DIGITAL HUMAN MODELING IN ERGONOMIC RISK ASSESSMENT OF WORKING POSTURES FOR HORIZONTAL LOG BAND SAWMILL

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SUMMARY

Digital Human Models (DHMs) are becoming a useful tool for ergonomics design and worker operations analysis in the industry field. The present study aims to initially assess the risk of biomechanical and the postures assumed by a worker during the manual operation of the horizontal log band sawmill (HLBS) machine in Vietnam. The Rapid Upper Limb Assessment (RULA) and Biomechanical compression force (BMCF) methods of Ergonomic Design & Analysis module in CATIA software were used to analyze pushing and pulling operation postures on the HLBS machine. The results indicate that the RULA score of pulling and pushing operation of the 5th percentile workers is 5. For the 95th percentile, the analysis scores are 7 and 6, respectively. The biomechanical analysis results show that the compression force of 5th and 95th percentile workers in pushing operation are1433 and 1718 N, while pulling operations are 1379 N and 1654, respectively. The results indicate that the risk levels associated with two operation postures are high. Therefore, it is necessary to implement ergonomic interventions to reduce risk levels of these operations. This study results also show that Ergonomic Design & Analysis module in CATIA software is very useful to study ergonomics in workstations and industrial environments.

Keywords: CATIA software, digital human model, ergonomic risk assessment, horizontal log band sawmill.

1. INTRODUCTION

Human resources are considered as one of the most important factors in the enterprise's industrial production activities. To increase productivity and improve quality, it is important to consider the environment or workspace in which operators perform their tasks. In the last decades, norms and laws on safety and ergonomics of the workplace have taken importance among industrialized countries. Even though there are a lot of advances in automation of manufacturing process, human operators have essential role in most of production systems, due to the flexibility and adaptability of human beings. However, humans are usually at risk of injury, if they employ cyclic, continuous, forceful, or awkward working posture, especially problem of work-related musculoskeletal disorders (WMSD) are the most common occupational health problems in the developed and developing countries (Chaffin, 2008).

The term “musculoskeletal disorder” (MSD) is used collectively for disorders that affect the human body's movement or musculoskeletal system (thas is (i.e.) muscles, tendons, and/or joints, ligaments, nerves, discs, blood vessels, etc.). It is caused by a combination of risk factors such as repetitive motion, excessive physical exertion, and bad and/or awkward working postures (da Costa and Vieira, 2010). Reality shows that industrial accidents are closely related to the prevailing work environment, tasks carried out and other factors such as ergonomic, machine, workers characteristics, training, and many others (Clarke, 2006; Cooper, 2000; Das et al., 2008; Ratnasingam et al., 2011). Therefore, to improve the efficiency of the workers, their posture working needed to be assessed and corrective measures should be adopted to avoid the risk of musculoskeletal disorders and other related problems. Recently, digital human models (DHMs) and simulation software has been applied in ergonomics design and analyses for a long time. They are valuable methods for proactively understanding human performance limitations typical of a manufacturing environment without requiring the expense of creating physical mock-ups (Chaffin, 2005; Kumar et al., 2013). Many research results have shown that using DHM in design and evaluation is an effective method to reduce time and design cost, and achieving a higher standard of workers' health (Gawand, 2019; Rajesh and Srinath, 2016).

The forest product processing industry has been recognized as a highly hazardous industry (Gellerstedt, 2000). However, the studies of labor accident rates in the wood processing industry are sparse, although the industry is considered to be highly vulnerable. Most of the accident reports are focused on the nature of processing rather than the characteristics of the workforce. Holcroft and Punnett (2009) reported that the injury rate for wood product manufacturing in Maine was related to high physical workload, machine-paced work or inability to take a break, lack of training, absence of a lockout program, low seniority, and male gender. Ratnasingam et al. (2012) concluded that the contract workers are less prone to occupational accidents compared to permanent counterparts, and hence, are more productive. Therefore, to improve the efficiency of the workers their posture needed to be assessed and corrective measures should be adopted to avoid the risk of musculoskeletal disorders and other related problems.

In Vietnam, the wood processing industry has become the fifth leading export sector after crude oil, textiles, footwear and seafood. Vietnam is now one of the world's largest exporting countries for wood and wood products with around 4,500 timber processing enterprises across the country. In 2018 alone Vietnam earned a record US$9.3 billion from forestry exports (Vietnam, 2019). The industry continues to grow as demonstrated in the first six months of 2019, where the export turnover of wood and wooden products reached US$4.8 billion. In addition to being economically important, wood product processing is a highly hazardous industry. Currently, the wood processing industry in Vietnam has about 250,000 to 300,000 workers (Viettrade, 2019). In which, 10% of laborers have a bachelor's degree or higher; 45-50% of workers are regularly trained, and the remaining 35-40% are seasonal laborers. However, the majority of laborers are not well-trained and unprofessional, especially the workers operating the machines. Although there are no accurate statistics, the industry's judgment shows that the number of accidents in the wood processing industry is always higher than in many other industry fields. One of the reasons is that the management aims to gears towards mass production, focusing on increasing throughput with minimal focus on workers' safety and work environment. In addition, some of the common problems of the small scale and unorganized sector industries are inappropriate workplace design, poor human-machine system design, poor working postures and inappropriate management programs.

The horizontal log band sawmill (HLBS) machine is widely used in the wood processing industries in Vietnam. However, the operations on small scale industries are mostly manual work, without the use of hydraulic or supporting equipment. Poor working postures easily leads to rates of the incidence of WMSDs. Therefore, the aim of this study was to initially assess the risk of biomechanical postural overload, evaluating the postures assumed by workers during the manual operation of the HLBS machine based on Rapid Upper Limb Assessment (RULA). To obtain its objective, the research was designed with the following steps: Firstly, equipment and the main operations of workers when processing a product category at the factory were studied. Second, the work postures of workers were simulated and evaluated by using a DHM in CATIA software.

2. RESEARCH METHODOLOGY

2.1. Risk Factor Identification and Development of the Model

Log band saw is one of the main sawmilling machines designed to saw wood species with large diameters. A typical HLBS machine is driven by an electric motor via a belt transmission so the cutting speed is usually fixed. The blades are mounted on large diameter wheels (driving wheel and driven wheel) to prevent metal fatigue due to blade flexing when repeatedly changes from a circular to a straight profile (Figure 1). In the sawmill, the workers are subjected to the high noise of the bandsaw for durations above the safe limit. Also, the workers often carry heavy loads and perform many improper work postures, which easily leads to generation of health problems. Currently, there are many types of HLBS machines. They can be classified in many different ways such as based on the degree of mechanization and automation, the movement of cutting blade and workpiece (moving workpiece or fix workpiece), the size of the wheels, and others (Hoang, 2012).

In the small-scale sawmill, most work is done manually without much use of powered vehicles. The workers are subjected to the high noise of the bandsaw for durations above the safe limit. Saw workers, especially sawyers, are also exposed to high concentrations of sawdust while cutting the wood. Also, the workers often carry heavy loads and perform many improper work postures, which easily leads to the generation of health problems.

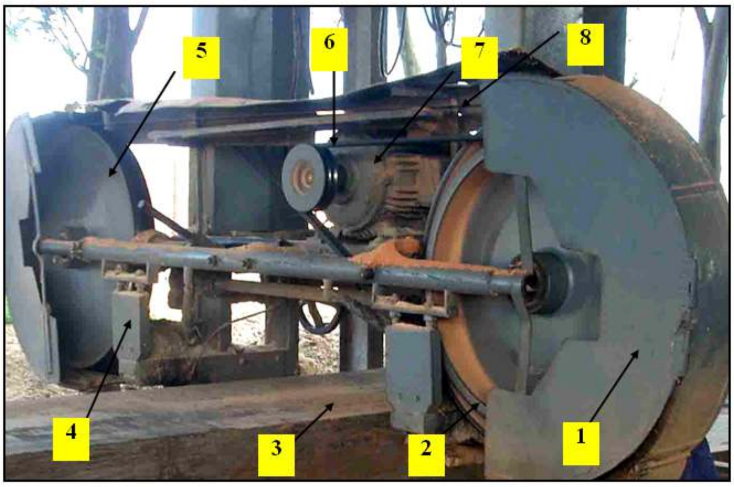

Figure 1. The general structure of the HLBS machine in the sawmill

1- Wheel cover bracket. 2- Driving wheel. 3- Wood log. 4- Guide section. 5- Driven wheel. 6- Belt driver. 7- Motor. 8- Bandsaw blade

In this study, we surveyed and interviewed workers at 18 sawmills in Ha Noi, Nam Dinh, and Quang Ninh. The results show that there are still many sawmills using manual band saws in production. Most of the equipment used is HLBS of Dong Thap Technology TT&P Company Limited, Dong Anh Licogi Mechanical Joint Stock Company, Thanh Tong Mechanical Joint Stock Company, and others, similar to the results of recent studies (Nguyen, 2012; To et al., 2018). This result shows that the manual band saws are still being used very popularly in the current conditions in Vietnam. We proceed to make video recordings of the manufacturing process in 18 sawmills followed by identification of the risk factors based on the ergonomics approach (Figure 2). Specifically, a redesigned 3-dimensional model of the HLBS machine based on the dimensions of the existing CD4 version machine. The next step was to simulate bad working postures and present acceptable working postures based on DHM workers (Figure 3). The anthropometric parameters used to build DHM are 1.68 m in height and 58 kg in weight. Other anthropometry data, such as sitting height, should breathe, and so forth, were applied based on the Asia population. The workpiece is a rectangular log with an average length of 2000-2400 mm, a width of 450-500 mm, and a thickness of 350-400 mm.

Figure 2. Push and pull operation when operating the HLBS machine

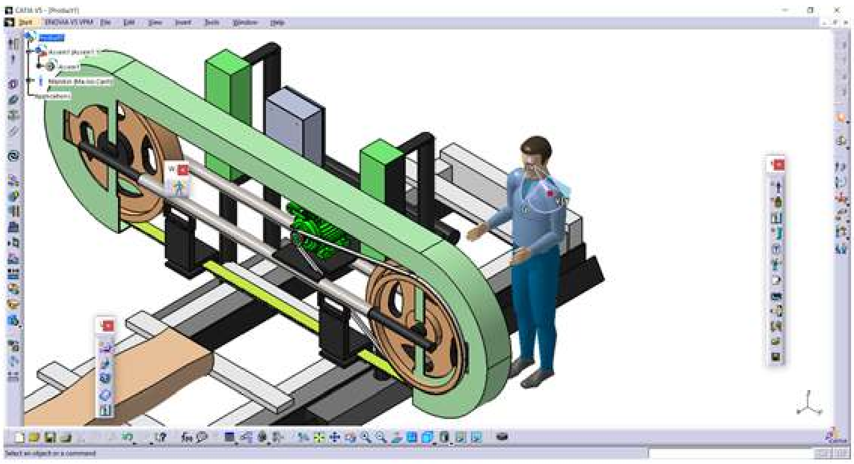

Figure 3. Existing workplace, manikin and HLBS machine model

2.2. Assessment Methods

2.2.1. Working Posture Assessment

Inappropriate working postures constitute one of the major elements that increase the frequency of accidents by causing various musculoskeletal issues and decreasing workers' concentration. It is directly related to the movement of heavy loads by hand or bodily force, and should be avoided when possible. Work-related upper limb disorders arise mainly from performing repetitive actions. If avoidance is not possible, risk of injury must be reduced as much as possible by actions that include 1) improving workplace design so that less movement is needed; 2) modifying the load by making it lighter or easier to hold; and 3) training workers in good practices such as proper handling techniques.

To determine the postures of the worker, the most repetitive working postures were observed in real-time and analyzed by Rapid Upper Limb Assessment (RULA) which is the most applied posture analysis tools (Hignett and McAtamney, 2000; Nishanth et al., 2015). RULA is a tool used to evaluate the upper body (neck, arms, forearms, wrists, and legs) of workers based on various variables and user data, such as lifting distance, lowering distance, operation duration, task frequency, and other. The RULA score displayed is combined with a color indicator zone. The color of this zone changes from green to red according to the total score and consists of basic mode and advanced mode (Figure 4). In the RULA method, the decision depends on the level of which can be categorized into four action levels, specifically:

Level 1: Low risk level. A score of 1 or 2 indicates that posture is acceptable if it is not maintained or repeated for long periods.

Level 2: Medium risk level. A score of 3 or 4 indicates that further investigation is needed and changes may be required.

Level 3: High risk level. A score of 5 or 6 indicates that investigation and changes are required soon.

Level 4: Very high risk level. A score of 7 indicates that investigation and changes are required immediately.

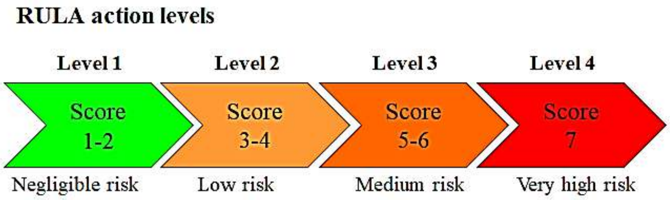

Figure 4. RULA evaluation levels

2.2.2. Biomechanical Analysis

Biomechanics is the application of the principles of mechanics to the physical structure of human beings. Among the recommendations proposed by various agencies, the National Institute of Occupational Safety and Health (NIOSH) Work Practices Guide has been more widely distributed and adopted. The compressive forces on L4–L5 lumbar spines, due to the mass of a body plus load acting on hand and trunk, have a safe/cut-off limit of 3433 N with the maximum permissible limit of 6376 N (Figure 5). Based on the various design criteria, two limits are proposed. Action limit (AL) loads under this limit can be lifted by 99% of men and 75% of women, and maximum permissible limit (MPL) loads that can be sustained by only 25% of men and 1% of women.

Figure 5. Spine limits in NIOSH Guide

2.3. Ergonomic Design & Analysis in CATIA software

Currently, there are many software tools that have been developed to study ergonomics-related issues such as Safe Work, CATIA, Humancad, Delmia, Mannequin, and others. Among these ergonomics software tools, CATIA is one of the most commonly used. With the ergonomic design & analysis module, the DHM in desired sizes can be created and this manikin can be positioned in any working posture.

There are four main modules such as Human Measurement Editor, Human Action Analysis, Human Posture Analysis, and Human Builder Module. Human Measurements Editor dedicate to the creation of detailed DHM for extended analysis. This module also allows for the creation of the human manikin by complex series of advanced anthropomorphic tools. There are 103 anthropomorphic variables that can be adjusted and therefore anybody's size can be precisely adjusted as required. In addition, it is also possible to create the manikin by adaptation of a smaller number of "critical" variables and then to request the program for completion of the rest variables (Figure 6).

The Human Builder module consists of the complex set of tools that are dedicated to the creation of DHM, manipulation with the manikin, and analysis their interaction with the product. The manikins can be used to advisement of the product from the point of view form, comfort and function. This module incorporate the manikin generation, sex specification and percentiles, techniques to manipulation with the manikin (normal and inverse kinematics), creation of the animation, simulation of the monocular, binocular and ambinocular sight as well as the cone of viewing filed.

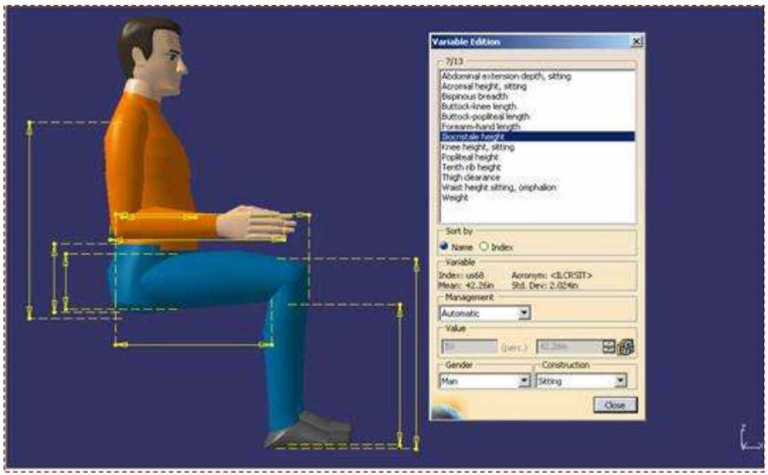

Figure 6. Operation example in Human Measurement Editor module

Human Posture Analysis analyzes how the human posture influences productivity by task execution. They are analyzed the local and total postures, preferred angels and convenience. This module allows the user qualitative and quantitative analysis of all aspects of the manikin postures. Whole-body and localized postures can be tested, evaluated, iterated and optimized (Figure 7).

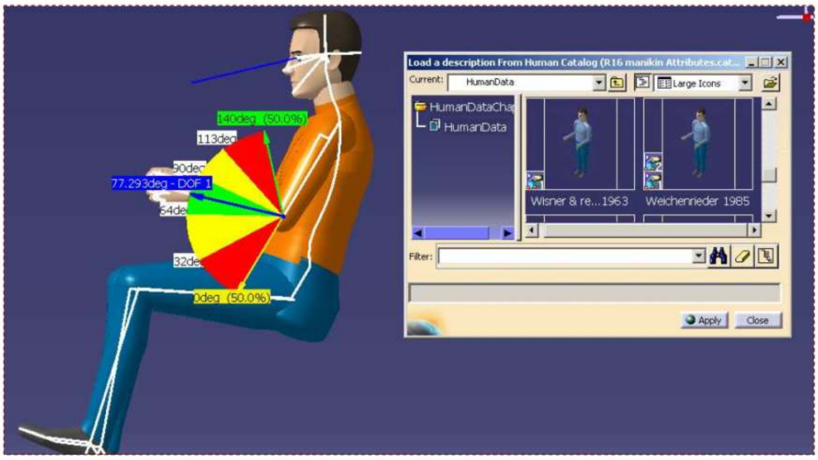

Figure 7. Operation example in Human Posture Analysis module

Human Activity Analysis uses to interact the human with the objects in the working area as well as to effects of the lifting, sinking, pressing, pulling and bringing to the efficiency. This module evaluates all aspects of human effectiveness from the analysis of the static position up to the complex activities by task execution. It supports the following analysis: RULA, loading analysis by load lifting (according to NIOSH 1981, NIOSH 1991 and Snook & Ciriello), Push/Pull analysis, Carry and biomechanical analysis (Václav et al., 2010).

3. RESULTS AND DISCUSION

The RULA and postural score analyses were performed by considering 5th and 95th percentile anthropometric databases. In this analysis, pushing and pulling operations along with posture were observed and captured in image and video format. The most commonly adopted working postures were simulated virtually with a CAD model of HLBS and further RULA and biomechanical analysis were carried out. The RULA score of 5 for pulling and pushing operation of the 5th percentile worker was found a high-risk level which shows that the working posture is improper and needs to be modified. The body part score like wrist and arm was found a higher score, i.e. 6 for pull and 5 for push compared to other body parts. Trunk score was found 6 in both cases.

Table 1. RULA score and BMCF for worker

Percentile	Working posture			
	Push		Pull	
	RULA	BMCF(N)	RULA	BMCF(N)
5th	5	1433	5	1379
95th	7	1718	6	1654

For 95th percentile workers, a higher RULA score was found for pushing operation (i.e. 7) than pulling operation (i.e. 6), which recommends the investigation and changes are required immediately. Trunk score was found higher value (i.e. 7) for pushing operation which may be due to more forward bending of the worker. This has a great effect on the worker and for safe operation, it must be improved.

Figure 8. RULA score of 95th percentile worker during pushing (a) and pulling (b) operation

The biomechanical analysis was carried out for single-acting force analysis of L4–L5 spinal segment for all two-percentile workers and compared with the NIOSH limit. For the pushing, L4–L5 compression force of 5th and 95th percentile workers were 1433 and 1718 N and for pulling 1379 N and 1654, respectively (as shown in Table1). The absolute values of the L4–L5 compressions were found to be within acceptable limits. The results indicated that all the compression forces were below the safe limit. For the representative sample, the result of 95th percentile of both pulling and pushing were shown in Figure 8 and 9, respectively.

Ergonomically improved workplace layout helps in reduced stress on workers, elimination of repetitive tasks, cycle time reduction and hence increased productivity. Hence from the RULA score and bio-mechanics force analysis, it is seen that there is a need for investigation and immediate changes are needed in the existing posture of workers. The results also indicate that DHM technology have made it possible to identify key design issues behind difficulties which may be faced by workers in performing their tasks and can decrease the risk operation problems in the phase of the design process.

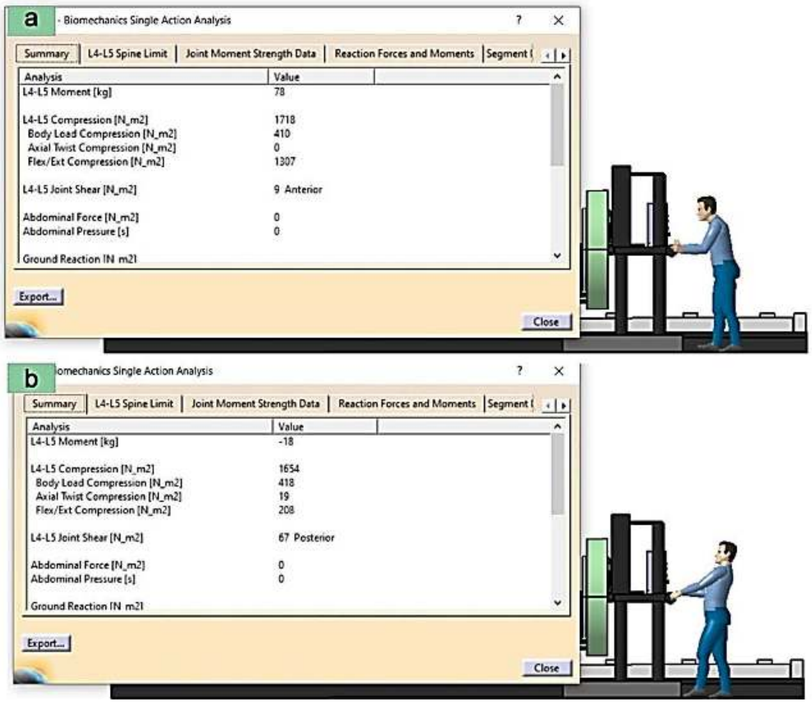

Figure 9. Biomechanical compression force of 95th percentile worker during pushing (a) and pulling (b) operation

4. CONCLUSIONS

In this study, the risk of biomechanical and the working postures of workers during the manual operation of the HLBS machine was investigated. Specifically:

- The risk elements were evaluated to estimate the potential risk for workers based on surveys and video recordings. Then, the HLBS machine model and worker were developed using Ergonomic Design & Analysis module in CATIA software.

- The results indicated that the risk levels associated with push and pull postures are high, so it is necessary to implement ergonomic interventions to reduce the risk levels of these operations. Thus, it can be concluded that CATIA software is very effective for proactive analysis of the ergonomic of the human and for determining the optimal postures in industrial environments.

However, this study has some limitations to be mentioned. First, only two postures were analyzed while many other postures have not been considered such as lifting and carrying the wooden logs, moving board, etc. Second, the study mainly focused on RULA and Biomechanical compression force analysis, the other indices, i.e., musculoskeletal disorder, noise, vision, entire body assessment, etc, were not explored. Therefore, future research needs to be conducted to get more detailed and accurate assessment results.

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MÔ HÌNH CON NGƯỜI KỸ THUẬT SỐ TRONG ĐÁNH GIÁ RỦI RO CÔNG THÁI HỌC TƯ THẾ LÀM VIỆC CHO MÁY CƯA VÒNG NẰM

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TÓM TẮT

Mô hình con người kỹ thuật số đang trở thành một công cụ hữu ích để thiết kế công thái học và phân tích các hoạt động của công nhân trong các lĩnh vực công nghiệp. Nghiên cứu này đã đánh giá rủi ro về các tư thế đẩy và kéo khi người công nhân thực hiện trong quá trình vận hành máy cưa vòng nằm dựa trên phương pháp đánh giá nhanh chi trên (RULA) và phân tích lực nén cơ sinh học (BMCF) của mô-đun Thiết kế & Phân tích công thái học trong phần mềm CATIA. Kết quả cho thấy điểm số RULA cho hoạt động kéo và đẩy của công nhân ở phân vị thứ 5 là 5 và đối với phân vị thứ 95 lần lượt là 7 và 6. Kết quả phân tích cơ sinh học cũng cho thấy lực nén cơ sinh học của công nhân theo phân vị thứ 5 và 95 tương ứng của hoạt động đẩy là1433 và 1718 N và hoạt động kéo lần lượt là 1379 N và 1654. Dựa trên thang điểm theo tiêu chuẩn, những giá trị này cho thấy rằng mức độ rủi ro liên quan đến hai tư thế hoạt động là tương đối cao. Do đó, cần phải có các biện pháp can thiệp công thái học để có thể giảm thiểu mức độ rủi ro của các hoạt động này. Kết quả nghiên cứu này cũng cho thấy mô-đun Thiết kế & Phân tích công thái học trong phần mềm CATIA là rất hữu ích trong việc nghiên cứu và đánh giá các rủi ro công thái học trong các máy trạm và môi trường công nghiệp.

Từ khóa: cưa vòng nằm, đánh giá rủi ro công thái học, mô hình con người kỹ thuật số, phần mềm CATIA.

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