Workstation and posture improvement in cutting machine process using virtual modelling

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Abstract. The activity of squatting and bending can cause an awkward working body posture and the risk of Musculoskeletal Disorders (MSD). This is mainly happening in the cutting machine process as a workstation that needs high precision so that it requires close eye contact with the workpiece. Through an initial assessment using an NBM questionnaire, it is obtained that almost all of the Cutting Operator’s body parts are uncomfortable after finish working. A further investigation is done towards two healthy males (height 169 ± 1.4 cm and weight 73.75 ± 2.5 kg) by capturing the current working body posture and then be translated to a virtual model and virtual environment, by using JACK 8.2 software. The MSD risk parameters are using PEI by processing LBA, OWAS, and RULA data. Improvement of the posture is done by enhancing the workstation through virtual simulation so that the PEI on the two operators are decreasing from 2.81 and 2.43 to 1.52 and 1.12. Unexpected things happen in this semi-manual cutting workstation, the awkward posture is inevitable as seen in the RULA output of the improved workstation that did not show if the posture is safe from MSD risks. However, MSD risks can be reduced.

1. Introduction
The activity of ‘cutting’ requires a high level of precision and most of the time, it comes with squatting or bending posture. Muscles hold a static burden repeatedly for a long period. In many cases, it will cause potential injuries for the operators. The symptoms are stiffness in muscles, limited joint motion, and swelling [1]. If the injuries come to the long term, it potentially causes Musculoskeletal Disorders (MSD). Another research related to cutting machines noted that too much time spent by human labour can cause an increase in workload [2]. Therefore, some companies also tried to change the process of cutting to make production faster and easier by setting up the full automation process [3][4]. Similar research has designed the cutting processes that applied in leather which has a huge dimension by using die cutting and collaborated with electro-mechanical technology [5].

Based on field observation towards the Cutting Division in one of the leather tanning automotive company in Jakarta City, Indonesia, it can be acknowledged that the operator’s posture is very awkward. To be able to put a leather workpiece that is very thin and wide on the working table, the operator must squat up at the top of the working table. The symptom of MSD is found as 90% of operators that complained about sustained stiffness so that they are absent at work. Besides the awkward posture, the physical workload of an operator is very high because they have 8 hours/day working hours, for 5 working days/week. Therefore, as the initial confirmation, 18 operators are completing the Nordic Body Map (NBM) and from that, it confirmed that the most uncomfortable body part is the back, left shank, and right shank. This is related to the squatting posture the operators
do when working which applied another research that analysed the influence of work design to psychological strain labour [6]-[8].

Modelling using a virtual human and virtual environment simulation has been used many times to investigate MSD problems [9]-[13]. The existing MSD risks from postures can be identified through symptoms that can be measured afterward through simulation so improvement in posture can be applied to minimize the impact of MSD risks that could happen in the future. Simulation can facilitate to know whether the improvement has done was accurate or not, considering that the MSD risks are only can be seen in a long-time frame.

In doing the simulation, this research is using JACK 8.2 software, with some advantages as it makes easy for users to manage human model based on Biomechanics principles as possible and as accurate in term of a virtual environment, virtual human, and analyse their performance [14]. Also, the Anthropometry data can be adjusted with the real system. Parameters used in this software are Posture Evaluation Index (PEI) that is obtained from processing the data from Low Back Analysis (LBA), Ovako Working Posture Analysis (OWAS), and Rapid Upper Limb Assessment (RULA). Another information obtained is the Static Strength Prediction (SSP) that can biomechanically identify the percentage of operators who can do the posture with sufficient energy needed and associated Anthropometrics factors that allow the body to move [10].

There was some earlier study that connects work body posture improvement and virtual simulation, but there has been no research that specifically analyses the impactful relationship between process in cutting activity, squatting posture, and MSD risks. Therefore, this research can complement prior researches about virtual modelling in analysing MSD risks in cutting process activity. The purpose of the present study is to improve the work body posture in Cutting Machine Operator so that the risks of MSD can be minimized, by doing a virtual human and virtual environment modelling.

2. Methods
The condition of the existing workstation can be viewed in Figure 1. In the picture, sheets of the very large leather seat are put on the top of the working table manually by the operator. After that, the cutting machine will cut the leather seat according to the pattern. Two healthy males are chosen as the representation from 18 Operators. Overall, the operator’s tasks can be divided into two job descriptions as Operator 1 and 2 did. Operator 1 is responsible for putting the pattern on the table, then the Operator 2 is responsible to give working objects in the form of leather seat to the Operator 1 and then to move the pieces that already been cut to the next workstation. Due to the huge size and the height of the table, to reach the centre of the table, the Operator must climb to the top of the working table and squat to adjust the leather seat to be in an accurate position.

Figure 1. Operator’s working posture (existing).
Left for operator 1 and right for operator 2.

In this research, Task Analysis Toolkit (TAT) in the JACK software is chosen to evaluate the human virtual posture that is working in the virtual environment as Caputo framework [14]. The algorithm of this research can be seen in Figure 2.
2.1. Parameters
At the end of the research, the Posture Evaluation Index (PEI) score in the first posture and final posture will be compared. PEI parameters are chosen because they can comprehensively provide posture analysis information that includes LBA, OWAS, and RULA in various population percentiles [14]. Following are the data needed to count the PEI score:

1. Low Back Analysis (LBA)
   This parameter is used to evaluate the force taken by the Operator’s spine L4/L5, especially in the squatting and bending posture. The allowed LBA score according to the NIOSH standard is 3400 N at the maximum [10][14][15][16].

2. Ovako Working Posture Analysis (OWAS)
   This analysis is used to obtain the level of discomfort caused by the working posture of the Operators. Four things to be analyzed by OWAS such as the back, arm, leg, and the load of the body undertaken by the operator. OWAS output that is made by JACK is in the form of code that explains all the four matters.

3. Rapid Upper Limb Assessment (RULA)
   The use of RULA is to measure the upper body posture risks of the operator that can cause MSD. In the JACK software, the RULA calculation is divided into group A (upper arms, lower arms, wrists, and hand rotation) while group B consists of the torso and neck.

Another data that can be considered in the model analysis is the %SSP that is used to figure out the percentage of the operator that can perform certain work postures. The SSP score expected is higher than 90% which means 90% of workers can perform the job in a static strength simulation [10]. The evaluated body parts are wrist, elbow, shoulder, torso, hip, knee, and ankle.

2.2. Developing the Virtual Environment and Virtual Human Model
The virtual environment is developed by measuring the dimension of the real workstation and then translated into objects in the AutoCAD software. The objects then imported into the JACK as a virtual environment. The workstation is referred to as a combination of 6 working tables that are used by the cutting machine operator.

To make a human model (Operator), the Advanced Human Scaling function is chosen in JACK because the function generates a better detail by inputting 14 Anthropometry parameters of the cutting operator. The two healthy operators (average height 169±1.4 cm and average weight 73.75±2.5 kg) that have an average performance, are chosen to be the subjects to represent human in JACK. The Anthropometry data that has been inserted such as stature, head breadth, head height, head length, b-deltoid, hip breadth, arm length, shoulder-elbow, elbow rest height, elbow-fingertip, buttock-knee, thigh clearance, ankle height, and foot length. Human models that have been formed will be the virtual human in this research. Besides inputting the Anthropometry data, the angles of posture were adjusted in the form of a virtual human and virtual environment. The model is shown in Figure 3.

Figure 2. Research algorithm.
2.3. Model Validation
Before simulating, validation is needed to ensure that the virtual human and virtual environment model has represented the real system. Validation is conducted by comparing between LBA, OWAS, and RULA scores that are obtained from the manual calculation, and a score that is obtained by TAT output from JACK software. The model validation is shown in Figure 4.

2.4. Improvement in Operator’s posture
A better posture is expected from the improvement of the existing workstation. To design the new workstation, Anthropometry data from the operators will be processed so that the improved workstation (by AutoCAD) can be re-inserted to be the virtual environment in JACK.

2.5. Posture Evaluation Index (PEI) Calculation
Analysis using the PEI is to acknowledge which working posture that gives comfort to as many populations as possible [14]. The lower the PEI score, the more comfortable the posture is so that the MSD risks will also be decreased [10][14]. PEI calculation is conducted by using the formula below [14]:

\[
PEI = I_1 + I_2 + (I_3 \times mr)
\]

Where:

\[
I_1 = \frac{LBA}{3400 N}
\]

(2)

\[
I_2 = \frac{OWAS}{4}
\]

(3)

\[
mr = amplification\,factor = 1.42
\]

(4)

3. Results
3.1. Parameter Evaluation of the Existing Workstation
It proven that there is an MSD risk, the first analysis is done by using the Static Strength Prediction (SSP) parameter in JACK. From the SSP result, Operator 1 and 2 has an SSP score that is lower than 90%, with the highest MSD risk of Operator 1 is on the hip and knee, while in Operator 2 on the hip
and sole of the feet. The low score of SSP shows that the current posture is unsafe to be performed for a long period.

The next test is the Low Back Analysis (LBA) in JACK software, with a result that scores of Operator 1 and 2 are 2169 N and 1735 N or still below the NIOSH standard which is 3400N. Therefore, the squatting and bending posture of the Operator are not potentially causing back spine L4/L5 injury, because the pressure point of the Operator is on another body parts.

The OWAS score for Operator 1 and 2 in consecutive were 3 and 2, with code 2141 and 4121. Operator 1 with the code 2141 means that the back posture (2) is forward flexion, hand (1) is on the level below shoulder height, feet (4) bent and focused on the feet, and weight (1) that is focused is below 10 kg so that the final score is 3, which shows that the posture of Operator 1 will cause a harmful level of stress on MSD.

The OWAS score for Operator 2 with code 4121 means that the back posture (4) is bent to the side/forward and accompanied by rotation or movement to the side, hands (1) located below the shoulder height, legs (2) standing with both straight legs, and weight (1) less than 10 kg, so the final score is 2. Therefore Operator 2 has a better posture than Operator 1 but still may harm MSD. This is because Operator 2 is not only doing a static posture in which his job responsibility is to put the pattern on the working table, but also to occasionally stand up to help to move the pattern from the working table to the next workstation.

In contrast to the JACK output for SSP, LBA, and OWAS parameters, the JACK software generates RULA output that is similar to the whole operators, in which the scores are 7. Or in other words, the score reaches the maximum limit. Therefore, according to this result, the MSD risks for all the operator’s posture has to be investigated and improved as soon as possible. A recapitulation of MSD risks potential for all parameters can be viewed in Table 1.

Table 1. Evaluation of MSD risks (existing posture).

| Operator   | Parameters          |       |
|------------|---------------------|-------|
|            | SSP     | LBA         | OWAS                          | RULA                                  |
| Operator 1 | <90%    | Safe        | Will cause harmful level of stress on MSD | Investigation and changes are required immediately |
| Operator 2 | <90%    | Safe        | May harm MSD                  | Investigation and changes are required immediately |

The validation of the JACK output can be done for OWAS and RULA parameters by using a manual calculation, while for LBA it cannot be calculated manually because to make it sure it requires observation using x-rays. The manual calculation results for OWAS output towards Operator 1 and 2 in consecutive are 3 and 2 or corresponded and matched to the OWAS score from JACK. Besides, the RULA score for the manual calculation to all Operator is 7, which means it has already corresponded to the output on the software. Thus, it can be confirmed that the human model and the human environment is valid for representing the posture in the real workstation.

Table 2. Result of PEI calculation (existing posture).

| Operator | I₁     | I₂     | I₃     | Mr   | PEI |
|----------|--------|--------|--------|------|-----|
| 1        | 0.64   | 0.75   | 1      | 1.42 | 2.81|
| 2        | 0.51   | 0.5    | 1      | 1.42 | 2.43|

As seen in Table 2, the PEI score of Operator 2 has a smaller PEI score which is 2.43. Through the PEI score of Operator 1 and 2, the existing posture must be improved because the PEI score approaches 3.
3.2. Workstation Improvement

Improvement of the workstation is done by considering the Anthropometry size from the working table that is used by the operators. This anthropometric data was chosen to be more fit with current workers. Although currently the cutting process is done in a semi-manual manner, in the future this process will lead to a fully automatic process, so that the current process is a transition process.

The existing working table has a length of 350 cm and 295 cm wide so that the operators are having difficulties to reach the centre of the table and must climb up the top of the table and do a squat posture. Therefore, improvement is done to the workstation that consists of 6 cutting working tables, by re-designing the cutting worktable so that it can improve the operator’s work body posture.

Seven types of Anthropometry data are needed to re-design the new cutting worktable. Each dimension was averaged to consider the size of the 50 percentiles from all of the operators to accommodate more. The heights and wideness of the new working table are adjusted by considering that, during manual work where workers often need space for equipment, material, and containers, the height of the working platform just below the height of the standing elbow [17].

According to the anthropometry measurement result on all cutting operators, the height of the standing elbow is on average 101.86 cm so that the height of the working table must be adjusted lower than that height. The wideness of the table is reduced by 50 cm and become 345 cm so that the operator can reach an object in the centre of the table. Therefore, the squatting posture is no longer needed and the stairs to climb the top of the table can be removed as shown in Figure 5 below is the dimension comparison of the existing and improved workstation.

![Figure 5](image_url)

Figure 5. The dimension of existing cutting workstation (left) and improvement (right).

The virtual environment of the model is improved, and work posture is simulated by using the same virtual human with the existing model. The result from the virtual human and virtual environment modelling in the improved workstation can be seen below, the posture of the operator is better than the awkward posture. However, verification is conducted by recalculating the final PEI score for operators that work in the improved workstation. Figure 6 shows an improved operator’s workstation in JACK.
3.3. **PEI Scores of Improved Posture**

TAT calculation is done with the same steps as the calculation made to the existing workstation. The SSP output on JACK coloured grid. It means that the posture has been able to accommodate the posture capability of more than 90% of operators. Furthermore, the LBA score for improvement posture on Operator 1 dropped from 2169 N to 1288 N and for Operator 2 it dropped from 1735 N to 883 N. Thus, the pressure on the operators L4/L5 decreased and better. The OWAS score for Operator 1 has dropped from 3 to 2 which means that the posture of Operator 1 might cause a risk of MSD so further investigation must be carried out again. For Operator 2, the OWAS score dropped from 2 to 1 so that the posture safe. Finally, the RULA score for all operators dropped from 7 to 3. However, although the score has dropped, the implication of score 3 still requires further investigation and improvement. According to the output produced, the comparison between the PEI output of Operator 1 and 2 improved posture can be seen in Table 3 and Table 4. The PEI score for Operator 1 is 1.52 and Operator 2 is 1.12.

### Table 3. Evaluation of MSD risks (improved posture).

| Operator | Parameters | SSP | LBA     | OWAS        | RULA                                      |
|----------|------------|-----|---------|-------------|-------------------------------------------|
| Operator 1 | >90%       | Safe | May harm MSD | Further investigation needed. Changes may be required. |
| Operator 2 | >90%       | Safe | The working posture seems normal and natural | Further investigation needed. Changes may be required. |

### Table 4. Result of PEI calculation (improved posture).

| Operator | I₁  | I₂  | I₃  | Mr  | PEI  |
|----------|-----|-----|-----|-----|------|
| 1        | 0.41| 0.50| 0.43| 1.42| 1.52 |
| 2        | 0.26| 0.25| 0.43| 1.42| 1.12 |

4. **Discussion**

4.1 **Output Analysis**

According to the reference [14], the score at I₁ indicates the level of posture pressure on the L4 and L5 lumbar with a valid value that is a score below value 1. The scores of I₁ on Operator 1 and Operator 2 respectively on the existing and improved posture are 0.64; 0.41 (Figure 7) and 0.51; 0.26 (Figure 8). As such, this output meets the requirements of the PEI calculation.
An I2 score indicates the level of discomfort in posture [14]. From the following data, the discomfort score falls on the posture of improvement with the value for Operator 1 is 0.5 (Figure 7) and Operator 2 is 0.25 (Figure 8).

I3 score indicates the level of fatigue in the upper body part [14]. In Figure 7 and Figure 8 for both operators can be seen, the level of fatigue dropped from 1 to 0.4.

The minimum score for PEI is 0.47 while the maximum score is 3 [14]. The maximum PEI value is very dependent on the I1 score because when the PEI score reaches 3, it means that the pressure on L4 and L5 reaches a maximum limit of 3400 N. According to the calculation results obtained, the PEI score on the existing posture is close to the maximum value but after improvement, the score drops for Operator 1 of 2.81 to 1.52 for Operator 2 and 2.43 to 1.12.

From Table 3, we can see, even the overall scores have decreased but the OWAS scores for Operator 1 still may harm MSD and also the RULA scores for both operators still noted ‘Further investigation needed, and changes may be required. This becomes natural because the activities carried out by the operators are manual, so it’s difficult to get an ideal posture that has no MSD risk for the operators especially if the work is carried out repeatedly over a long time.

4.2 Standing Posture for Cutting Workstation

Improvements to the operator's workstation has been reduced the risk of MSD in the future according to the analysis in section 4.1. However, some similar research has observed that almost all the cutting
activity is performed with bending posture even if it can be done by sitting, squatting, or standing. To be noted that to cut or to position a workpiece it needs an approximate close distance from the eyes. The smaller the workpiece, the required distance is also smaller.

As Operator 2 tasks, it known that the Operator did squatting and standing by the period of time. Squatting is harmful for the risk of MSD and it suggested to choose the standing position because it is more alert and good for mental state. However, another reference [18] stated that the energy needed by standing position is higher by 10-15% compared to sitting position. So that, how to overcome this problem are periodical stretching and minimizing subjective complaints in reaching, bending, and making awkward head posture [19].

Nevertheless, not all activities that require a level of detail are better done with standing postures. The activity that is best done with standing posture has the following four criteria [18]: (1) There is no space available for legs and knees, (2) Must hold objects which weight more than 4.5 kg, (3) Often carried upwards, bottom, and sides, and (4) This work is carried out frequently and is kept downward.

5. Conclusion
The present study is aimed to improve the working body posture of the Cutting Machine operator process so that the risk of MSD can be minimized by doing a virtual human and virtual environment modelling.

From this study, the enhancement of working body posture is done successfully by improving the workstation. The MSD risks can be seen in the size of the PEI parameter by calculating the value of LBA, OWAS, and RULA. At the end of the study, the PEI value decreases from 2.81 and 2.43 to become 1.52 and 1.12. So, it means that the improvement of the workstation can lower the MSD risks in Cutting Operators. This result supported by SSP value that was bigger than 90%.

Future research on virtual modelling will be carried out not only by using one software but also by several integrated software to get a more realistic model. The next trend research might include aspects of human behaviour analysis, a combination of modelling with AR, workplace design, and also collaboration between humans and robots [20] but in addition, that research will need much more anthropometry data.

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