Vol. 07, No. 01, January 2023, pp. 78-94

INTERNATIONAL JOURNAL OF INNOVATION IN ENTERPRISE SYSTEM

Journal homepage: https://ijies.sie.telkomuniversity.ac.id

e-ISSN: 2580-3050, DOI: https://doi.org/10.25124/ijies.v7i01.191

Designing Ergonomic Standing Chair for Computer Numerical Control Machine Operators using TRIZ

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ARTICLE INFO

Article history:
Received 27 December 2022
Accepted 28 January 2023
Published 31 January 2023

Keywords:

Quick Exposure Check, Ergonomics, Anthropometry, Theory of Inventive Problem Solving, Standing Chair Design

ABSTRACT

In this research, the working hours and posture of CNC (Computer Numerical Control) machine operators were investigated to determine the physical workload that they experienced during their daily work. Based on our observations, the operator works 8-hour regular shifts or 12-hour long shifts for 5 – 6 days a week. During these shifts, the operators work in front of the CNC machine while standing upright without any tools to rest. Preliminary research was conducted to evaluate these conditions the results show 13 out of 20 CNC machine operators complained about physical fatigue while working the CNC machines. It can also be concluded that the operators are experiencing excessive workload based on a workload assessment using the Quick Exposure Check (QEC) method. To solve this problem, a standing chair is designed with ergonomics in mind. The dimensions of the standing chair are based on the anthropometry of the CNC machine operators, which was never used before. The design process is conducted using the Theory of Inventive Problem Solving (TRIZ) methodology. Need statements from the CNC machine operators and design requirements from the stakeholders are converted into design specifications using TRIZ methodology. Parameters are determined to increase the capability of the existing design based on the design specifications. The result of this research is a standing chair that is suitable for the operator's needs. Based on the analysis of the design result and the stress analysis simulation, it can be concluded a functional standing chair can be ergonomically designed with the TRIZ methodology.

1. INTRODUCTION

Manufacturing is an economic term that means the manufacture of products or services to meet human needs. The product or service has the value of applying physical work or mental work.

The process carried out to create a product or service is referred to as the manufacturing process. The manufacturing process converts raw materials into finished products. The process is carried out using machines or machine tools.Examples of manufacturing process media are injection molding, die casting, progressive stamping, milling, arc welding, painting, assembling, testing, pasteurizing, homogenizing, and annealing [1]. Manufacturing operations are divided into 2 (two) types, namely processing operations and assembly operations. The processing operation converts the material from the initial state before processing to a condition that is closer to the final product. Assembly operations combine 2 (two) or more components to create an assembly, sub-assembly, or weldment [2].

The process of removing materials is a group of product formation operations by removing part of the material from the workpiece. One of the formation operations in this group of operations is conventional machining. In conventional machining operations, a cutting tool is used to cut materials. The most used conventional machining operations are turning, milling, and drilling [2]. The surface of the workpiece cut by metal machining tends to cause defects in the form of rough surfaces. Chemical and electrochemical surface finishing is used to eliminate such defects [3].

HFE (Human Factors and Ergonomics) is considered when an ergonomic design is to be made. HFE is a scientific discipline that helps a scientist or researcher to understand the reciprocal relationship between humans and other elements of the system. In addition, HFE is also referred to as a workgroup that applies ergonomics and human factors to designs to improve human well-being and system performance [4]. The International Labor Organization (ILO) stated that there are more than 250 million work accidents that have occurred and 160 million workers are injured because of occupational hazards, and 1.2 million workers died because of work accidents and occupational hazards [5].

Numerical control (NC) is a method of controlling the movement of machine components using numeric instructions or codes. The movement of the machine is determined by a series of codes that define the type of operation to be performed, the location of the target of the operation, as well as the characteristics of the operation. The next iteration of NC is computer numerical control (CNC). CNC machines use the concept of feedback control, which means that the position of the process is determined using sensors [1]. The main benefits of using CNC machines are that the high size accuracy and size tolerances used can be tighter. Thus, the result of cutting with such machines is smoother than with conventional machines. However, the cutting surface of CNC machines can become rough if the feeding rate and cutting speed settings are not suitable [5].

PT Yogya Presisi Tehnikatama Industri (YPTI) is a manufacturing company located in Dhuri, Tirtomartani, Kalasan District, Sleman Regency, Yogyakarta Special Region Province. PT YPTI consists of 3 main divisions, namely the manufacturing (MFG) division, the mold-making (MM) division, and the injection molding (IM) division. Based on the data of the list of machines used in the *manufacturing* section, the types of CNC machines totaling 30 (thirty) machines are the most widely owned types of machines owned by the company. The process carried out with such CNC machines takes place automatically. Nevertheless, the operator is still assigned to perform setup, start the process, supervise the process, as well as retrieve the results of the machining process on each CNC machine.

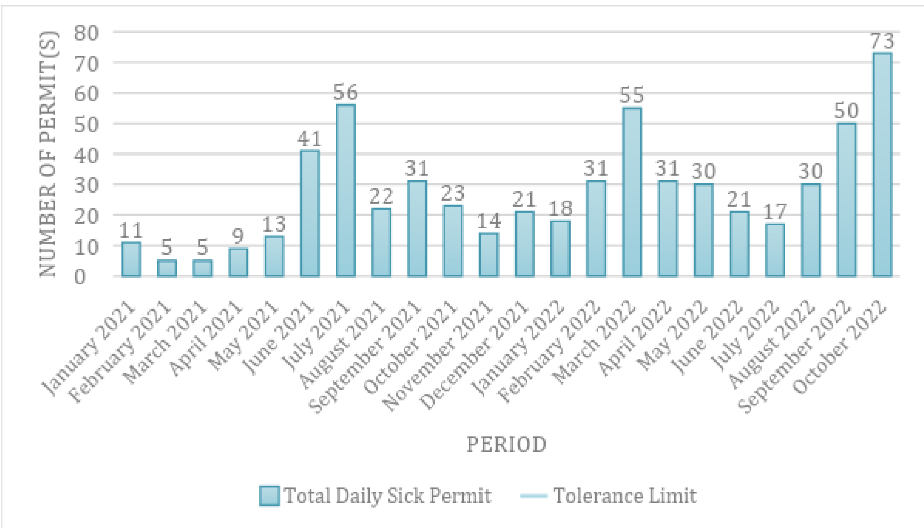


Figure 1 – Total Daily Sick Permit of CNC Machine Operators Per Month Chart
Source: [6]

The total number of manufacturing parts operators of the MFG division operating CNC machines are 66 people in 2021 and 58 people in 2022. The manufacturing unit of PT YPTI's MFG division implements a rotational work system using metal cutting machines. However, the number of daily sick permits for June 2021, July 2021, August 2021, September 2021, October 2021, December 2021, February 2022, March 2022, April 2022, May 2022, June 2022, August 2022, September 2022, and October 2022 exceeds the tolerance limit of 20 (twenty) days of sick permit per month.

The data on the number of days sick permits per month is determined by calculating how many days a machine operator counts as absent due to illness on the unit-level attendance data. Unit-level attendance data can be used to determine an individual's health [7]. Thus, the individual health of CNC machine operators affects the presenteeism of the manufacturing unit, especially machine operators.

Direct observation of the CNC machine operator is carried out to determine whether the operator's body receives excessive loads when working. Operators who oversee carrying out the machining process on CNC machines have various obstacles in carrying out their duties. Operators have limited rest time because the company uses an 8 (eight) hour shift system. In addition, the operator must still supervise the machining process that occurs in the CNC machine. The picture of the operator of PT YPTI when on duty on a CNC machine can be seen in Figure 2.

(a) (b) (c)

Figure 2 – Machine Operator of PT YPTI
(a) Operator position for entering commands to the machine controller. (b) Operator position for supervising the machining process. (c) Operator position for writing on the work order.
Source: [8]

Based on the observations of researchers, CNC machine operators of PT YPTI often stand up straight to supervise the machining process and enter commands into the machine controller. This posture causes a static physical load on the soles of the feet that can cause pain. In addition, operators also often bend over to perform writing activities on work orders. This posture can cause pain in the back and neck.

Analysis of the current condition of the CNC PT YPTI machine operator was carried out based on the calculation of the Quick Exposure Check (QEC) score. QEC is a method used for determining the body parts that are receiving excessive workloads [9]. The calculation is carried out by using the quota sampling technique, the number of samples of 3 (three) people, and the activities carried out are entering commands to the machine controller, writing on the work order, and supervising the machining process. Each activity is carried out by 1 (one) person. Measurements are made after the CNC machine operator has been working for 5 (five) hours.

Table 1 – QEC Assessment Data

No.	Factors	Activity		
		Entering Commands into the Machine Controller	**Supervising the Machining Process**	**Writing on the Work Order**
1	Back	14 (Low)	26 (High)	18 (Moderate)
2	Arm	14 (Low)	26 (Moderate)	18 (Low)
3	Wrist	22 (Moderate)	30 (High)	22 (Moderate)
4	Neck	10 (Moderate)	18 (Very High)	10 (Moderate)
5	Driving	1 (Low)	1 (Low)	1 (Low)
6	Vibration	1 (Low)	9 (High)	1 (Low)
7	Work pace	4 (Moderate)	4 (Moderate)	1 (Low)
8	Stress	4 (Moderate)	4 (Moderate)	1 (Low)

Based on the QEC score data, several parts of the CNC machine operator's body are experiencing workloads with high and very high categories. The workload for factors number 1 (one) through number 4 (four) should be categorized as low, with each interaction score below 8 (eight). Thus, the chances of the appearance of muscle and bone diseases are low.

A preliminary survey is conducted to determine the obstacles experienced by machine operators. The survey was conducted on 20 machine operators who had operated CNC machines for more than 3 hours in 1 day with questionnaires that had been tested for validity and reliability. The number of respondents is at least six people, which is determined based on the population size of 58 people using the Gay theory. The number of samples in descriptive studies is at least 10 percent of the total population [10]. Respondents have also worked at PT YPTI as machine operators for more than one month. The survey produced 2 (two) data sets related to this research.

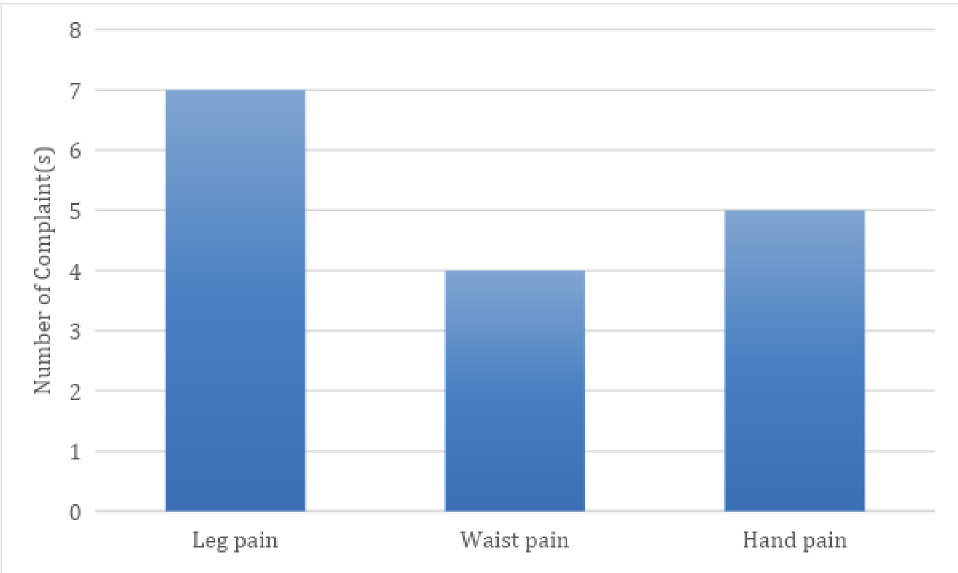


Figure 3 – Total Pain Complaint Based on the Body Part

The first data obtained from the preliminary survey is data on the number of pain complaints based on the body parts of the PT YPTI machine operator. Based on the data set, the machine operator feels pain in the leg, waist, and hands during work. The part of the machine operator's body that is most at risk of pain based on the number of pain complaints is the leg with the number of complaints, which is seven complaints. Based on prior observations, the leg pain is caused by the posture (as shown in Figure 2) and working hours of the machine operator. The machine operator works in front of the machine in a standing position for at least 8 hours in 1 shift.

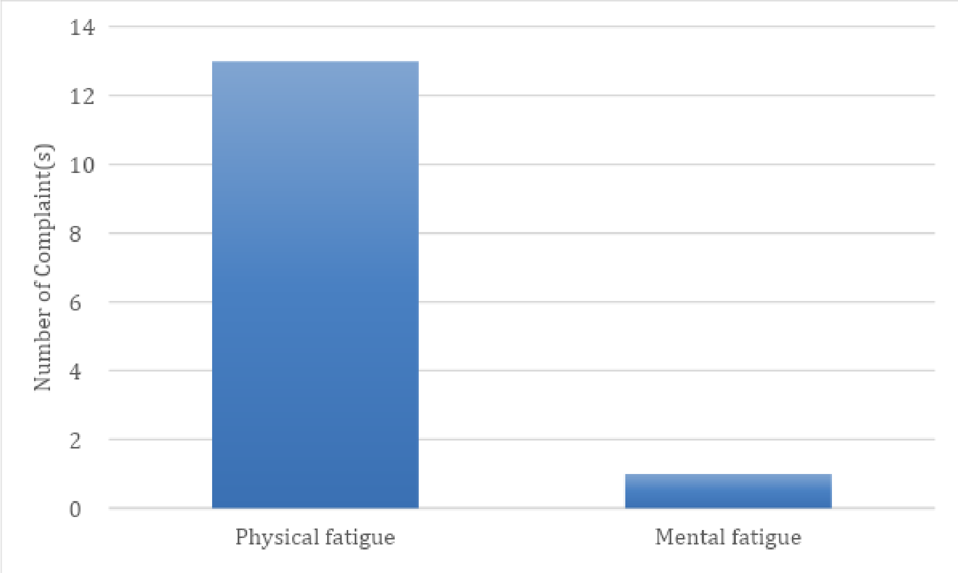


Figure 4 – Total Fatigue Complaint Based on the Body Part Chart

Data on the number of complaints regarding machine operator fatigue was recorded in a preliminary survey. Of the respondents, there were 13 complaints about physical fatigue and mental fatigue. The type of fatigue most experienced by PT YPTI machine operators is physical fatigue. Based on respondents' explanations in the survey results, this is due to long working hours per day and the unavailability of tools to rest during work.

Table 2 – Gaps Between the Ideal Condition and the Existing Condition

No.	Factor	Activity			Ideal Category
		Entering Commands into the Machine Controller	Supervising the Machining Process	Writing on the Work Order	
1	Back	14 (Low)	26 (High)	18 (Moderate)	Low – Moderate
2	Arm	14 (Low)	26 (Moderate)	18 (Low)	Low – Moderate
3	Wrist	22 (Moderate)	30 (High)	22 (Moderate)	Low – Moderate
4	Neck	10 (Moderate)	18 (Very High)	10 (Moderate)	Low – Moderate
5	Driving	1 (Low)	1 (Low)	1 (Low)	Low
6	Vibration	1 (Low)	9 (High)	1 (Low)	Low
7	Work pace	4 (Moderate)	4 (Moderate)	1 (Low)	Low
8	Stress	4 (Moderate)	4 (Moderate)	1 (Low)	Low

The ideal condition of the presence of manufacturing machine operators, namely the score per activity category, is in the ideal score category range. This is done so that the number of days of sick permits per month of manufacturing employees is smaller than the tolerance limit that has been set. Such conditions can be obtained by providing auxiliary tools for fixing the position and resting the body of the CNC machine operator during work. Therefore, this research was carried out so that a standing chair for CNC PT YPTI machine operators could be designed.

The activity of machine operators with the excessive physical workload, if not repaired, results in the presence of machine operators decreasing. This is due to the association of physical workload with the individual health of the machine operator. The individual health of the operator affects the attendance rate of employees [7]. The consequences of such neglect are cumulative and continuous, so the longer it is left unchecked, the more intense the effect of physical workload on the individual health of the machine operator.

Company performance can be measured by the productivity of work units tasked with producing products or services that are marketed. Productivity is a comparison between the output of a work unit and the input used to produce that output [11]. A manufacturing division is a work unit tasked with producing products in the form of precision parts based on client requests at PT YPTI. The manufacturing employees who work on the client's request are machine operators. In the absence of the machine operator, the input (material) cannot be processed to produce output (product client request). Therefore, the number of daily sick permits per month needs to be reduced to maintain and even improve the company's performance.

The TRIZ (Theory of Inventive Problem Solving) methodology was chosen in designing the standing chair with the consideration that the design needs to be produced as soon as possible so that the negative effects of the problem are not prolonged. TRIZ is a product development method that is focused on solving problems with standard solutions based on previous research. The TRIZ method consists of tools that can be used to solve problems encountered in the process of designing and developing the standing chair. The Effects Database can be used to determine how to improve the design parameters of the standing chair. The Contradiction Matrix is used to solve the problem of contradictions of 2 (two) technical parameters that need to be improved on the concept of the standing chair design so that both technical parameters can be improved.

This research concerning the design process of a standing chair will benefit fellow researchers, PT YPTI, and the workers. Fellow researchers will benefit from the references and the findings about product development and HFE. Increased work efficiency and decreased idle time of the CNC machine operators will also be beneficial for PT YPTI. The workers will also benefit from the design implementation by lowering the chance of fatigue and work accidents occurring.

In the present study, the design of a standing chair for the operator of the CNC machine was proposed, as it was never used before on the PT. YPTI plant. We identified the need statement, design requirement, and anthropometric data to design the chair. We reviewed some published papers on product design development related to human factors and ergonomics, and the overview is summarized in the following section (see Table 3 for an overview of studies on product development related to human factors and ergonomics).

Table 3 – Overview and Comparison of Studies on Product Development Related to HFE

No.	Author(s)/Year [# in reference list]	Object	Methodology and Analysis	Processed Data	Results (findings)
1	(Ningsih, 2022) [12]	The production floor of a manufacturing company	Ergonomic Function Deployment (EFD) and General qualitative analysis	Customer statement, factory layout, anthropometric data.	Design of safety sign
2	(Sugiono, 2022) [13]	The railway carriage of the Indonesian railway	Quality Function Deployment (QFD) and Qualitative analysis based on illustrations	Technical drawings of the train seat, anthropometric data, standard sizes of wheelchairs and walking sticks	Design of new railway carriage
3	(Sen, 2019) [14]	Car wishbone	TRIZ, Contradiction Matrix, and Qualitative analysis based on the dynamic simulation result	Previous experiment data, design improvement data	Design of new car wishbone
4	This journal article	The CNC machine operator of PT YPTI	TRIZ, Effects Database, Contradiction Matrix, and Qualitative analysis based on stress analysis simulation result	Need statement, design requirement, initial concept, anthropometric data.	Proposed design of a standing chair

Some studies mostly used one methodology (product development concept) to design a product. However, in our study, we tried to explore more on TRIZ method more as it may be less used in product development research to propose a design of an object. Although anthropometric data are commonly used in research about ergonomic product design, this research also uses other data that are less commonly used, such as the initial concept, need statement, and design requirement data. The result of this research is a design of a standing chair that is different from the other research based on the product category.

2.METHOD

2.1. Research Design

The purpose of the research is to design a standing chair based on the anthropometric data, need statement data of the CNC machine operators of PT YPTI, and design requirement data. The second purpose is to simulate the design using the stress analysis simulation of Autodesk Inventor Professional 2022. To achieve these purposes, the research is designed to be executed in 4 (four) main steps, as shown in Figure 5.

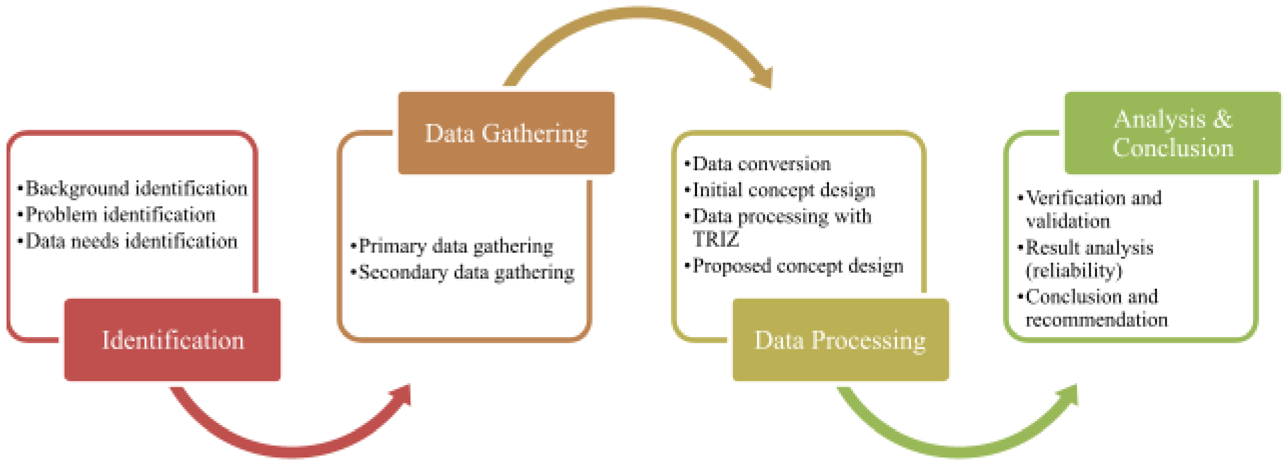


Figure 5 – Research Steps

The primary data used in this research are the need statement data and the design requirement data. A questionnaire is used to gather the need statement data. It is targeted toward CNC machine operators. The sampling technique utilized for the need statement data-gathering process is purposive sampling. Purposive or judgmental sampling is a non-probability sampling technique in which the respondents are determined by selected criteria. The criteria are chosen to increase the probability that the sample gathered will be representative of the whole population [15]. CNC machine operators that have been working for PT YPTI for at least one month and have experienced at least a 3-hour shift workday are qualified to fill out the questionnaire. The sample size is determined using the sample size theory of L. R. Gay. Because of the nature of this research, the minimum sample size ($_{minimal}$) is 10 percent of the total population of the target respondents (N) [10].

$$n_{minimal} = 10\% \,.\, N \quad (1)$$

$$n_{minimal} = 10\% \,.\, 58 \quad (2)$$

$$n_{minimal} = 5.8 \quad (3)$$

$$n_{minimal} \approx 6 \quad (4)$$

The design requirement data is acquired from the managing director of PT YPTI. The data is obtained using a formal semi-structured interview. Qualitative research commonly integrates the use of semi-structured interviews [16]. Semi-structured interviews consist of a set of questions based on a topic that is prepared before the interviews begin. The delivery of the questions depends on the response of the interviewee, and the interviewer can add more questions that are more fitting for the situation and the interviewee's character [17].

Anthropometric data is the secondary data used in this research. The data is obtained from a published journal article. The theme of the journal article is the anthropometric measurement of human subjects. The subject criteria are matched with the characteristics of the CNC machine operators of PT YPTI.

The need statement data and the design requirement data are converted into design specifications based on anthropometric data. These design specifications are used to develop the initial design concept to match the characteristics of the proposed standing chair design with the need statements and design requirements. The design requirement data is also used to validate the design result by comparing the final specifications and the design specifications that are generated from the design requirements and asking for feedback from the managing director of PT YPTI.

The proposed design reliability is tested by determining whether the standing chair can withstand the physical load of its purpose. The weight of the operator and the proposed standing chair were the primary factors that contributed to the physical load. The weight of the operator that is used in the reliability testing is obtained from anthropometric data. The reliability testing is conducted using the stress analysis simulation of Autodesk Inventor Professional 2022.

2.2. TRIZ Methodology

TRIZ methodology (also known as TRIZ PRISM) is the method used to solve the problem regarding the CNC machine operator's workload. TRIZ PRISM produces solutions by converting factual problems into conceptual problems. By converting the factual problem into a conceptual problem, TRIZ tools can provide conceptual solutions that are linked to the factual problem. To produce a factual solution, the conceptual solution is adjusted based on the characteristics of the factual problem [18].

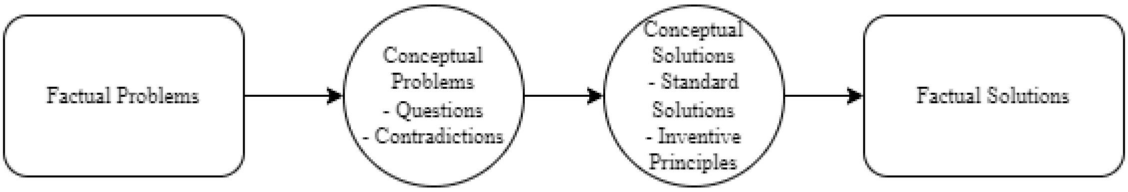


Figure 6 – TRIZ PRISM

The TRIZ tools that are used to find the solution to this research-specific problem based on its generalization are the Effects Database and the Contradiction Matrix. The Effects Database provides Effects and Applications that can be implemented to improve certain Parameters of a design. Parameters are characteristics of a product or a component that can be improved by stabilizing, decreasing, or increasing its value. Effects are theories and laws that are related to the changes of a Parameter, while Applications are the methods and tools that can also change a Parameter [19].

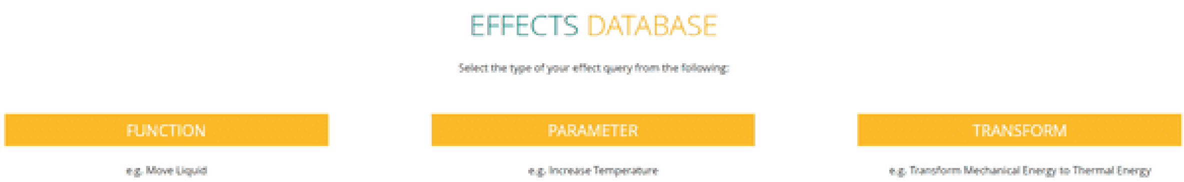
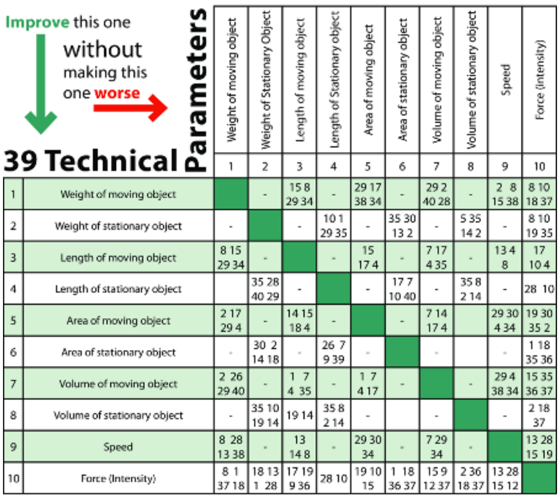


Figure 7 – TRIZ Effects Database

Improving certain Parameters can worsen other Parameters that are also being improved. The Contradiction Matrix is used to prevent such events from happening [19]. The matrix contains a set of numbers that correlates with the 40 Inventive Principles of TRIZ. Each matrix is formed by a Technical Parameter that is going to be improved and another Technical Parameter that is going to be kept stagnant.

The Parameters of the standing chair design are obtained from the design specifications. Need statement data, anthropometric data, and design requirement data are used to determine the design specifications. Need statement data is used to incorporate the CNC machine operator's needs regarding ergonomics in the standing chair design. Anthropometric data is used to determine the dimensions of the standing chair and its components. Design requirement data is acquired to record the required characteristics that need to be present in the final design of the standing chair.



Improve this one without making this one worse – 39 Technical Parameters		1 Weight of moving object	2 Weight of Stationary Object	3 Length of moving object	4 Length of Stationary object	5 Area of moving object	6 Area of stationary object	7 Volume of moving object	8 Volume of stationary object	9 Speed	10 Force (intensity)
1	Weight of moving object		-	15 8 29 34	-	29 17 38 34	-	29 2 40 28	-	2 8 15 38	8 10 18 37
2	Weight of stationary object	-		-	10 1 29 35	-	35 30 13 2	-	5 35 14 2	-	8 10 19 35
3	Length of moving object	8 15 29 34	-		-	15 17 4	-	7 17 4 35	-	13 4 8	17 10 4
4	Length of stationary object		35 28 40 29	-		-	17 7 10 40	-	35 8 2 14	-	28 10
5	Area of moving object	2 17 29 4	-	14 15 18 4	-		-	7 14 17 4		29 30 4 34	19 30 35 2
6	Area of stationary object	-	30 2 14 18	-	26 7 9 39	-		-		-	1 18 35 36
7	Volume of moving object	2 26 29 40	-	1 7 4 35	-	1 7 4 17	-		-	29 4 38 34	15 35 36 37
8	Volume of stationary object	-	35 10 19 14	19 14	35 8 2 14	-		-		-	2 18 37
9	Speed	8 28 13 38	-	13 14 8	-	29 30 34	-	7 29 34	-		13 28 15 19
10	Force (Intensity)	8 1 37 18	18 13 1 28	17 19 9 36	28 10	19 10 15	1 18 36 37	15 9 12 37	2 36 18 37	13 28 15 12	

Figure 8 – TRIZ Contradiction Matrix (Zoomed In)

3. RESULT AND DISCUSSION

3.1. Data Gathering and Initial Processing

3.1.1. Anthropometric Data

The data is obtained from a journal article about anthropometry measurement. The measurements of the data from the research were categorized by citizenship which is Indonesian and Singaporean gender, which is male and female, and ethnicity, which is Chinese and mixed ethnicity [20]. The data that is used from the journal article is categorized as Indonesian males with mixed ethnicity.

Table 4 - Anthropometric Data

No.	Designation	Dimension	Chosen Percentile	Size
1	D6	Knuckle height	50	75 cm
2	D19	Hip breadth	95	43 cm
3	D37	Body weight	95	89.25 kg

The knuckle height dimension is used to determine the height of the tool when hydraulics is in the middle position. The dimension uses the 50th percentile so that operators with low or high elbow positions can use the tool comfortably. The hip breadth dimension is used to determine the width of the saddle. The hip breadth measure uses the 95th percentile so that operators with wide hips can use the tool comfortably without disturbing the operator's comfort with narrow hips. The body weight dimension is used to determine the force that the tool needs to withstand. Operators with high body weight can use the tool without damaging the tools, and operators with low body weight can still use the tool properly is a consideration of the selection of the 95th percentile for body weight measures.

3.1.2. Design Specification Data

Data regarding design specification is obtained by converting need statement data and design requirement data. Four design specifications are obtained from the need statement data. These need statements and design specifications are shown in Table 5.

Table 5 - Design Specification Based on Need Statement Data

No.	Need Statement	Design Specification
1	The standing chair can prevent leg injuries.	The saddle height is adjustable.
2	The standing chair can prevent back injuries.	
3	The standing chair can prevent physical fatigue.	The saddle angle is adjustable.

Table 5 - Design Specification Based on Need Statement Data

No.	Need Statement	Design Specification
4	The standing chair can be used to store measurement devices	The minimum saddle length is 30cm
		The minimum saddle width is 43 cm

The design requirement data is also converted into design specifications. There are four design requirements that are converted into four design specifications. The conversion results are shown in Table 6.

Table 6 - Design Specification Based on Design Requirement Data

No.	Design Requirement	Design Specification
1	The standing chair length is shorter than or the same as the available space.	The maximum standing chair length is 45 cm.
2	The standing chair width is shorter than or the same as the available space.	The maximum standing chair width is 45 cm.
3	The standing chair can be used while the machine operators are supervising the machining process.	The saddle distance from the base is approximately 75 cm.
4	The standing chair can withstand the body weight of the machine operators.	The standing chair can withstand body weight with a magnitude of at least 876 N.

3.1.3. Initial Design Concept

An initial design concept is selected based on existing common chair designs. Based on the shapes and characteristics of these chairs, the bar stool is the most fitting chair for CNC machine operators. A bar stool is a type of chair that has a small saddle at the top of the chair for the user to sit and legs to support the weight of the chair and the user [21].

Figure 9 – Initial Design Concept

The initial design concept is based on a bar stool. The design consists of four legs that hold the saddle on top of the chair. The legs are interconnected by three legs located at three different spots. The top ring connects the upper ends of the legs and the saddle. The middle ring holds the legs' midpart. The bottom ring prevents the legs from spaying out.

Table 7 - Initial Design Concept Specifications

No.	Characteristic	Description
1	Weight	7,350 kg
2	Saddle material	Walnut
3	Frame material	Round cast iron tube 21,3 mm x 2 mm
4	Equipment height	78 cm
5	Saddle diameter	30 cm
6	Equipment diameter	45 cm

3.2. TRIZ Design Process

3.2.1. Effects Database

Functions, Parameters, and Transformations are determined based on design specifications obtained from need statement data and design requirements. Functions are not used because the types of actions and objects available in the tools do not match the design needs. Transformations are also not used because there is no relevant change in the form of energy. Thus, only the Parameters used in the design process of the standing chair. Some design specifications are not developed through the Effect Database and Contradiction Matrix because the conformity of the final specifications to the specifications of the draft is not complex to achieve.

Table 8 - Effects and Applications

No.	Operation	Parameter	Effect and Application	Description
1	Stabilize	Pressure	Pascal's Law	The pressure exerted on a fluid that cannot be pressed in a closed place will be spread evenly in all directions along the length of the fluid so that the pressure ratio remains the same
2	Decrease	Pressure		
3	Decrease	Weight	Holes	Absence of structure on a certain part of an object
4	Decrease	Surface Area	Spheroid	A type of surface shaped like an ellipsoid with 2 (two) semi-diameters of the same.
5	Decrease	Length	Sponge	A tool made of porous material.

Effects and Applications can be determined based on the Parameters obtained in the previous design step. An Effect and Application can be used to perform several Operations on Parameters at once. Therefore, there are several Operations against Parameters performed with a type of Effect or Application. The Effects and Applications are still generalized, so they need to be transformed into solutions that are specific to the standing chair design.

3.2.2. Contradiction Matrix

Performing operations on Parameters can induce Contradictions. The Contradiction Matrix is used to identify these Contradictions. The matrix also provides standardized solutions in the form of Inventive Principles to improve the Parameters without making the other Parameters worse.

Table 9 - Inventive Principle

No.	Technical Parameter That Will Be Improved	Technical Parameter That Will Be Kept	Inventive Principle Number	Inventive Principle
1	Weight of a stationary object	Area of the stationary object	30	Flexible Membranes/Thin Films
2		Stress or pressure	29	Pneumatics and Hydraulics
3		Length of the stationary object	29	Pneumatics and Hydraulics
4	Area of the stationary object	Weight of a stationary object	30	Flexible Membranes/Thin Films
5		Stress or pressure	15	Dynamic
6		Length of the stationary object	7	Nested Doll
7	Stress or pressure	Weight of a stationary object	29	Pneumatics and Hydraulics
8		Area of the stationary object	15	Dynamic
9		Length of the stationary object	1	Segmentation
10	Length of the stationary object	Weight of the stationary object	29	Pneumatics and Hydraulics
11		Area of the stationary object	7	Nested Doll
12		Stress or pressure	1	Segmentation

Some Contradictions are solved by the same Inventive Principle. These are done to simplify the usage and maximize the impact of the Inventive Principles. The Inventive Principles are the TRIZ-provided solutions for the Contradictions. They need to be converted into problem-specific solutions to be applied to the standing chair design.

3.2.3. Design Results

Based on the Effects and Applications determined using the Effects Database, the standing chair design will use certain design aspects to satisfy the user's needs and the stakeholder's requirements.

Table 10 - Effects and Applications Usage

No.	Parameter	Effect and Application	Usage
1	Stabilize Pressure	Pascal's Law	The use of hydraulics instead of a frame.
2	Decrease Pressure		
3	Decrease Weight	Holes	The use of ribbing on components.
4	Decrease Surface Area	Spheroid	The use of a spheroid-shaped base and saddle
5	Decrease Length	Sponge	The use of porous material on the top of the saddle.

The standing chair design will use hydraulics to replace the chair frame. The reason behind the usage of hydraulics is to reduce and stabilize the pressure received by the standing chair. The base will be ribbed to reduce its weight. Ribbings are additional structures that reinforce the overall rigidity of an object with minimal added weight [22]. Furthermore, the base and the saddle will be shaped similarly to a spheroid to decrease their size. The top part of the saddle will consist of porous material. The usage of Inventive Principles that have been selected for each Contradiction needs to be defined. These are done to adapt the solutions provided by the TRIZ methodology to the problem identified in this research

Table 11 - Inventive Principal Usage

No.	Inventive Principle	Usage
1	Segmentation	Separation of frame parts into hydraulics and a base.
2	Nested Doll	Placement of the hydraulic upper end on the inside of the saddle and the hydraulic lower end on the inside of the base.
3	Flexible Membranes/Thin Films	The use of a 3-dimensional shell-shaped base.
4	Pneumatics and Hydraulics	The use of hydraulics instead of a frame.
5	Dynamic	The use of rubber as a hydraulic damper.

The standing chair is designed based on the planned usage of Inventive Principles, Effects, and Applications. However, the design is simple enough to be manufactured and robust enough to be used on the production floor. The design is separated into 3 (three) main sub-assemblies. The hydraulic subassembly is in the middle of the standing chair. It functions as the main support structure of the standing chair. The height of the subassembly can be adjusted via the button that is located below the saddle. The saddle and the storage compartment belong to the upper subassembly. The hydraulic subassembly is planted to the ground via the lower subassembly.

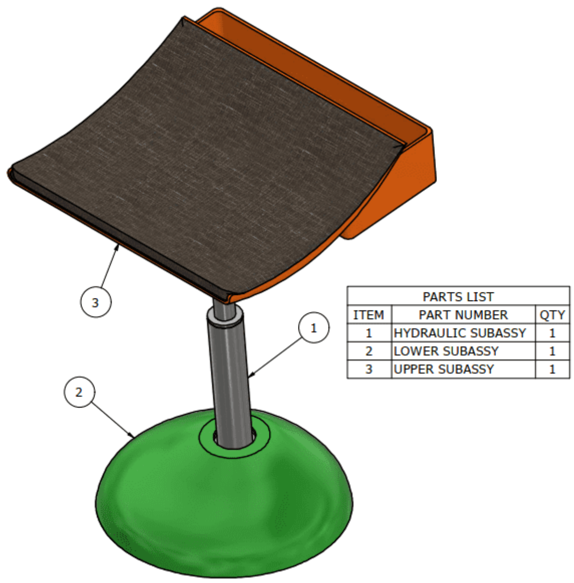


Figure 10 – Proposed Design

Table 12 – Proposed Design Final Specification

No.	Characteristics	Description
1	Weight	12.312 kg
2	Length	42 cm
3	Width	45 cm
4	Height	65.5 cm

The perspective view is inadequate for depicting the whole shape of the design. A 6-view projection is also created to portray the standing chair more clearly. The projection consists of 6 distinct views of the standing chair. It is taken from the front, the right, the back, the left, the top, and the bottom side of the standing chair. The projection is drawn in the third angle, also known as the American projection.

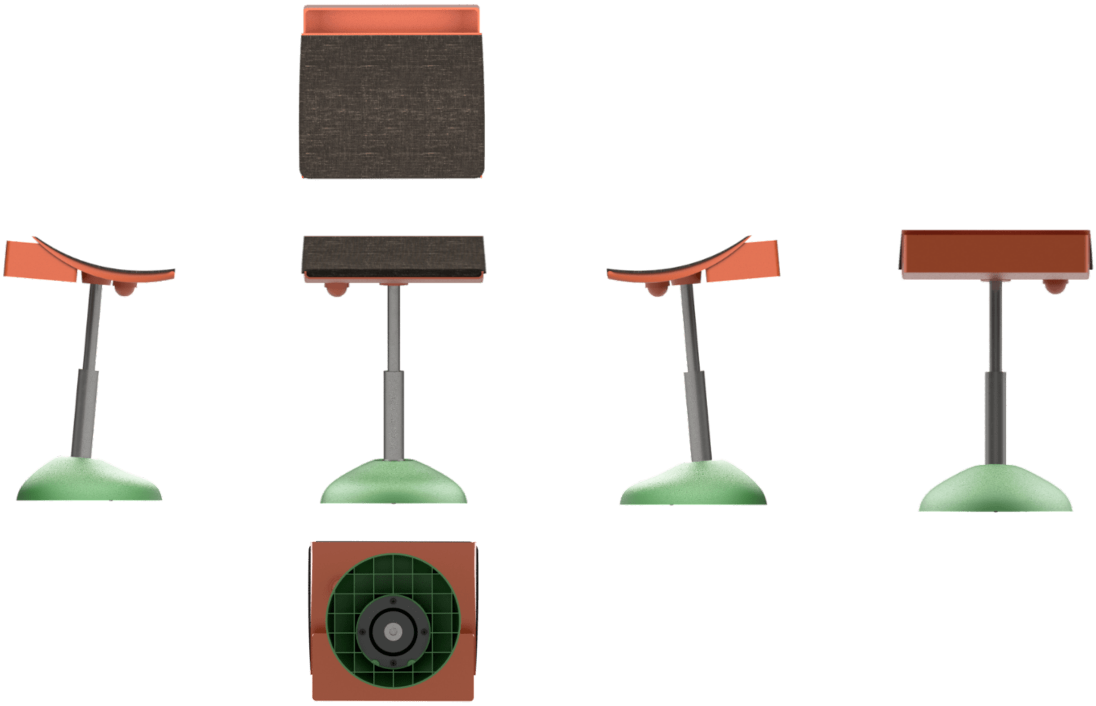


Figure 11 – Proposed Design Third Angle Six-View Projection

The standing chair design consists of 7 different parts. The hydraulic cylinder, the locking ring, and the lower hydraulic arm are made from alloy steel. The hydraulic pressure is rated at 0.6 MPa. The rubber housing and the base are made from thermoplastic resin that is impact resistant and has high dimensional stability. The rubber dampers are made from silicone rubber which has a higher life cycle than natural rubber. The saddle is made from thermoplastic resin for its structural rigidity. Silicone is added on top of the thermoplastic resin to increase the comfortability of the CNC machine operators. The complete component final specifications are shown in Table 13.

Table 13 – Final Component Specifications

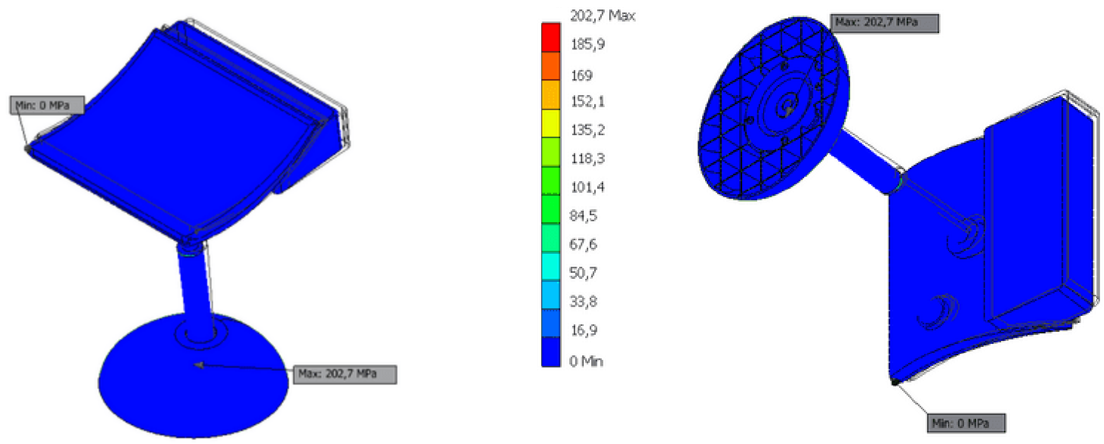
No.	Component	Specification	
1	Hydraulic Cylinder	Serial Number	GLS-200
		Material	Alloy Steel
		Length	55 cm
		Large cylinder length	30 cm
		Large cylinder diameter	5 cm
		Small cylinder diameter	3 cm
		Travel	20 cm
		Hydraulic pressure	0.6 MPa
2	Rubber housing	Material	Thermoplastic Resin
		Outer diameter	19 cm
		Hole diameter	10 cm
		Hole depth	4 cm
		Height	5.5 cm
3	Rubber locking ring	Material	Alloy Steel
		Outer diameter	12.5 cm
		Inner diameter	7.5 cm

Table 13 – Final Component Specifications

No.	Component	Specification	
		Thickness	0.3 cm
4	Rubber damper	Material	Silicone
		Outer diameter	9,5 cm
		Inner diameter	6 cm
		Thickness	2 cm
5	Lower hydraulic arm	Material	Alloy Steel
		Outer diameter	8 cm
		Hole diameter	5 cm
		Hole depth	7.5 cm
6	Saddle	Material	Thermoplastic Resin and Silicone
		Length	42 cm
		Width	45 cm
		Height	10.5 cm
7	Base	Material	Thermoplastic Resin
		Length	36 cm
		Width	36 cm
		Height	11.2 cm

3.3. Reliability Testing

The reliability testing is conducted using the stress analysis simulation of Autodesk Inventor Professional 2022. The type of stress analysis that is used to test the reliability is the Von Mises Stress. The results of the simulation are shown in Figure 12.



(a) (b)

Figure 12 – Standing Chair von Mises Stress Analysis
(a) Top Perspective View (b) Bottom Perspective View

Stress analysis is conducted towards the standing chair using Autodesk Inventor Professional 2022. The force from the operator weight is applied towards the saddle facing downwards with a magnitude of 876 N. Other than that, the force from the weight of the standing chair is also simulated with an acceleration value of 9.81 m/s^2. The weight of the operator and the standing chair are centralized at the lower hydraulic arm that is located inside the rubber housing. This is indicated by the Von Mises Stress that is received by the component, which is 202.7 MPa. The tensile stress of alloy steel ranges between 758 – 1,882 MPa. Based on the comparison of the maximum stress acquired from the simulation and the tensile stress of the material, the standing chair can withstand the weight of the CNC machine operator and its own weight.

3.4. Validity Testing

The proposed standing chair design is validated by comparing the dimensional measurements of the standing chair with the design specifications obtained from the design requirements. Stress analysis simulation from the reliability testing is also used to validate the last design requirement regarding the load capability of the standing chair. The results of the design validation are shown in Table 14.

Table 14 – Design Validation

No.	Category	Validation Target	Validation Method	Fulfillment and Feedback
1	Design Requirement	The standing chair length is shorter than or the same as the available space.	Dimensional measurements	Fulfilled
2		The standing chair width is shorter than or the same as the available space.	Dimensional measurements	Fulfilled
3		The standing chair can be used while the machine operators are supervising the machining process.	Dimensional measurements	Fulfilled
4		The standing chair can withstand the body weight of the machine operators.	Stress analysis simulation	Fulfilled

The available space for the length and width of the standing chair is 45 cm. By measuring the standing chair using the Measure Tool of Autodesk Inventor Professional 2022, the length and width of the proposed standing chair are 42 cm and 45 cm, respectively. The saddle distance from the base is determined by the height of the standing chair, which is 65.5 cm. This is compliant with the design specification regarding the approximate saddle distance, which is 75 cm. The stress analysis simulation from the reliability testing indicates that the standing chair design can hold the weight of the operator and its weight.

4. CONCLUSION

Design improvement of an existing chair design concept is possible using the TRIZ methodology. The result of the process is a standing chair with adjustable saddle height and angle. The standing chair design is designed to be ergonomic because the dimensions of the chair are determined based on the need statement data and anthropometric data of the CNC machine operators. The standing chair design can withstand the weight of the CNC machine operator and the chair itself based on the stress analysis simulation using Autodesk Inventor Professional 2022. Further research regarding the live prototyping and/or work posture simulation is still needed to evaluate the QEC score after the design implementation. The anthropometric data obtained from secondary data with general criteria is the main disadvantage or shortcomings of this research. The implementation of the standing chair design will lower the fatigue and work accident occurrence for the CNC machine operators of PT YPTI. It will also reduce idle time and increase the work efficiency of the operators. Based on the shortcomings and what remains to be learned from this research, it is recommended that further research analyze the work posture after the design implementation by live prototyping and/or work posture simulation using Jack. The anthropometric data should also be gathered by performing measurements directly on the research subjects.

Disclaimer

The authors whose names are written certify that they have no conflict of interest.

Acknowledgment

The author is pleased to inform you that this research is possible due to the assistance and support of the managing director (Mr. Petrus Tedja Hapsoro), the Human Resource Department, and the CNC machine operators of PT YPTI. The author is also pleased to give acknowledgment to Mr. Dino Caesaron and Mr. Yusuf Nugroho Doyo Yekti for their guidance.

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