centered Technology for a Better Tomorrow*,
Lecture Notes in Mechanical Engineering,
https://doi.org/10.1007/978-981-16-4115-2_46

1 Introduction

1.1 Background of the Study

The cases of work-related musculoskeletal disorders (WMSDs) in Malaysia are increasing every year, and the total compensation for WMSDs cases was found to be higher than other occupational disease cases. The increase in trend was the result of increased awareness among Malaysian employers and workers. The chairman of the National Institute of Occupational Safety and Health (NIOSH) Malaysia quoted as saying that for one out of four cases reported to the Social Security Organization (SOCSO) in 2013 was related to MSDS [1]. MSDs are a condition in which the muscles are under stress due to muscles being exposed to static and repetitive motions over prolonged periods of time. The action causes damage to the ligaments, tendons, and joints [2].

Tasks that require awkward postures and/or excessive efforts may cause fatigue and discomfort to the employees. Furthermore, this may lead to damage of the muscles, tendons, nerves, and blood vessels [3]. Over the last decades, industrial practitioners and academicians have paid a lot of attention to manual material handling (MMH) as it is known as one of the most causes of back injury which impacts on work efficiency [4]. MMH can be defined as any activity requiring the utilization of force exerted by someone either lifting, lowering, pushing, carrying and holding of an object. It will delineate as moving something by victimization of human energy [5].

An operation involved with the lifting of a load is considered as one of the MMH activities. It involves the factors of imbalance that are encountered in industries like warehousing and maintenance [5]. Ohnishi et al. [6] revealed that inappropriate design of a mechanical aid will result in postures change and leading to higher muscular loads during pushing activity. One of the strategies to improve efficiency in MMH activities is to introduce assistive devices that can reduce exertion requirements and poor working postures [4].

Fire department is one of the toughest industries which provide services to people who need help. Fire department is one of the most hazardous, physically demanding and psychologically stressful occupations [7]. 86% of American career firefighter reported a history of lower back pain and 55% reported current lower back pain [8]. Roh and Kim [9] reported in their study that 41.5% of firefighter experienced work-related lower back pain within a year and 12.3% of firefighter had chronic lower back pain.

Thus, it gives a high ergonomic risk factor towards firefighter who are doing the most high risk work. In Malaysia, the fire department still demands manual handling when doing their work and currently there is no standard operation procedure. This leads to various WMSDs problems and one of them is awkward posture. The objective of this paper is to identify and assess the risk of WMSDs to firefighter at Pagoh fire station due to unnatural or awkward postures. This paper also proposed a new tool to improve the ergonomic and manual handling of firefighter.

1.2 Ergonomics and Manual Material Handling

Ergonomics is known as human factors which engineering science involved with the understanding of interactions among humans and alternative components of a system. Therefore, the profession that applies theory, principles and data to optimize human well-being and overall performance [10]. The ergonomics consist of three domain as shown in Fig. 1. Physical ergonomics is expounded to the target of activity Safety and Health Act 1994 (OSHA 1994), that is to market activity environment for person at work that related to their physiological.

Ergonomics is that the study of the connection between the employees and the operating atmosphere. It is important for the employees to concern and realizes the potential engineering risk factors around them [11]. Ergonomic assessment is one of the techniques to determine the ergonomic risk factor. Ergonomic assessment is importance in industry nowadays especially on a technical work. Therefore, it is necessary to adapt it and applicable to a technical work in industry [12].

Awkward posture is known as positions of the human body whereas work activities that deviate considerably from the neutral position. Samples of awkward postures are twisting, bending, operating with neck or back bent quite thirty degrees with no support and over reaching [13]. Due to awkward posture, muscles and tendons must work harder and can be stressed. An outside range of motion, joint of body bents could led to awkward posture. It is related to associate magnified risk of injury. It is typically considered that a lot of joint deviates from the natural position, the bigger chance to have an injury [13].

Manual handling is known as one of the most causes of back injury. It can be outlined as any activity requiring the utilization of force exerted by someone either lifting, lowering, pushing, carrying or holding of an object. It will delineate as moving something by victimization of human energy [5]. An operation involved with the lifting of a load is considered as one of the manual handling activities. It involve the factors of imbalance that encountered in industries like warehousing and maintenance [5]. Besides, pushing and pulling also one of the manual handling activities. In

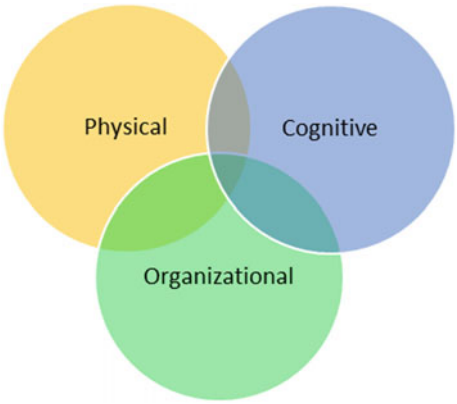


Fig. 1 Domains in ergonomics

industry, various techniques of pushing and pulling is used by workers to avoid manual handling activities since those actions contribute to injuries in industries.

2 Literature Review

2.1 ERA and FMEA

Method used to identify the most ergonomic risk factors that cause harm to employees. There are several step involved in an ERA. Hierarchical task analysis is one of the step to analyze the ergonomic risk factor and it is a recommended method for mapping all performed task by workers [14]. In ERA, the mapped performed task will be ranked by it levels of severity.

Next, FMEA is a systematic designing tool that is used to see the probable potential failures which might occur in an industries [15]. FMEA is an engineering technique used to outline the potential failures on system, design, process, or services before it reach client. FMEA used to mistreatment previous experiences or technology and coming up with new development for those failures to not occur [15]. FMEA is a technique practiced by firms that adopted the philosophy of total quality management (TQM). This method can result in an improvement of product for client satisfaction. This method was used for hazard analysis control point (HACCP) for the Apollo Space Program and later at the food industry in general [16]. In the late 1970s, the Ford Motor Company introduced the FMEA to the automotive industry for safety and regulatory consideration. It was applied by them as the same approach on process failure mode and effect analysis (PFMEA) to consider potential process induced failures prior to launched production [16].

FMEA is consist of three main type which is FMEA system, FMEA design and FMEA process. FMEA system is the highest level of analysis which focused on system related to deficiencies [17]. FMEA design focused on product design, typically at the subsystem or component level. Related deficiencies is focused in this system with emphasis on improving the design and ensuring product operation is safe and reliable. The product that will be manufactured according to specifications usually will be assumed by FMEA design [17]. FMEA process is focused on the manufacturing or assembly process, emphasizing how the manufacturing process can be improved to ensure the product is built in safe manner. This type of FMEA focused on potential failures modes of the process that caused by manufacturing process. This way, engineer can see which uses of the system are desirable and which are not.

Table 1 Previous research using ERA and FMEA

Author, Year	Method	Findings
[18]	FMEA	• Higher RPN value obtained for stripping process • Proper care and maintenance should be given to stripping unit • Misalignment of robotic axis could effect on the sheet delivering process
[19]	FMEA and Grey Relation Analysis (GRA)	• **Problem**: sharp corners of the step caused cuts in the seal • **Solution**: Magnetic protectors were made • **Problem**: noisy window glass from hole position • **Solution**: position of rivet hole was moved to 3 mm lower position
[20]	FMEA	• **Potential failure**: size outer diameter plus/minus • **Potential cause**: dept of cut • **Potential effect**: displacement during operation.
[21]	ERA	• Respondents are still lack of awareness on the importance of MSDs management

2.2 Previous Research Work on ERA and FMEA

Table 1 shows the previous research work that using ERA and FMEA on different type of industry.

2.3 Principle of Motion Economy

Motion economy is known as making and refining plans for a certain group of simple task in industries. A motion economy is used to generate plan, which is related to fundamental of hand motions and it is economic from the view of motion economy expertise. Manual operation is categorized as one of scope of motion economy task which required the use of arms limited time for completion [22]. Motion economy help to reduce the cumulative trauma as a result to repetitive work done by workers. It is used to prevent from unnecessary motion so that it is avoided [23].

Hence, reduce the fatigue cumulative trauma. The motion economy used as a guideline to examine and design a workstation. The principle of motion economy are based on the combination of ergonomic principles so that it what are the basis for developing the principle. In principle of motion economy, there are three categories which is use of human body, arrangement of workplace and design of tools and

Table 2 Recommendation and description of design of tool and equipment [23]

No.	Recommendation	Description
1	Hands should be relieved of all work of holding	Tool should be as simple to operate as possible
2	Two or more tools should be combined wherever possible	Easier to perform a task without changing tool and too many movements
3	Tools and material should be pre-positioned	The load should distributed in accordance with the inherent capabilities of the finger

equipment. Design of tool and equipment helps to minimize the distance of workers must move in the workstation. The recommendation of design of tool is shown in Table 2.

3 Methodology

The observational method is used on manual handling observation towards firefighter. This observation is commonly to observe the working posture and determine the risk factor of MSDs. ERA and FMEA was then used to analyze the most risk factor occur by conducting a survey. The assessment of FMEA is done using FMEA form.

3.1 ERA

An ERA is done using a questionnaire that distributed to 30 firefighters as respondent at Pagoh fire station. The criteria of the questionnaire is shown in Table 3.

Table 3 Example of questionnaire

Ergonomic assessment checklist	Answer (tick one only)	
	Yes	No
1. Have any workers been previously diagnosed with any of the following disease: Carpal tunnel, Tendonitis, Tenosynovitis, Trigger Finger or Back ailments?		
2. Have there been any worker complaints concerning ergonomic issues?		
3. Do the employees perform high repetition task?		
4. Do the employees routine task require repeated heavy lifting?		
5. Are employees using awkwardly designed tools?		

Fig. 2 Firefighter carrying a hose

Fig. 3 Setting up the hose

3.2 Observational Method

Based on observational method, several pictures were snapped during the observation at Pagoh fire station. The observation of firefighter doing manual handling is shown in Figs. 2, 3, 4 and 5.

3.3 FMEA

The first step of FMEA method is to analyze functional requirements and their effects to identify all failure mode. List all failure modes per function in technical terms,

Fig. 4 Setting up the hose nozzle

Fig. 5 Warm up session

considering the ultimate effects of each failure mode and noting the effects. This method is done by determine the severity (s), occurrence (o), failure detection (d) by referring its own categories of rating value. It is then multiplied to get the highest risk priority number (RPN) so that the most ergonomic risk factor detected.

Severity It is the seriousness of failure consequences of failure effects [23]. Usual practice rates failure effect severity (s) on a scale of one (1) to ten (10) where one (1) is the lowest severity and ten (10) is highest. Rate of the severity and its meanings is shown in Table 4.

Occurrence Examine the cause of each failure on how often it occurred. Look at similar processes or products and their documented failure modes. Failure mode are assigned an occurrence ranking (o) from one (1) to ten (10) as shown in Table 5.

Failure Detection These step enable researcher to determine the likelihood of identifying failures. Then each combination from steps one and two is assigned a detection

Table 4 Severity rating and meanings [18]

Rating	Meaning
1	No effect, no danger
2	Very minor—usually noticed only by discriminating or very observant users
3	Minor—only minor part of the system affected. Noticed by average users
4–6	Moderate—most users are inconvenienced and/or annoyed
7–8	High—loss of primary function. Users are dissatisfied
9–10	Very high—hazardous. Product becomes inoperative, customer angered. Failure constitutes a safety hazard and can cause injury or death

Table 5 Occurrence rating and meanings [18]

Rating	Meaning
1	No documented failures on similar product or process
2–3	Low—relatively few failures
4–6	Moderate—some occasional failure
7–8	High—repeated failures
9–10	Very high—failure is almost certain
9–10	Very high—hazardous

value (d), which indicated how likely it is that failures was detected. The higher the value of (d), the more likely the failure not detected. Failure detection rating is shown in Table 6.

Risk Priority Number (RPN) RPN value is calculated from the value of severity (s), occurrence (o) and failure detection (d) shows in Eq. (1).

$$\mathrm{RPN} = \mathrm{S} \times \mathrm{O} \times \mathrm{D} \tag{1}$$

RPN is calculated for the entire design or process and documented in the FMEA form. Result will shows the most problematic areas with the highest RPN value that should get highest priority for corrective measures. The corrected measures then

Table 6 Failure detection rating and meanings [18]

Rating	Meaning
1	Fault is certain to be caught by testing
2	Fault almost certain to be caught by testing
3	High probability that tests will catch fault
4–6	Moderate probability that tests will catch fault
7–8	Low probability that tests will catch fault
9–10	Fault will be passed undetected to user

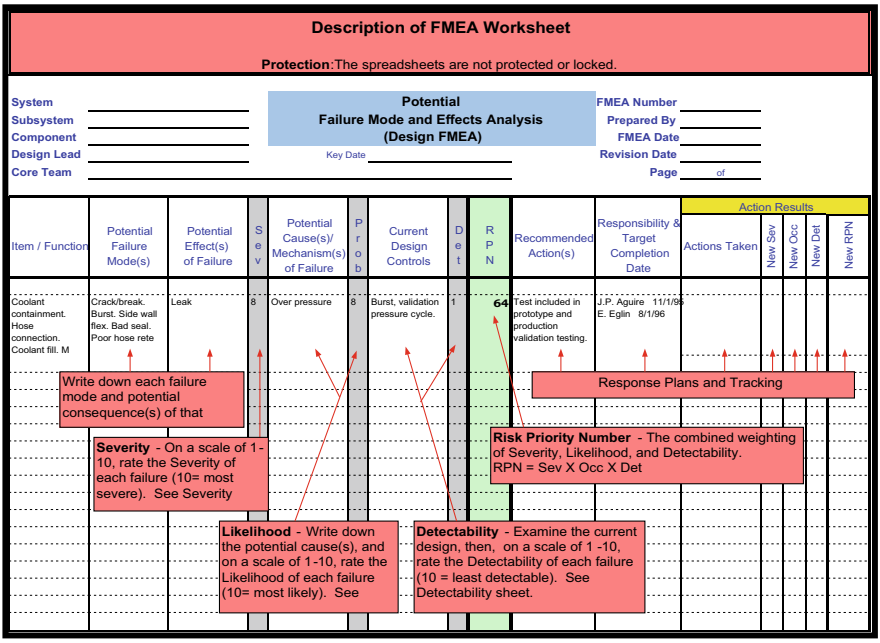


Fig. 6 FMEA form sheet

calculated again on the RPN value and documented in the FMEA form. An FMEA form sheet is shown in Fig. 6.

4 Result and Discussions

4.1 Questionnaire Analysis

Awkward Posture. It is generally acknowledged that awkward posture is a posture not suitable or not proper for certain working activities. The awkward posture analysis result is consisting of few questions concerned on awkward posture. The question that the firefighter answered between "Yes" and "No" on concerned of awkward posture is shown in Fig. 7. It shows that 56% of respondents agreed that manual handling that firefighter done related and concern with awkward posture. However, 44% does not agree because of several firefighters are not involved in works that concerned with awkward posture. The potential cause of awkward is shown in Fig. 8.

The result shows the equipment obtained the largest section with 53% of the respondent agreed that equipment contribute to awkward posture. Awkward posture analysis followed by body part affected by awkward posture work. The result of

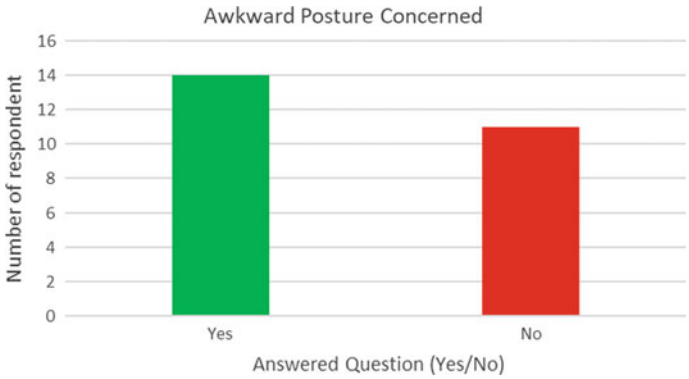
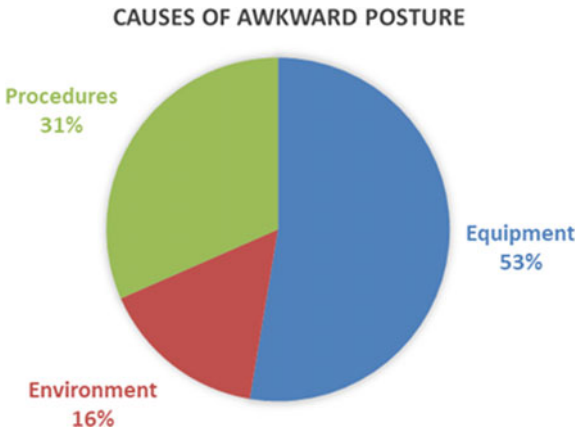


Fig. 7 Frequency of awkward posture

Fig. 8 Potential causes of awkward posture



body part affected is shown in Fig. 9. The most affected body part is back part with score of 45% of the respondent experienced it. It followed by second highest, which is upper body with score of 35%, 10% of lower body and both 5% for arm and leg.

Repetitive Motion. Part B is the question related to repetitive motion applied during working among firefighter at Pagoh fire station. The result of repetitive motion analysis is shown in Fig. 10. It shows that the repetitive motion is not too concerned with manual handling among firefighter at Pagoh fire station which is the highest score goes to "No" answer. This is because 56% of respondent choose "No" answer that shows several firefighter does not involved with repetitive motion.

Vibration. Part C is a question regarding on vibration that could be an ergonomic risk. The result of vibration concern is shown in Fig. 11. The result shows 40% of respondent agree that vibration contributed to ergonomic risk factor. However, 60% of respondent does not agree that vibration contributed towards ergonomic risk factor.

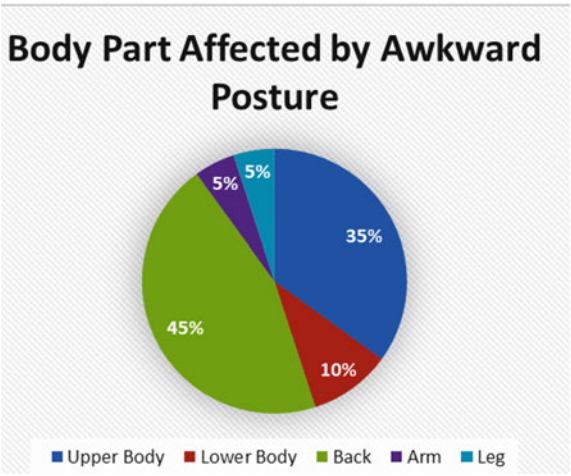


Fig. 9 Body part affected by awkward posture

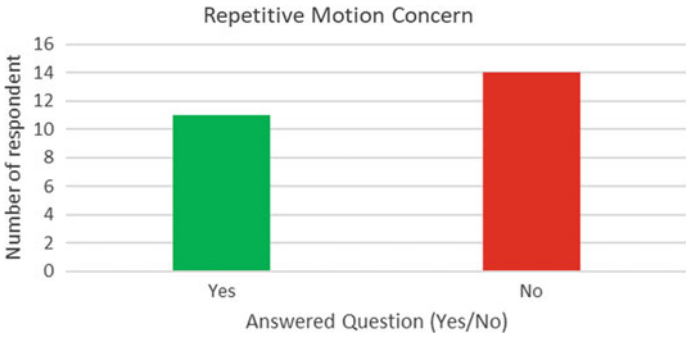


Fig. 10 Frequency of repetitive motion

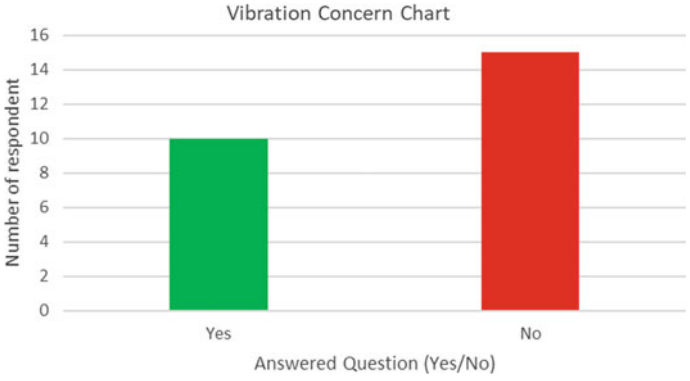
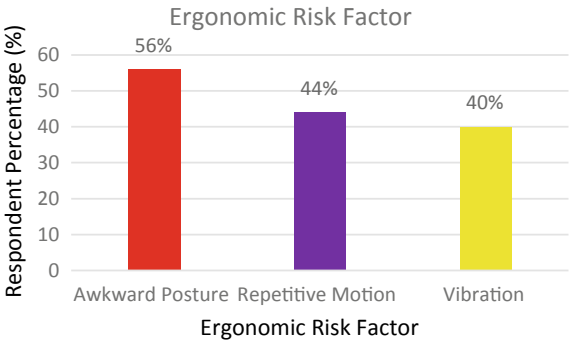


Fig. 11 Frequency of vibration motion

Fig. 12 Overall result



This is because majority of firefighter does not doing their work that concerned with equipment that related to vibration.

Overall Result. Overall, based on those result of awkward posture, repetitive motion and vibration analysis, the overall result is concluded in Fig. 12. For overall result of the questionnaire analysis, it shows that the awkward posture risk factor obtained the highest result with 56% of respondent experienced the awkward posture ergonomic risk factor. It followed by 44% of respondent on repetitive motion analysis that experienced it lesser than awkward posture. Lastly, the vibration analysis obtained a result of only 40% of respondents does the work related to vibration. It can be concluded that the awkward posture is the most ergonomic risk factor that has been determined for the project.

4.2 FMEA Result

This assessment is based on the observation towards firefighter doing the hose rolling work. From the analysis, the result obtained shows which work give the most ergonomic risk effect towards firefighter. The data collected using FMEA form to detect the injury that occurred during the hose roll process. The FMEA form result is shown in Table 7. The FMEA result shows that the highest RPN value goes to potential failure of injury on back part of body that related to awkward posture. It is then compared to the result of questionnaire and ERA to find the best solution for workplace improvement at Pagoh fire station.

4.3 Proposed Design of Ergonomic Tool for Firefighter

As seen from the result of all ERA and FMEA analysis, it is recommended to propose a design of ergonomic tool for firefighter. The proposed ergonomic tool should be

Table 7 Result of FMEA analysis

System _____
Subsystem _____
Component _____
Design Lead _____
Core Team _____

Potential Failure Mode and Effects Analysis (Design FMEA)

Key Date _____

FMEA Number _____
Prepared By _____
FMEA Date _____
Revision Date _____
Page _____

Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Occ	Current Design Controls	Det	RPN	Recommended Action(s)
Hose									
Hose rolling	Injury to hand	Delay of operation	2	Fast roll work during operation	4	Manually roll	3	24	Develop SOP for hose rolling
	injury of leg	couldn't roll the hose completely	2	repeatedly doing the same task	5	repeatedly train for the same task	4	40	Tool development
	injury on back part of body	couldn't proceed for operation	7	Awkward posture during task working	6	Random posture during task completion	5	210	Suitable posture applied
Carrying a hose	Injury of shoulder	Couldn't carry the hose	5	Improper of carrying a hose	1	Manually carry by firemens	5	25	Proper way of carrying the hose

able to provide support for firefighter when rolling the hose during operation. This proposed design of tool aims to reduce the firefighter movement. It is also use the concept of the use of human body. This concept is under principle of motion economy that used to reinforce the effectiveness of work. The concept also can lead to smooth and automatically performance of any operation. The proposed design of tool is shown in Fig. 13.

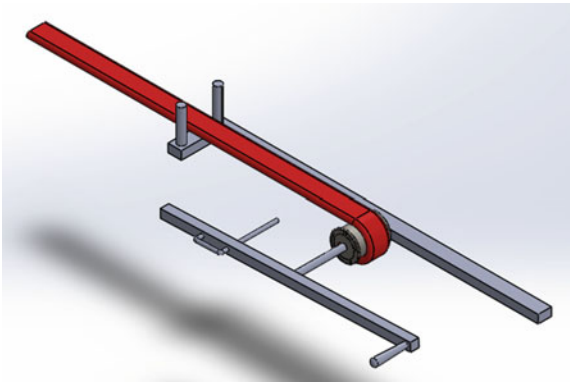


Fig. 13 Proposed design tool

5 Conclusion

The aim of the study is to identify most ergonomic risk factors that may cause harm to firefighter. The aim is achieved by applying the ERA to identify ergonomic risk factor (ERF) among firefighter. The ERF is applied by an observation towards firefighter doing their manual handling at Pagoh fire station. Awkward posture is the most ergonomic risk factor identified compare to other factors (repetitive motion and vibration). The second aim of the research to improve ergonomic at workplace is achieved by proposing a new tool that control the ergonomic risk factor experienced by firefighter. However, the proposed tool need further investigation especially on the design, strength, functionality, portability and suitability for firefighter. The proposed design tool will be discussed detailed for further research.

Acknowledgements Authors would like to thanks Ministry of Higher Education Malaysia (MoHE), Universiti Tun Hussein Onn Malaysia under Collaborative Research Grant (CRG) for the research funding No. K263 and X158.

References

1. Yazuli ZA, Karuppiah K, Kumar E, Md Tamrin SB, Sambasivam S (2019) Discomfort, fatigue and work-related musculoskeletal disorders associated with prolonged standing among Malaysian manufacturing workers: a mini review. Songklanakarin J Sci Technol 41(2):271–275. https://rdo.psu.ac.th/sjstweb/journal/41-2/4.pdf
2. Sholihah Q, Hanafi AS, Bachri AA, Fauzia R (2016) Ergonomics awareness as efforts to increase knowledge and prevention of musculoskeletal disorders on fishermen. Aquat Proc 7:187–194. https://doi.org/10.1016/j.aqpro.2016.07.026
3. Aqlan F, Lam SS, Ramakrishnan S, Testani M (2014) An ergonomic study for 6s workplace improvement. In: IIE annual conference. Proceedings. Norcross, pp 3063–3068
4. Radin Umar RZ, Ahmad N, Halim I, Poh YL, Hamid M (2019) Design and development of an ergonomic trolley-lifter for sheet metal handling task: a preliminary study. Saf Health Work 10(3):327–335. ISSN 2093-7911. https://doi.org/10.1016/j.shaw.2019.06.006
5. DOSH Malaysia (2018) Guidelines for manual handling at workplace 2018, pp 1–90
6. Ohnishi A, Takanokura M, Sugama A (2016) Evaluation of interhandle distance during pushing and pulling of a four-caster cart for upper Limb exertion. Saf Health 7(3):237–243
7. Kim MG, Seo JI, Kim K, Ahn YS (2017) Nationwide firefighter survey: the prevalence of lower back pain and its related psychological factors among Korean firefighters. Int J Occup Saf Ergon 23(4):447–456
8. Karter M Jr, Molis J (2008) U.S. firefighter injuries-2007. National Fire Protection Association, Quincy, MA
9. Roh SG, Kim JH (2013) Work related diseases in Korean fire fighters. J Digital Converg 11(10):571–576
10. DOSH Malaysia (2017) Guidelines on ergonomics risk assessment at workplace 2017. Department of Occupational Safety and Health, p 155
11. Tee KS et al (2017) A study on the ergonomic assessment in the workplace. AIP Conf Proc 1883, Aug 2017
12. Jithin V (2016) Ergonomic assessment and implement controls in automobile closed room testing by using risk assessment methodology. Int Res J Eng Technol 3(5):2737–2742

13. Jaffar N, Abdul-Tharim AH, Mohd-Kamar IF, Lop NS (2011) A literature review of ergonomics risk factors in construction industry. Proc Eng 20:80–88
14. Wilhelmus GJA, Johanssons E (2018) Observational methods for assessing ergonomic risks for work-related musculoskeletal disorders. A scoping review. Rev Cienc Salud 16(special issue):8–38
15. Hamdi (2008) Graduate school of natural and applied sciences. Program, p 508
16. Prajapati DR (2012) Implementation of failure mode and effect analysis: a literature review. Int J Project Manage 2(7):264–292
17. Carlson CS (2015) Understanding and applying the fundamentals of FMEAs summary. In: 2015 annual reliability and maintainability symposium. ReliaSoft Corporation, USA
18. Rakesh R, Jos BC, Mathew G (2013) FMEA analysis for reducing breakdowns of a sub system in the life care product manufacturing industry. Int J Eng Sci Innov Technol 2(2):218–225
19. Baynal K, Sari T, Akpinar B (2018) Risk management in automotive manufacturing process based on FMEA and grey relational analysis: a case study. Adv Prod Eng Manag 13(1):69–80
20. Shinde RR, Shrivastava R, Morey RB (2015) Failure mode effect analysis-case study for bush manufacturing process. Int J Sci Eng Appl Sci 1(4):2395–3470
21. Adnan NH, Ressang A (2014) Ergonomics awareness on construction site. Engineering UTM. Available at: http://civil.utm.my/wp-content/uploads/2016/12/Ergonomics-Awareness-on-Construction-Site.pdf. Accessed on Jan 2019
22. Abide A (2013) Applications of principles of motion economy. Bahirdar University Institute of Technology, pp 7–19
23. OSHA (2007) Ergonomic assessment checklist. vol 1, pp 1–2