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Posture and Motion Analysis on Operation of Two-Wheel Tractor with Trailer used as a Transportation

Muhammad Dhafir, Tineke Mandang, Wawan Hermawan, Muhammad Faiz Syuaib

Abstract— Two-wheel tractor that is used to pull trailer as a means of transportation have weaknesses when the tractor turns. The tractor handlebars move away from the operator, resulting in the position of the handlebars being out of control of the operator so that the operator must bend to turn the tractor. done to fix it. There are three types of work elements which are analyzed when driving a two-wheel tractor as a means of transportation, namely the movement of a straight tractor, the tractor's movement turns <45 °, and the tractor's movement turns> 45 °. The motion analysis results show that based on the analysis of Range Of Motion (ROM) on the third operator percentil (5%, 50 and 95%), the part that enters the danger zone (zone 3) is the knee flexion (Kf) while the entry into in the alert zone (zone 2) are the neck rotation (Nr), back flexion (Hf), and shoulder flexion (SF). Design modifications have been able to reduce the RULA score so that the results of the designs obtained are better which can minimize awkward postures and MSD risks.

Keywords— trailer, two wheel tractor, handlebar, ROM, RULA

1 Introduction

The trailer coupled with a two-wheel tractor is one of the conveyances used by farmers in Indonesia. But in terms of ergonomics, the use of trailer and two-wheel tractor is not ergonomic. The operation of two-wheel tractor handlebar with trailer has disadvantages that occur when the tractor turns. The tractor handlebar will move away from the operator when turning, while the trailer has not turned. This results in reduced steering control by the operator.

According to Nafchi [3] that the design of steering handlebar for the operation of two-wheel tractor with trailer that have been installed so far on the tractor's body has a weakness. The disadvantage is that when the tractor turns, the tractor handlebar moves away from the operator resulting in the position of the handlebars being out of control of the operator's reach so that the operator must bend to turn the tractor. These conditions can cause fatigue, discomfort, difficulty, even workplace accidents for the operator.

Several studies related to ergonomics have been carried out before, including the design of agricultural equipment that takes into account the strength parameters of the operators (Yadaf et al. 2010), determination of design parameters for hand tractor handles which can result in minimal loads on operators especially the muscular electric spark characteristics of operators were observed using electromyography (EMG) surfaces and analyzed in relation to differences in body posture and specifications of tractor handrails [9], anthropometry in the design of simple agricultural tools [7] simulation of work motion to produce work procedures that can minimize bad posture and disorders of musculoskeletal disorders (MSD) [8], identification of dimensions of several two-wheel tractor in Indonesia [4], identification of dimensions of several two-wheel tractor with couplings trailer in Indonesia [10], and the design of hand tools and equipment using anthropometric data of local workers in northeast India [1].

The purpose of this study is posture analysis and work motion to determine the ergonomic risks associated with operating a two-wheel tractor to pull the trailer. Furthermore, modifying the optimum two-wheel tractor steering handlebar to minimize awkward posture and MSD risk.

2. The working motion of operating a two-wheel tractor with a trailer

The elements of work related to the operation of two-wheel tractor with trailer for transportation (Figure 1) are of three types, namely:

a. Straight motion: this movement shows that the trailer with a two-wheel tractor runs straight with the operator's position sitting on the front of the trailer and both hands are on the handlebars of a two-wheel tractor. In this position the operator does not experience flexion in the neck. While the back, knees, shoulders and elbows are flexed in a safe zone based on the Range of Motion table.

b. Turning movement ≤ 45 °: this motion shows that the two-wheel tractor turns at an angle of <45 ° and the trailer follows the movement of the tractor. At this position the operator is still sitting on the front of the trailer, however, only one hand

- *Muammad Dhafir is Postgraduate Student of Bogor Agricultural University (IPB) and lecturer of Syiah Kuala University, Indonesia, PH+628126951501. E-mail: m.dhafir2001@gmail.com,m_dhafir2001@yahoo.com*
- *Tineke Mandang, Wawan Hermawan, Muhammad Faiz Syuaib are Lecturers of Bogor Agricultural University (IPB), Indonesia.*

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holds the handlebar, one example is when the tractor wants to turn left at an angle of <45 °, then the left hand holds the tractor handlebar on the right, and the right hand holds the trailer to maintain balance. On ergonomic rules this hand movement has passed through the midline area of the body so that this movement is classified as dangerous where this movement can cause the tractor to roll over when using a fairly high speed and when walking on bumpy land. At this position flexion occurs in the back and shoulders which enter the alert zone based on the ROM table.

c. Turn> 45 °: this motion shows that the two-wheel tractor turns at an angle> 45 ° and the trailer follows the tractor's movements. At this position, the operator tends to lower his legs fatigue / road because the turning radius is too large so that the hand is not able to reach when the operator's position is still in a sitting position on the front of the trailer. According to ergonomic rules such movements are very dangerous to know outside the work area of the hose because the operator's feet can be run over if the tractor's speed is too fast or when the road conditions are decreasing, this can of course lead to work accidents that can be detrimental to the operator or person others around it, so that for a movement of turn> 45 ° this is not recommended to do because it has a very large impact.

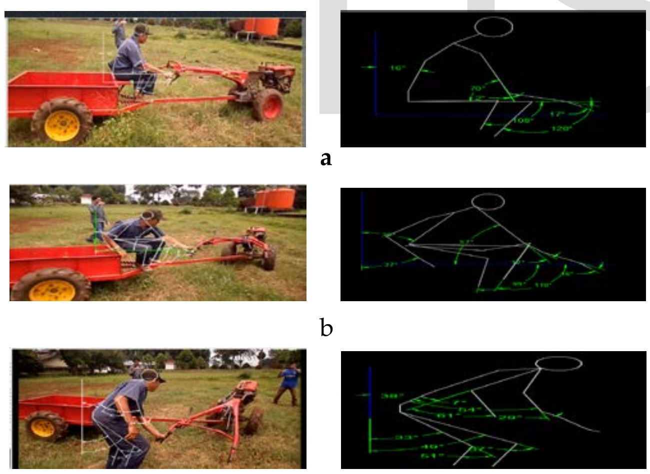

Fig. 1. Actual work movement, a. The operation of the tractor moves straight, b. Operation turns <45º c. Operation turns> 45º

3. Materials and Methods

3.1. Introduction Stage

This preliminary stage consists of secondary data collection and field observations. Secondary data taken are farmers' anthropometric data in Indonesia and ROM data. While field observations in the form of video how to drive a two-wheel tractor by using a trailer, as well as measuring the dimensions of two-wheel tractor and trailer used and body dimension measurements (anthropometry) of a two-wheel tractor operator.

Data of two-wheel tractor dimensions taken are steering distance or steering width (mm), steering handlebar height from ground level (mm), steering handlebar length (mm), handlebar stem diameter (mm), tractor engine size (mm), and diameter tractor wheel (cm). While the dimensions of the trailer data taken include the length (mm) and the width of the trailer (mm), the length and width of the operator's seat and seat height from the ground and also the tractor handlebar distance with the operator's seat (mm), and operator's footrest. The tools used are anthropometers, tractor and trailer of the Yanmar type Bromo DX brands, video recorders, meters, scales, and laptops. Some supporting software for data processing and analysis, including spread sheets, computer aided design (CAD), and Video Converter to Jpeg.

3.2. Analysis of work motion and posture

The video of operating a two-wheel tractor for transportation by the operator is made into a collection of photos by capturing movements that are considered dangerous / outside the working interval when driving can be seen in Figure 1. The video capture results are analyzed the motion elements and the risks that occur each movement. The collected angle data is compared with the operator's movement angle when operating the tractor with reference in the form of a Range of Motion (ROM) table as shown in (Table 1) to map out the risk distribution of movements that occur in each part of the body. Load and risk assessment of muscular keletal (MSD) was analyzed by Rapid Upper Limb Assessment (RULA). With the RULA method is an ergonomic method used to predict the level of work risk, this method is grouped into two parts. The first part (A Score) consists of the shoulder, elbow to the arm, and wrist. The second part (Score B) consists of the neck, back and knee. By adding strength and muscle load factors, the total posture analysis score can be calculated, because it is guided in the RULA procedure (Figure 2). Risk is calculated to be 1 (low) to 7 (high), which is then grouped into four levels of risk control measures.

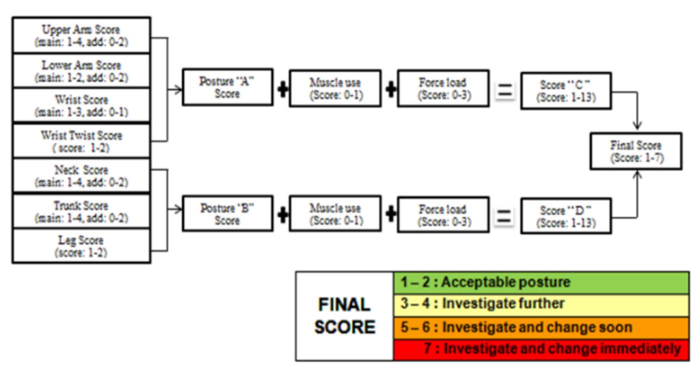

Fig 2. RULA assessment procedure (McAtamny and Corlett, 1993)

TABLE 2

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Range of Motion (ROM)

	Move-	Distance of movement zone °)			
		Zone 0	Zone 1	Zone 2	Zon 3
Elbow	Flexion	0-28	29-62	63-124	125+
Hand arm**	Supination	0-21	22-48	49-96	97+
	Pronation	0-13	14-29	30-59	60+
Ankle**	Extension	0-7	8-16	17-32	33+
	Flexion	0-6	7-13	14-26	27+
Knee**	Flexion	0-21	22-48	49-94	95+
Hips**	Adduction	0-5	7-12	13-23	24+
	Abduction	0-12	13-27	28-53	54+
	Flexion	0-22	23-50	51-99	100+
Wrist*	Flexion	0 – 10	11 – 25	26 –	51+
	Extension	0 – 9	10 – 23	24 –	46+
	Deviation	0 – 3	4 – 7	8 – 14	15+
	Deviation	0 – 5	6 – 12	13 –	25+
Shoulder*	Flexion	0 – 19	20 – 47	48 –	95+
	Extension	0 – 6	7 – 15	16 –	32+
	Adduction	0 – 5	6 – 12	13 –	25+
	Abduction	0 – 13	14 – 34	35 –	68+
Back*	Flexion	0 – 10	11 – 25	26 –	46+
	Extension	0 – 5	6 – 10	11 –	21+
	Rotation	0 – 10	11 – 25	26 –	46+
Neck*	Flexion	0 – 9	10 – 22	23 –	46+
	Extension	0 – 6	7 – 15	16 –	31+
	Rotation	0 – 8	9 – 20	21 –	41+

[a]Sourcer :*)Chaffin (1999) dan Woodson (1992) diacu in Openshaw [5]

**)Adapted fromHouy 1983 diacu in Sanders dan McCormick (1987)

3.3. Design Modification Stage

This stage includes conducting design alternatives based on design criteria that have been analized through an ergonomic approach. At this stage, engineering procedures / procedures for operating two-wheel tractor and trailer will also be carried out. The new steering handlebar design criteria are the handlebar that is still comfortable and safe when turning <45º and able to withstand workload well and ergonomically so that the operator is comfortable when using it. The design concept was made by analyzing the operator's body movements when driving a tractor with three types of movements, through Indonesian farmers' anthropometric data and ROM analysis so that the operator's initial motion angle for each movement can be seen, so that each movement into the comfort, safe, alert or dangerous. safe for all three operations (straight motion, turn <45º, and turn> 45º) and third human body size (percentl 5, percentile 50, and percentile 95).

Based on the initial motion angle data, we can change the angle value in each movement that enters the alert zone (zone 2), the value of the angle of motion is adjusted to fit into the safe zone (zone 1) based on ROM analysis. This angle of motion data will be used as a reference / criterion in determining the dimensions, length, width and height of handlebar and anthropometric data for each percentil can also be used as a reference to change the dimensions of the length and width of the footrest and seat of the new operator.

The design concept of the steering handlebar offered is a fixed steering handlebar (fix), which is the steering handlebar as it has been so far, where the length, height, width, and steering angle are fixed for all three types of operations referring to the local operator ROM. This is because the fix design has a greater value of strength than the adjustable handlebar, based on the ROM table analysis handlebar design must be higher and narrower to get a safe working angle for the operator to reduce / avoid fatigue / workplace accidents. The RULA score can be used as an evaluation of the new steering handlebar design, the low RULA score indicates that the steering handlebar is optimum for use.

4. Results and Discussion

4.1. Work Motion Analysis

Data from the work motion analysis using ROM tables in percent 5, 50, and 95 can be seen in Tables 2, 3, and 4. Based on the analysis, the body part that often goes into the danger zone is the knee both in straight motion, turning motion <45 ° or turn> 45 °.

TABLE 2
Analysis of 5 percentile work motion

Element of Work	Ne	Nr	Hf	Hr	Sf		Se		Sab		Ef		Kf		Wf	
					R	L	R	L	R	L	R	L	R	L	R	L
Straight	0	0	16	0	70	59	0	0	46	47	0	13	95+	95+	17	28
Turn ≤45°	10	25	35	23	0	89	11	0	11	7	87	11	95+	95+	0	0
Turn >45°	15	30	38	10	95+	95+	0	0	0	0	125+	125+	95+	95+	51+	0
Repair Straight	0	0	12	0	35	42	0	0	18	18	61	47	83	82	0	15
Repair Turn	0	19	18	0	85	0	0	17	14	0	3	105	90	87	0	6

TABLE 3
Analysis of 50 percentile work motion

Element of Work	Ne	Nr	Hf	Hr	Sf		Se		Sab		Ef		Kf		Wf	
					R	L	R	L	R	L	R	L	R	L	R	L
Straight	0	0	16	0	59	52	0	0	52	46	3	12	95+	95+	17	28
Turn ≤45°	8	35	43	20	0	89	4	0	14	10	90	43	95+	95+	8	0
Turn >45°	14	30	37	10	95+	95+	0	0	0	0	125+	125+	95+	95+	51+	0
Repair Straight	0	0	14	0	43	45	0	0	18	18	69	65	90	90	0	13
Repair Turn	0	20	20	0	72	0	0	25	17	0	48	124	91	94	0	0

TABLE 4
Analysis of 95 percentile work motion

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Element of Work	Ne	Nr	Hf	Hr	Sf		Se		Sab		Ef		Kf		Wf	
					R	L	R	L	R	L	R	L	R	L	R	L
Straight	0	0	20	0	64	57	0	0	17	18	2	17	95+	95+	15	5
Turn ≤45°	9	25	32	10	0	82	4	0	6	3	72	19	95+	95+	0	0
Turn >45°	13	30	30	10	95+	95+	0	0	0	0	125+	125+	95+	95+	51+	0
Repair Straight	0	0	10	0	24	26	0	0	18	18	58	49	84	85	0	9
Repair	0	18	15	0	64	0	0	25	12	0	30	108	94	94	0	15

Information : in degree

Hr	=	Hip Rotation	Ne	=	Neck Extension
Ef		Elbow Flexion	Nr	=	Neck Rotation
Wf		Wrist Flexion	Sf	=	Shoulder Flexion
Se		Shoulder Extension	Sab	=	Shoulder Abduction
Kf		Knee Flexion			

Zona 0 / comfortable zone
Zona 1 / comfortable zone
Zona 2 / alerts zone
Zona 3 / danger zone

While the body parts that are included in the zone of caution are the shoulder, neck and elbow. In this ROM-based analysis, the operator whose body part enters the danger zone must immediately change its angle of motion to enter the safe or comfortable zone.

This is the same as operators who often make a <45 ° turn where the operator's shoulders and elbows have crossed the center line of the body of the opertor itself, this will result in the operator falling while driving a tractor or injury. Turning> 45 ° is not recommended because the turn is too high in its rotational radius and has been outside the area of the work-space hose based on the ROM table so that the operator's foot must go down to the ground, this can have a negative impact on the operator, one example operator foot that can be run over by tractor tires when the road is down or when the tractor is at high speed.

4.2. Simulation of Safe Work Motion Models

Based on Tables 2, 3, and 4, there are some data on the angle of motion that still need to be improved on some parts of the operator's body in Indonesia based on ROM Table. In a straight motion for the shoulder (Sf), especially the left part which initially goes into the alert zone (zone 2) because it has a fixed motion angle of 59 ° to 42 ° which has entered into the safety zone (zone 1). Whereas at the knees which initially get a motion angle above 95 ° and enter into the dangerous zone (zone 3) but after being fixed the motion angle becomes 83 ° and enter into the alert zone (zone 2), for this knee part itself cannot indeed be changed the maximum initially entered in zone 4 can only be changed into zone 3, this is because the knee is used as a fulcrum / support workload on the operator's body when driving, if the knee is converted into zone 1 or even zone 0 the knee position is too straight so that the strength to support the workload of the body is greatly reduced so that it can cause the operator to experience injury or even a work accident.

On a turning motion <45 ° the body part that is repaired is the neck part (Nr) which initially gets an angle of 25 ° and goes into zone 2, but after repairing the angle becomes 0 ° and goes into zone 0. Other body parts that are repaired in turn 45 ° i.e. the knee which is initially above 95 ° (zone 3) is fixed to 90 ° (zone 2).

The initial motion simulation using a mannequin can be seen in Figures 3a and 3c while the simulation of the motion that has been improved can be seen in Figures 3b and 3d. For data on the initial motion angle and the angle of motion that have been fixed in percentages 5, 50 and 95 can be seen in Table 2 , 3, and 4. This safe motion simulation is used as a parameter to determine the new handlebar design that is more in line with the dimensions of the operator's body in Indonesia. This safe motion simulation will produce a design not only on the handlebar, but on the operator's seat and also the operator's footrest. This safe movement simulation is only used for operators when driving a tractor for transportation not for processing land.

4.3. Working angle analysis with RULA.

The following is the result of the RULA analysis used as a comparison of the results of the analysis using ROM Tables. The score on this RULA can also be used as a reference related to the relationship between the designs that have been made with the movements carried out by the operator. The results of the RULA score on work movements can be seen in Table 5.

Based on Table 5 for straight movements both at the initial movement or after experiencing changes in the angle of motion, each still has a final score of 3 which means that the movement is still classified as a safe movement, even though it has the same final score in each percentile (Percent 5, 50 and 95) but there is a change in the part of the hand where each percentil initially gets a score of 3, but after experiencing improvement the score angle changes to 1 for percentile 5, percentile 50 and 95. Although this hand is part of posture A but changes in score on the hand part does not change the score on posture A this has been analyzed based on the RULA Worksheet where the angle of interval for each score is far. So that it does not rule out the possibility that when analyzing the angle of motion using RULA get the same score on all three percentiles (percent 5, 50 and 95).

TABLE 5

THE RULA score of a straight motion

Posture	Score Percentil 5		Score Percentil 50		Score Percentil 95	
	Before	After	Before	After	Before	After
Shoulder	4	3	4	3	4	3
Arm	2	2	2	2	2	2
Hand	3	1	3	1	3	1
Twist	1	1	1	1	1	1
Neck	1	1	1	1	1	1
Trunk	2	2	2	2	2	2
Leg	1	1	1	1	1	1
Posture A	4	4	4	4	4	3
Posture B	2	2	2	2	2	2
Finally	3	3	3	3	3	3

TABLE 6
THE RULA score of moement <45°

Posture	Score Percentil 5		Score Percentil 50		Score Percentil 95	
	Before	After	Before	After	Before	After
Shoulder	4	4	4	4	4	4
Arm	3	2	3	2	3	2
Hand	3	2	2	2	2	2
Twist	1	1	1	1	1	1
Neck	5	2	5	2	5	2
Trunk	4	2	4	2	4	2
Leg	2	1	2	1	2	1
Posture A	5	4	5	4	5	4
Posture B	9	3	9	2	9	2
Finally	7	3	7	3	7	3

The RULA score for turnover <45 ° (Table 6) has a very significant change in score from the score based on the initial motion angle with a final score of RULA of 7 for the third percentile, but after improvement the final score of the RULA becomes 3. Second score in motion the beginning of either posture A or posture B had a high score of score 5 for posture A and score 9 for posture B. Posture A was affected by movements of shoulder, arm, and twist. There is a score change in the arm and hand section which initially has a score of 3 changing the score to 2. This is affected because when the initial movement of the operator tends to cross the midline, where in the RULA analysis the additional score is 1, while after handlebar modification, operator's seat and movement footing becomes normal / doesn't cross the midline of the body so there is no additional score Posture B is influenced by parts of Neck, Trunk, and Leg. The Initial Neck score is 5 which changes the score to 1, for the trunk score that initially 4 changes to 2 this is influenced by the initial movement that only uses one hand so it requires a trunk that bends excessively to reach the steering handlebar that is turning and the hand used has crossed the midline of the body due to the steering handlebar which should be held by the right hand, in the initial motion the right handlebar handle is held by the left hand. In part the initial leg score of 2 changes to 1, this is because the foot on the initial oeprator movement cannot be used as a pedestal this is evident because one of the operator's hands must hold the high part of the seat so that the body's balance is maintained. The operator after repairing the steering handlebar, operator seat and footrest where the operator's hand is still on the steering handlebar and the operator's feet are still safely standing as the body's support because the operator's footrest has been made longer and the operator's seat has been made more spacious and wide.

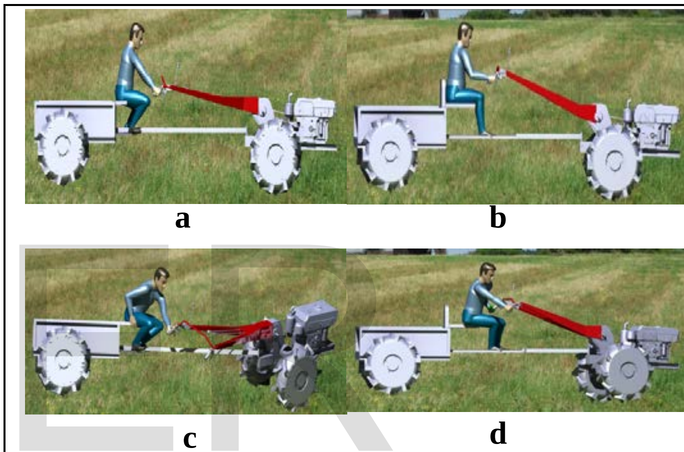

Fig 3. Initial movement simulation and improvement a. The tractor simulation runs straight ahead b. The tractor simulation goes straight for repairs c. Simulation turns <45º early d. Simulation turns <45º improvements

4.4. Modified Design

This design modification is a recommendation for the operation of the tractor in terms of transportation, while the operation of the tractor for land processing requires further analysis, because it will produce different results because the operator's movement when operating the tractor for tillage has more movement if compared to operators when operating tractor for transportation.

This modification was made to produce a safe movement for local operators in Indonesia based on the three percentiles (Percent 5, 50 and 95), which needed to be changed on the steering handlebar which included handlebar length, handlebar width, and handlebar height. In addition to the new design on the steering handlebar, a new design is needed for the operator's seat and footrest. This new design is to support the operator's movements, especially when performing an operating position turning <45º. The size of the new steering handlebar, operator seat and operator footrest has been made based on anthropometric compatibility of 5, 50 and 95 percentiles and simulated safe motion angles. The initial size of the design with the new design can be seen in Table 7. Changes in dimensions are done to create a safe and comfortable movement for the operator when driving a tractor for transportation.

Based on the data in Table 7 the changes that occurred in the handlebar, seat, and initial design footrests with improved designs experienced a significant change in dimensions. The initial handlebar length has a dimension of 1560.47 mm changed to 1463.9 mm (fit percentile 50, acceptable percent 5 and 95), with the initial width of the handlebar 844.19 mm to 559.21 mm (fit percentile 50, acceptable percent 5 and 95) and the initial handlebar height 1070.18 mm to 1234.12 mm (fit percentile 95, acceptable percentile 5 and 50). This change in steering handlebar design is based on motion angle analysis using the ROM Table of the movements carried out by the operator when driving a tractor running straight or turning <45º.

Changes in the dimensions of the operator's new seat, the seat which initially has a length of 170 mm to 445 mm (fit percentile 50, acceptable percentile 5 and 95) and the initial seating width of 400 mm changes to 510 mm (fit percentile 95, acceptable percentile 5 and 50) and there is an additional seat support for the operator in the new design, while the initial design does not have a backrest on the operator's seat. The dimensions of the backrest are 125 mm (fit percentile 95, acceptable percentile 5 and 50) with the width of the backrest following the width of the design of the seat of the new operator.

In addition to changes in the dimensions of the operator's seat, changes also occur in the footrest, this is of course done to provide a sense of security for the operator when driving the tractor for transportation. The design of this footrest is influenced by the anthropometry of each percentil (percent 5, 50 and 95). Changes in dimensions on the operator's footrest, ie the initial length of 390 mm changes to 1060 mm (fit percentile 95, acceptable percentile 5 and 50) and initial leg width of 290 mm changes to 360 mm (fit percentile 95, acceptable percentile 5 and 50).

Table 7
The initial design size and modification

Description	Initial Size	Modification Size
Handlebar length	1560.47 mm	1463.9 mm
Handlebar width	844.19 mm	559.21 mm
Handlebar height	1070.18 mm	1234.12 mm
Length seat	170 mm	445 mm
Width seat	400 mm	510 mm
High Seat	0 mm	125 mm
Footrest length	390 mm	1060 mm
Footrest widt	290 mm	360 mm

5. Conclusions and Suggestions

5.1. Conclusion

This research has identified the movement of the operator when operating the tractor for transportation is at an ergonomic risk. The results of motion analysis show that the upper body, namely shoulders, elbows, and hands experience relatively extreme movements and dangerous postures, therefore it is at high risk in terms of safety and MSD, especially for turn movements. Furthermore, the RULA score indicates that the operator's posture when turning is in the action level category 4 which means that investigation and change are needed immediately.

Safe movement model simulation can be used to reduce work risks for operators in operating two-wheel tractor for transportation. The results of model simulations can be used to modify handlebar designs that are useful to minimize awkward postures and MSD risks and improve work safety.

5.2. Suggestion

Need further analysis on modified handlebar, so that it is also optimum to be used to plow in paddy fields and dry land.

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