Design of Hose Roller for Firefighter: A Fatigue Study

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Abstract In a working environment, worker's safety and health are the most critical considerations. Previous study discovered that firefighters are exposed to a great deal of ergonomic risk factors (ERF). ERF exposure during hose rolling includes awkward posture and forceful exertion. Therefore, the primary goal of this research paper is to fabricate an ergonomic hose roller for firefighters and conduct a fatigue analysis to determine the efficiency of the tool designed to safeguard firefighters against the risk of low back disorder (LBD). Hose roller testing is necessary to guarantee that it can withstand the weight of fire hoses while still being comfortable for users' bodies. Fatigue analysis was conducted using Industrial Lumbar Motion Monitor (i-LMM) equipment to evaluate LBD risk during hose rolling. Manual handling contributes 57.67% to the total average percentage value used to compute LBD risk results, while utilizing a roller tool, the hose rolling procedure yields a 27% LBD risk limit value. The design of experiment (DOE) method should be used in future studies to gather more information for the LBD risk assessment.

Keywords Ergonomic design · Low back disorder · Fatigue analysis · Ergonomic risk factor

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M. H. A. Hassan et al. (eds.), *Proceedings of the 2nd Human Engineering Symposium*, Lecture Notes in Mechanical Engineering,
https://doi.org/10.1007/978-981-99-6890-9_4

1 Introduction

Before the use of mechanical tools, firefighters used to conduct the two-man hose roll method, which is believed to protect the firefighters' lower backs [1]. A fire station operates for 24 h, and usually involves two shifts which are 12 h shift and 24 h shift. The job scope during daytime and nighttime included maintenance of vehicles, rescue equipment, emergency training, rescuing victims, and also attempting to salvage the content of buildings [2]. According to data obtained from the Social Security Organization (SOCSO), there were 10 recorded cases of MSD among Malaysian employers and employees in 2005 and 675 cases in 2014 [3]. From 2009 to 2014, there was an increase in the total number of cases of musculoskeletal disorders (MSDs) as a result of incident involving manual handling tasks [4]. This trend is anticipated to increase awareness among Malaysian businesses and employees. To create awareness among firefighters regarding MSDs, this research paper proposed the development an ergonomic hose-rolling equipment for firefighters. This paper aims to design a lightweight, easy-to-carry and ergonomic hose roller for firefighters. As a result, having a good choice of tools and a design that is durable and easy to use is required to improve the fabrication process. This paper also aims to evaluate the efficiency of the hose rolling system during fatigue analysis by utilizing appropriate tools and applying Ballet Software. The efficiency and safety measures of firefighting tools are the most important factors that influence firefighters' performance. Delivering a fire extinguishing supply necessitates the use of high-efficiency firefighting equipment; otherwise, it could possibly lead to strain, injuries, and potentially dangerous circumstances. The use of gear and equipment designed to reduce the physical exertion required to manage heavy lifting and carrying duties is one of the approaches that can be used to reduce the danger faced by firefighters during fire extinguishing operations. However, the hose rolling tools' durability can have an impact on the firefighting process, as long-lasting tools are required to avoid performance failure during the operation period [5]. Firefighters have also encountered an issue where the tools used during operations were inefficient and took a long time to use.

Additionally, the hose rolling tools need to be of the right size and weight in order to be convenient to carry and store [6]. Previous research has shown that aluminium is recommended as the main material for the research due to its lightweight, durable, and easy to cast factors [7]. This paper offers the possibility of fabricating hose rolling equipment, which could help firefighters reduce the risk during firefighting operations and hose reel inspections. However, most previous research analyses did not focus on fatigue analysis after the fabrication [1]. As part of the fatigue analysis, this research paper analyzed the efficiency of the fire hose roller by obtaining the value of LBD risk in terms of percentage using iLMM tools. This ensures that the fire hose roller is adequate for firefighting operations while also reducing the ERF specifically for firefighters while rolling the hose, which is one of the critical tasks.

2 Materials and Methods

The selected materials and procedures were used to fabricate the hose roller tool. However, testing of the developed tool has been carried out to ensure that the hose roller tool performs appropriately and smoothly for fatigue analysis. The testing process also ensures that the hose roller tool can accommodate the sturdiness of the fire hose. Fatigue analysis was carried out to determine the average probability of possible LBD risk for firefighters. The methodology flowchart for this paper is illustrated in Fig. 1.

2.1 Fabrication

The fabrication process of the hose roller is mainly based on metal fabrication since most of the materials and equipment are made of steel. The procedures of casting or molding a raw or semi-finished metal workpiece is referred to as a metal fabrication. Forming, shaping, bending, and cutting are all parts of the processes involved. It is preferable to use the fitting and shaping process rather than welding when fabricating hose rollers. This is due to the possibility that welding will create a permanent junction, making hose roller maintenance virtually impossible. The Failure Mode Effect Analysis (FMEA) and proposed design from previous work were used to develop the hose roller outer and inner systems [8–10]. The fabrication process of

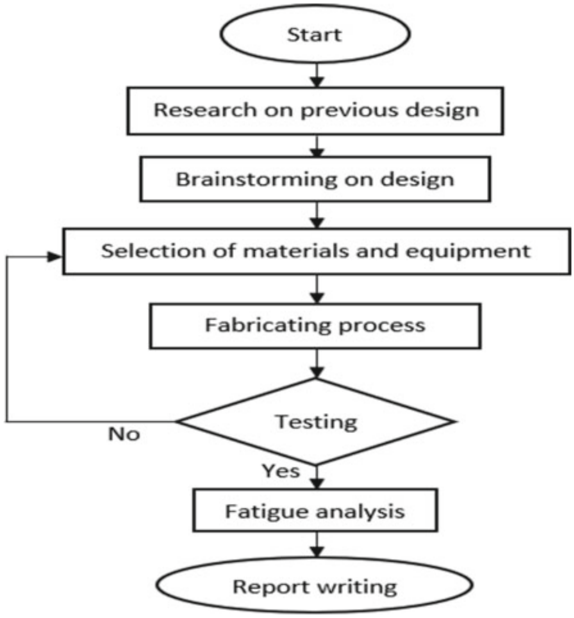

Fig. 1 The methodology flowchart of the project

Fig. 2 The result of an aluminum sheet after being shaped using grinder during fabrication

Fig. 3 The fitting task of shaped aluminum sheet using a bracket and a rivet

the hose roller was applied which are shaping, fitting and application of bolts and nuts respectively (see Figs. 2, 3 and 4).

2.2 Testing

The hose roller tool testing method is critical for ensuring that the fatigue analysis runs smoothly and correctly. The hose roller tool has been tested in order to determine its ability and efficiency in fatigue analysis, besides its ability to accommodate the weight and size of the fire hose during the hose rolling task. The fire hose used in the measuring process is 10 m long, 10.5 cm wide, and weighs 4.9 kg. The testing process for the hose roller conducted at Pagoh Fire Station is depicted in Fig. 5.

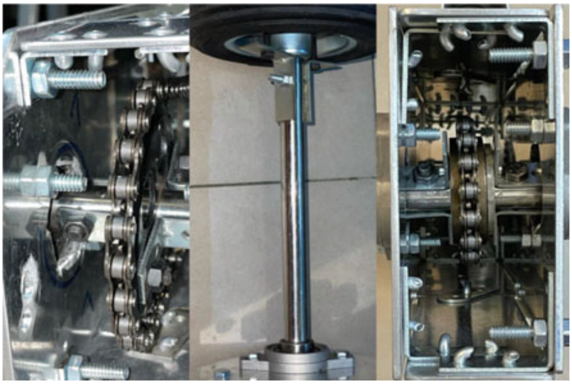

Fig. 4 The application of bolts and nuts respectively during the fabrication process

Fig. 5 The testing process of hose roller at Pagoh fire station

2.3 Fatigue Analysis

After the fabrication process, a fatigue analysis was performed to determine the hose roller's capabilities and durability, as well as the probability of a firefighter being exposed to an ergonomic risk while using the hose roller tool or manual handling hose rolling. Fatigue analysis is the study of a model's or material's tendency to fracture. For conditions when the stress cycles are regular and lower than the normal strength, this can be achieved by applying constant amplitude loading [11]. The National Institute of Occupational Safety Health (NIOSH) conducts a fatigue investigation of the hose roller, in which data on body posture will be acquired using i-LMM tools. As the fatigue analysis progresses, it will become clear whether the hose roller requires changes or adjustments to its materials or equipment, which may affect body posture while using hose rolling instruments. This method is necessary in order to demonstrate how the hose roller tool can decrease the risk of a firefighter being exposed to an ergonomic risk, particularly when it comes to body posture and repetitive action.

i-LMM is a set of tools working in collaboration with the Ergonomic Excellence Centre (EEC), NIOSH. It is a set of tools that allows assessing LBD risk in industrial

Fig. 6 The application of i-LMM tool

employment in terms of body postures and dynamic movement effects. The i-LMM is a tri-axial thoracolumbar goniometer that measures lumbar spine motion [12]. It also includes the BALLET software as well as a set of harnesses with two motion sensors attached. The respondent must wear harnesses, with one sensor directly in line with the spine and the other on the same level as the pelvis. The use of the i-LMM tool and harness was applied on a respondent before the data collection process (see Fig. 6). The lift rate, average twisting velocity, maximum moment, maximum sagittal flexion, and maximum lateral velocity are all detected by these motion sensors. The sensors capture position data at 60 Hz, which can be accessed via a desktop or notebook computer with BALLET software. After that, the BALLET software will determine the average risk of LBD in percentages. The data collected will then appear on the BALLET program start-up screen (see Fig. 7).

3 Results and Discussion

3.1 Fabrication

The fabrication procedure for this research is based on a concept proposed by previous research [13]. The dimensions of the produced hose roller tool differ slightly from the initial design. The testing process also resulted in improvements based on fatigue analysis which will be explained in the Data Analysis Section below. The dimensions of the hose roller tool have been extended broader and appeared to be larger on the hose roller hook in order for it to perform well during fatigue analysis. This also serves as a balancing mechanism for the hose roller tool's movement. The design of the fabricated hose roller tool was drafted using *SolidWork* software in both isometric and exploded views. The isometric view and exploded view of the hose roller tool

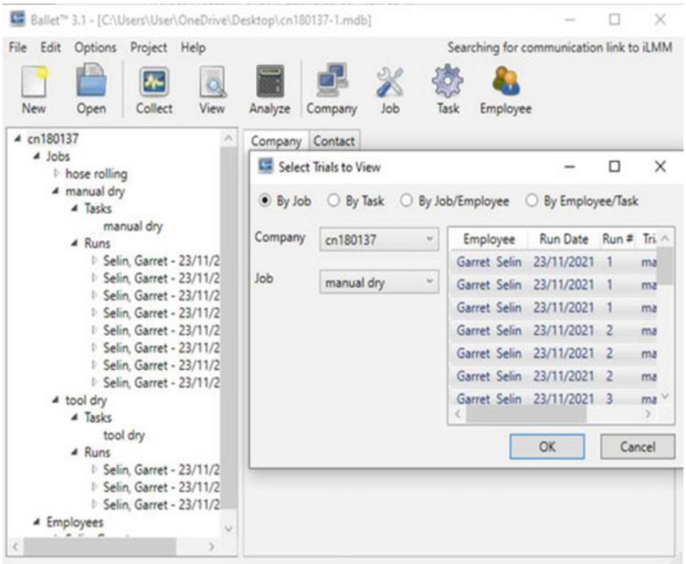

Fig. 7 Graphical user interface of BALLET software version 3.1

Fig. 8 Isometric view of hose roller tool

were extracted from *SolidWork* software respectively (see Figs. 8 and 9). The hose roller tool has been fabricated according to the extracted design (see Fig. 10).

3.2 *Data Analysis*

The data and results of the fatigue analysis were collected by two people, one of whom performed the hose rolling task and the other who monitored the data collection using

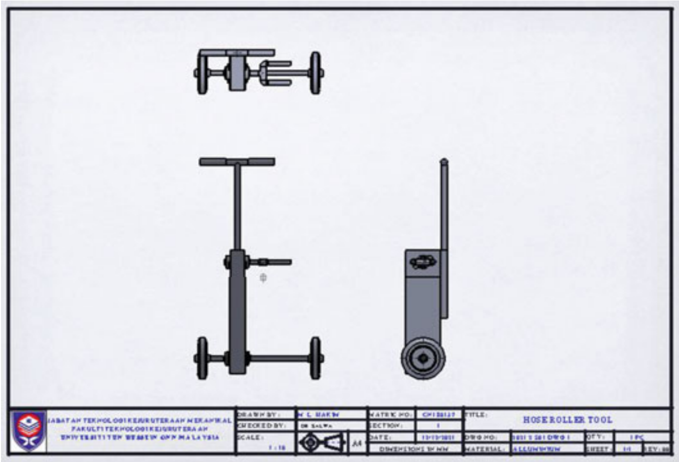

Fig. 9 Exploded view of hose roller tool

Fig. 10 A complete fabricated hose roller tool

BALLET software. The two methods for collecting hose rolling data are manual handling and the use of a hose rolling tool. Each method is repeated three times, and three average probabilities of LBD risk are generated in percentages. The values such as the specifications of the hose rolling tools and the distance between tools and respondent must be determined earlier in order to perform the data collection in the BALLET software (see Fig. 11). The information will then be used by the BALLET software to compute the average risk of LBD accurately.

Three distinct runs were recorded using both methods. Three independent data sets with an average likelihood of LBD risk from the manual handling approach are

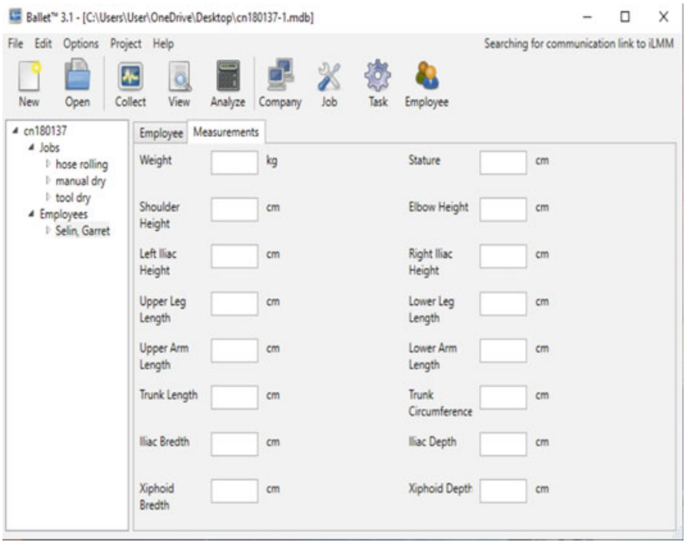

Fig. 11 The values required for hose rolling tool specification in BALLET software

given (see Figs. 12, 13 and 14). The average likelihood can be categorized as high, according to the data, increasing slightly from 55 to 59%, respectively.

For three distinct runs, the data for the hose roller tool approach was also recorded. According to the statistics from the hose rolling tool method, the average likelihood is lower than the manual handling approach, which ranges from 18 to 32%. The data obtained using the hose roller tool method are demonstrated in Figs. 15, 16, and 17.

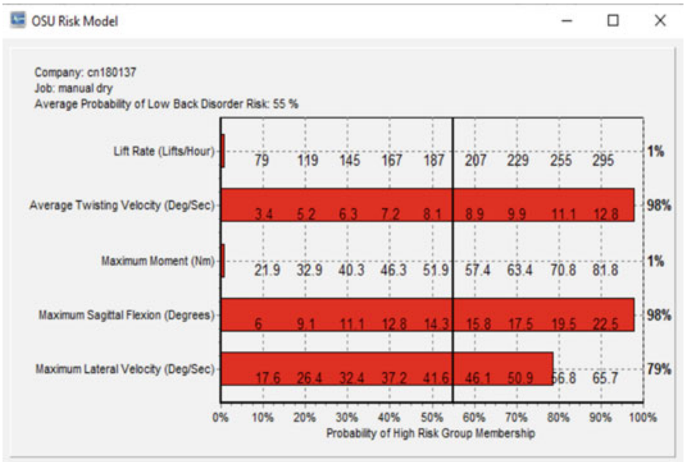

Fig. 12 Data on the average probability of LBD risk on the first run from the manual handling method

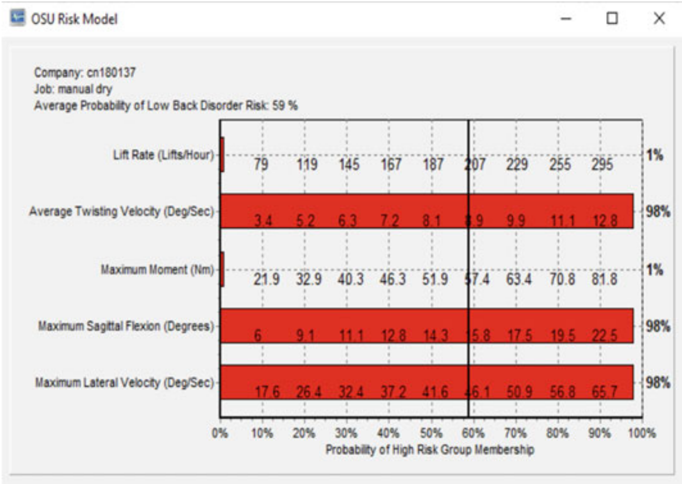

Fig. 13 Data on the average probability of LBD risk on the second run from the manual handling method

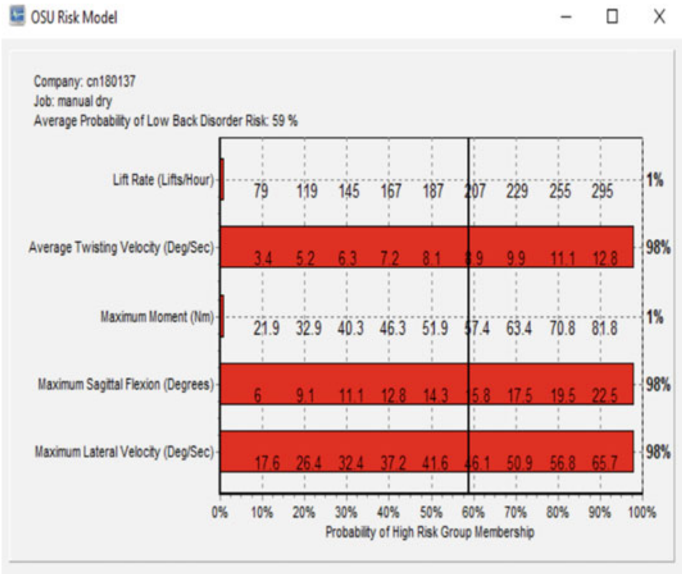

Fig. 14 Data on the average probability of LBD risk on the third run from the manual handling method

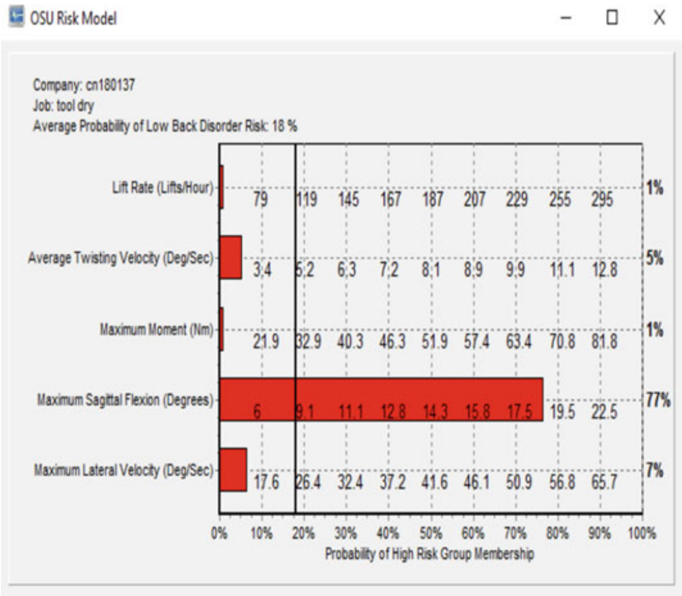

Fig. 15 Data on the average probability of LBD risk on the first run from the hose rolling tool method

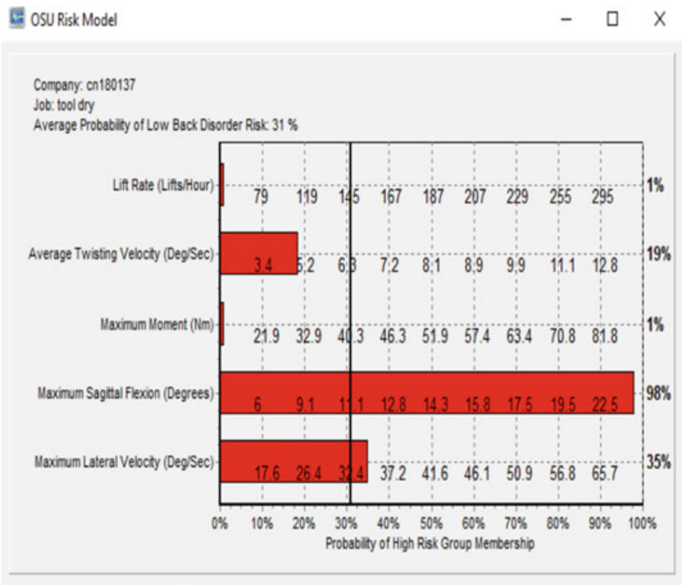

Fig. 16 Data on the average probability of LBD risk on the second run from the hose rolling tool method

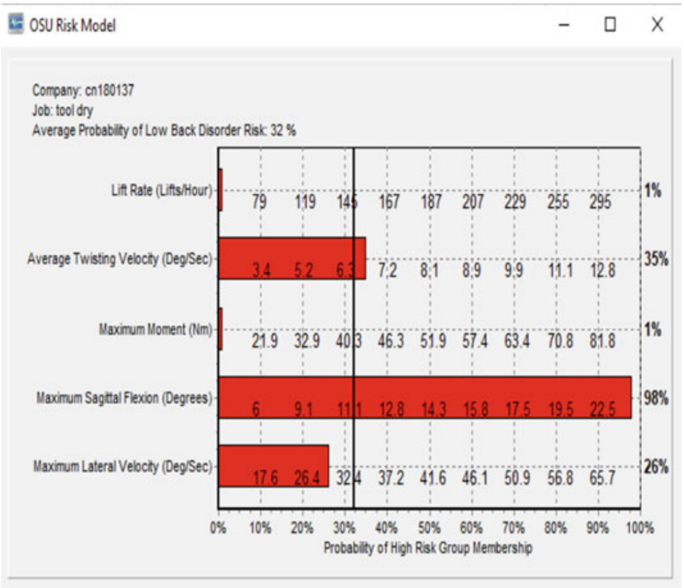

Fig. 17 Data on the average probability of LBD risk on the third run from the hose rolling tool method

3.3 Data Comparisons Between Manual Handling and Hose Rolling Method

In this paper, data comparison is used to compare and evaluate the efficiency of the fabricated hose rolling tool. The manual handling method and the hose roller tool method of hose rolling method data have been compared. The data comparison approach was used to determine the efficiency of the hose roller tool. Table 1 depicts a data comparison table of the average LBD risk for each approach.

According to the data shown, the outcome of LBD risks from BALLET software can be compared between manual handling and the usage of a hose rolling tool. When the average likelihood of LBD hazards reaches 30%, the work method is exposed to

Table 1 Data comparison of total average LBD risk

Method	LBD risk (%)	Run	Total average (%)
Hose roller tool	18	1	27.00
	31	2	
	32	3	
Manual handling	55	1	57.67
	59	2	
	59	3	

LBD risks. The average LBD risk percentage value for the manual handling method is higher on average, ranging from 55 to 59%, with a total average LBD risk value of 57.67%. Meanwhile, the percentage value of the hose rolling tool approach has increased slightly from 18 to 32%. Despite the value range exceeding 30%, the overall average is below the 27% LBD risk limit value.

According to fatigue research, the risk of LBD increases as body posture, flexure, and twisting are increased during hose rolling work. The manual handling strategy is more vulnerable to LBD hazards than the hose rolling method, which only recorded 27% because the overall average percentage number exceeds the LBD risks limit defined in the BALLET software, which is 57.67%. Utilizing a hose roller tool that requires less flexure, twisting, and moment on body posture to perform the hose rolling activity is essential for the response on the hose rolling task to maintain a favorable body posture condition. Employing a hose roller tool can help reduce the percentage of time that workers are exposed to LBD risks, according to the statistics [1].

4 Conclusions

The hose roller tool is intended to lessen the risk danger of ERF and LBD, particularly among firefighters when rolling the hose. The main objectives of this paper are to develop the hose roller as an ergonomic tool for firefighters and apply a fatigue analysis to evaluate the hose roller tool's efficiency in preventing ERF and LBD risks. The fatigue analysis was conducted with the aid of the i-LMM tools, which allowed for a comparison of the average chance of LBD risk when performing hose rolling activities using the manual handling method and the hose roller tool method. Based on data obtained from fatigue studies, it is shown that the development of a hose roller tool in the hose rolling work may minimize the ERF and LBD risk factors. When applying a hose roller tool for hose rolling, the average likelihood of LBD risk is lower than when using a manual handling method; 27% average LBD risk. Hence, from the analysis, it can be concluded that it can also avoid ERF caused by MSD which originates from awkward posture, forceful exertions, pressure points, and static postures [14, 15].

For future recommendations of this research, the hose roller tool has to be improved in terms of its fabrication and fatigue study. When replacing rivets, it is strongly suggested that the bolts and nuts are fully applied for fitting and joining parts. Besides, it is recommended that the fire hose is evaluated in two different situations namely in wet and dry conditions for improvement in the data collection stage. This could also determine the hose roller tool's efficiency in various fire hose conditions. As a result, future research may need to use the design of experiment (DOE) method to find the best, suitable condition to use as a factor in DOE. Moreover, another ergonomic design principle can be used, such as a motor installation for force reduction or a handle grip design for comfort. Additionally, a comparison between manual handling and the use of newly developed tools requires the conduct of an ergonomics risk assessment using the appropriate techniques.

Acknowledgements The authors wish to thank the Universiti Tun Hussein Onn Malaysia for their involvement in this research. This research is supported by the Ministry of Human Resources - National Institute of Occupational Safety and Health (NIOSH), under *Geran Kontrak Kementerian* Vot K447, and University Tun Hussein Onn Malaysia (UTHM) through GPPS Vot Q213.

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