WORK MOTION STUDY OF PIVOT TYPE TRAILER OPERATION ON TWO WHEEL TRACTORS
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STUDI GERAK KERJA PENGOPERASIAN TRAILER TIPE PIVOT PADATRAKTOR RODA DUA

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ABSTRACT
This study aims to analyze the pivot type trailer operation with an ergonomic approach and the necessary interventions required to minimize work risks. Data collection was carried out using questionnaires and video recordings of the operators when the tractors as well as trailers were being operated at various conditions such as track, load, speed, straight motion or turn. Based on the Range of Motion (ROM) analysis, it was discovered that while operating this pivot type trailer, the upper body segments such as neck, shoulders, elbows and back of the operator felt comfortable while he was controlling the tractor. Meanwhile, in the lower body segments, such as the thighs and knees, the operator generally felt discomfort. Furthermore, the analysis of the operator's subjectivity perception showed that discomfort was felt at several segments of the upper and lower body, such as the hands and knees. Therefore, several ergonomic interventions are required to increase the comfort of operating this pivot type trailer.

ABSTRACT
Tujuan dari kajian ini adalah untuk menganalisis pengoperasian trailer tipe pivot dengan pendekatan ergonomi dan intervensi yang diperlukan untuk meminimalkan risiko kerja. Pengambilan dan pengumpulan data rekaman video operator dan kuisiner saat pengopearsaian traktor dan trailer dengan berbagai kondisi lintasan, muatan, kecepatan, gerakan lurus atau belokan. Hasil analisis natural Range of Motion (ROM) didapatkan bahwa secara umum pada pengoperasian trailer tipe pivot ini segmen tubuh bagian atas yaitu leher, bahu, siku, dan punggung operator dengan nyaman dapat mengendalikan traktor, sedangkan pada segmen bagian bawah tubuh yaitu paha dan lutut secara umum operator tidak nyaman karena lutut cenderung tertekuk sehingga perlu penyesuaian ketinggian tempat duduk. Analisis persepsi subjektifitas operator menunjukkan beberapa segmen tubuh atas dan bawah yang dirasakan kurang nyaman yaitu tangan dan lutut. Beberapa intervensi ergonomi diperlukan untuk meningkatkan kenyamanan pada pengoperasian trailer tipe pivot ini.

INTRODUCTION
Two-wheeled tractor is commonly used by farmers in Indonesia, both on paddy fields (wetlands) and dry land. This is because it is suitable for agricultural activities in the country, which generally has relatively small plots of land. Furthermore, from an economic point of view, it is relatively cheaper to purchase, operate and maintain compared to other types of tractors.

The two-wheeled tractor is actually not only meant for land cultivation but also used for other purposes when some parts are adjusted and added. For example, it is used in the fertilization process, by adjusting the width of the wheels and fertilizer coupling, as well as spraying process. Furthermore, it is used as a means of transporting the agricultural products.

The use of this tractor to tow conventional trailers as a means of transportation is widely applied. This is achieved by attaching the hitch end of the trailer to the hitch point of the tractor behind the gear box, while the operator sits a little backward on the trailer hitch. However, this conventional trailer has the disadvantage of turning, where the tractor handlebar moves away from the operator's control position. This is because the handlebars have turned to follow the body of the tractor, while the operator's seat is yet to turn. Consequently, the position of the handlebar becomes out of the operator's reach, therefore the operator has to bend over to get both control grips of the tractor handlebar.

For turns, especially over large radii, the operator has to get out of the seat to control the tractor. This causes fatigue, discomfort, difficulty, risk of injury and even work accidents for the operator.

Dhafir et al. (2019) modified the conventional trailer to be a pivot type. In this type of trailer, the axle is behind the operator, therefore it is possible to fully control the tractor in a straight line or turn (Figure 1a). The performance test results showed that it is better than conventional trailers, but it has never been tested on the aspect of safety and operator comfort.

(a) *(b)*

Fig. 1 - The position of the operator when turning 90º

(a) pivot type trailer (b) conventional trailers (Dhafiret al., 2019)

Therefore, it is necessary to carry out an analysis of the operator's work motion, while operating a pivot-type trailer to determine the ergonomic risks related to its operation and modifications in order to minimize the risk of Musculoskeletal Disorder (MSD).

Musculoskeletal disorders (MSDs) are health problems involving joints, muscles, tendons, skeleton, cartilage, ligaments and nerves (*Van, 2016*). The level of this disorder ranges from the mildest to the most severe, which interferes with concentration at work, causes fatigue and ultimately reduces productivity (*Harcombe, 2014*).

Barnes (1980) stated that motion study is a branch of ergonomic studies commonly used to design an effective method, procedure or work method, with the least possible effort to obtain optimal results. Therefore, motion study may also be interpreted as a work method design.

Furthermore, *Syuaib (2015b)* carried out a motion and posture study of manual oil palm harvesters. The results of posture assessment using the Rapid Upper Limb Assessment (RULA) method showed that the work is outside the safe range. Meanwhile, work motion simulations produced work procedures that are able to minimize unsafe posture and musculoskeletal disorders (MSD). *Yadaf et al. (2010)* carried out a study of strength parameters in the design of manually operated agricultural equipment. These strength parameter data were very useful in designing equipment capable of providing the operator with comfort, safety and efficiency. Furthermore, *Toren (2001)* investigated muscle activity and range of motion for back rotation when driving a tractor in a sitting position. The results showed no significant difference due to the direction of back rotation performed. Therefore, the posture of the back that is twisted while driving the tractor is suspected to be a risk factor for low back pain.

This study aims to analyze the pivot type trailer operating activities with an ergonomic approach. The scope studied was a motion analysis to determine the safety and ergonomic risks of trailer operation based on the natural range of motion index and the operator's anthropometric suitability.

MATERIALS AND METHODS

Tools and Materials

The equipment used includes: (1) Yanmar two-wheeled tractor with Bromo DX model, a power of 8.5 HP, 2640 mm in length, 765mm in width, 1060cm in height, 250 kg in weight and a pivot type trailer, (2) a Handycam, (3) computer, (4) meter and calipers and (5) 18 MP digital camera.

Furthermore, some of the data processing and analysis software used include computer-aided design (CAD) 2013 software, spreadsheet and video to jpeg converter.

Study Stages

This study is generally described in the flow chart shown in Figure 2.

Study Subject

The subjects involved were two-wheeled tractor operators consisting of 4 (four) adult males. The selected subjects were quite close to the secondary anthropometric data of Indonesian society. Furthermore, they represented the three operator percentiles, namely the 5th, 50th and 95th percentiles. The trailer operation paths were paved roads and agricultural land on empty and full trailer load conditions with variations in the tractor forward speed of 4 and 6 km/hour.

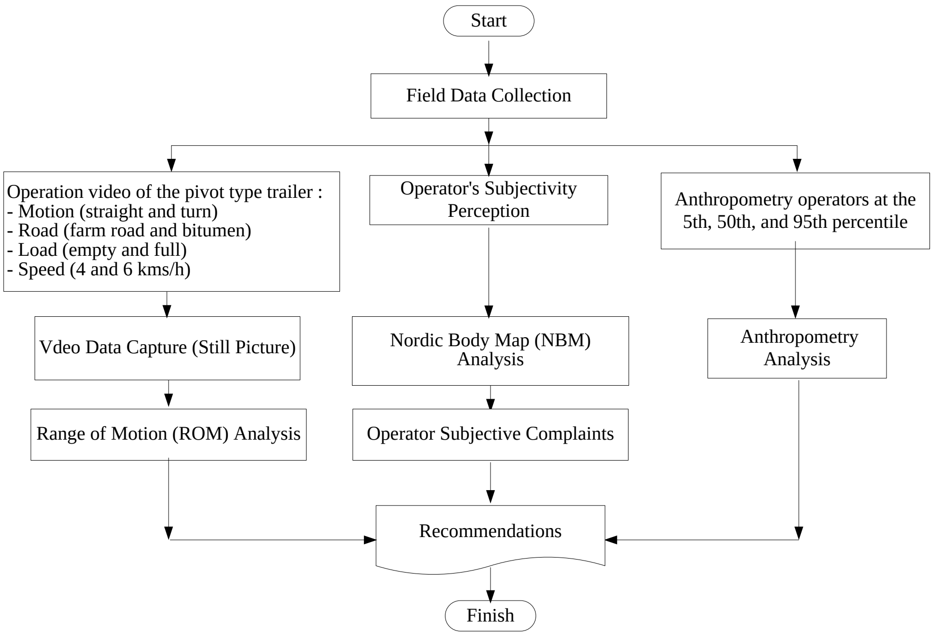

Fig. 2 - Study flow chart

Preliminary observations

The preliminary stages carried out were field observations, including primary and secondary data collection. Field observations include observing the operation of a two-wheeled tractor with a trailer. Primary data includes measurement of dimensions of two-wheeled tractors and trailers, while secondary data includes the anthropometric data of Indonesians according to *Syuaib (2015a).*

Data Collection

Data collection for the pivot type trailer prototype was carried out by 4 (four) male subjects with each individual carrying out 4 repetitions. Furthermore, tests were carried out on operation in a straight and turning line on (a) paved and (b) agricultural land with (a) empty and (b) full load and at a tractor forward speed of 4 and 6km/hour. Figure 3 shows the line of the pivot-type trailer operation test.

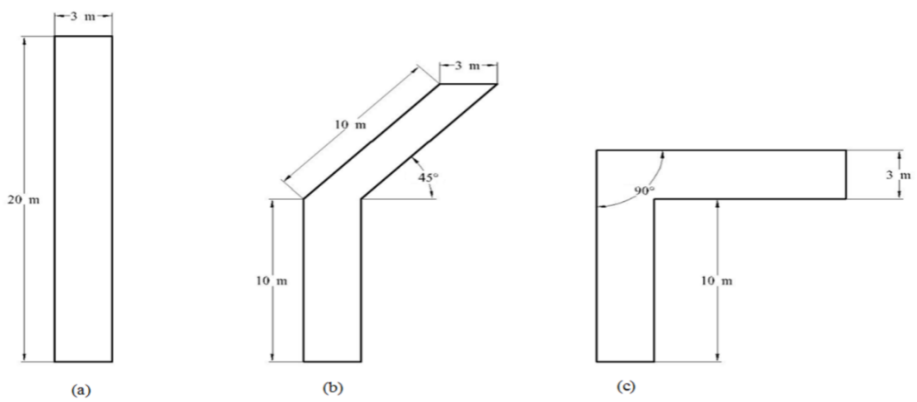

Fig. 3 - Line of trailer operation test

(a) straight (b) turn 45^{O} and (c) turn 90^{O}

Video cameras were used to record every movement from operating the tractor to analyzing its motion studies. The data obtained from these recordings were used as the main data source (quantitative data). Meanwhile, for motion study analysis, the video data (motion picture) was converted into still picture parts to be divided into motion elements. Furthermore, the range of motion data was obtained with the help of AutoCAD 2013 software.

The data collection design is shown in Figure 4. The data taken in this study were qualitative and quantitative. The quantitative data was in the form of a video recording while operating the two-wheeled tractor with a pivot type trailer. Meanwhile, the qualitative data was taken in the form of a questionnaire from the Nordic Body Map and distributed to the study subjects.

Data Analysis

The description of data analysis in this study is explained as follows.

a) Range of Motion (ROM)

Range of Motion (ROM) refers to the angles in the joints that normal humans are able to carry out in every segment of their body. The greater the range of motion angles carried out, the more the effort and risk incurred. Therefore, the working interval data for each element was analyzed by dividing it into four zones, namely the comfort, safe, alert and dangerous zone (*Openshaw, 2006*).

b) Nordic Body Map (NBM)

Nordic Body Map (NBM) is a method for obtaining complaints on Musculoskeletal Disorders (MSD) (*Sofyan and Amir, 2019*). It was used in the form of a questionnaire consisting of complaints regarding 27 body parts with four levels, which include no pain, mild, moderate and severe. The subjective perception of the operators was analyzed to determine which parts of the body experienced the greatest MSD complaints in relation to operation of the two-wheeled tractor. However, NBM cannot be used as a clinical diagnosis because it is subjective and specifically based on the subject's perception, not on a health diagnosis (*Suriyatmini, 2010*).

RESULTS

Operator Anthropometry

Ideally, the operator anthropometry chosen was one capable of representing the three percentiles of Indonesian society (5, 50, and 95%), but in reality, there were difficulties in fulfilling the proportional sample. Therefore, an operator close to the size of Indonesian society was chosen.

The anthropometric data for the operators of the trailer are shown in Table 1. As shown in the table, operator A represents the 5th percentile, operator B the 95th percentile, while operator C and D the 50th percentile. Furthermore, operator C was chosen to represent fat operators. Therefore, anthropometric data is very important as a basis in designing tools, equipment and work procedures in order for productivity compatibility to be optimal.

Table 1

Operator anthropometry for study subjects

No	Body Dimensions	Operator A (21 years)	Operator B (38 years)	Operator C (27 years)	Operator D (57 years)
1	Body Weight (kg)	62	59	91.2	69.3
2	Standing height	154	168.8	164	164.2
3	Eye height	142.8	158	153.2	153.4
4	Shoulder height	125.5	138.4	134.4	136.4
5	Elbow height	94.8	107.9	103.1	103.3
6	Wrist height	89.1	101.9	97.1	97.3
7	Knuckle height	65.1	77	72.2	72.4
8	Fingertip height	54.8	66.6	61.8	62
9	Hand stretch length	156.5	175	169	170
10	Elbow stretch length	78.4	93	87	88
11	Vertical hand reach	179.9	197.6	193.6	195.6
12	Horizontal grip reach	69	76	73	76

Table 1
(continuation)

No	Body Dimensions	Operator A (21 years)	Operator B (38 years)	Operator C (27 years)	Operator D (57 years)
13	Horizontal arm reach	80.2	87.5	84.5	87.5
14	Sitting height	84.3	84.8	82.7	79.8
15	Eye height when sitting	72.2	76.1	71.2	68.5
16	Shoulder height when sitting	52.9	57	55.8	52.2
17	Elbow height when sitting	20	23	23.6	19.7
18	Knee height	45.8	51.5	51.3	52.3
19	Upper limb length	53	55.5	55	52
20	Popliteal upper limb length	39	48	50	49
21	Popliteal	18.9	18.2	24.4	22
22	Chest width	36.1	44.2	54.9	47.2
23	Shoulder width	25.2	32.5	43.2	35.5
24	Hip width	29	35	32.2	33.7
25	Upper sleeve length	41	47	44	47
26	Hand length	16.7	18.2	17	18.7
27	Palm length	8.8	10.6	10.5	11.1
28	Hand width	3.5	4.2	4	4.7
29	Grip diameter (inside)	22	25.5	24	26
30	Foot length	8.4	10.2	9.3	13

Results of Work Motion Analysis in Pivot Type Trailer Operation

The work motion analysis was carried out by observing the working motion of the pivot-type trailer operation with reference to the body's Range of Motion (ROM). An example is taken from operator B for motion analysis as shown in Figure 4.

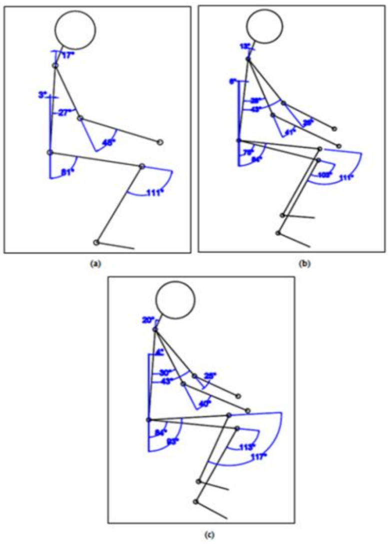

Fig. 4 - The work motion patterns of operator B on asphalt roads:
(a) go straight, (b) turn 45º, (c) turn 90º

Based on the results of the analysis of motion and natural range of motion (SAG) for each test element as a whole for operator B, the ergonomic risk is analyzable based on the aspect of work motion as presented in Table 2. It explains the risk of motion in each joint segment for each element of work accumulatively.

Zone-0 (white) and zone-1 (green) represent the safe zones for the subject's muscles and joints when working, zone-2 (yellow) is a zone that is still allowed but with a short time, the load is neither too heavy nor repetitive, but vigilance and care is required to work long and repetitive, while zone-3 (red) is a zone that should be avoided because it is dangerous for joints and muscles (*Openshaw, 2006*).

Table 2

Distribution of operator B Range of Motion for each body segment

Test number	Ef		Sf		Bf	Nf	Hf		Kf	
	R	L	R	L			R	L	R	L
B1	48	48	27	27	3	17	81	81	111	111
B2	41	25	28	43	6	13	75	84	103	111
B3	40	25	30	43	4	20	84	93	113	117
B4	46	46	27	27	22	19	86	86	113	113
B5	90	17		55	13	20	74	86	96	117
B6	73	33	11	46	14	16	78	90	100	101
B7	36	36	32	32	10	19	68	68	96	96
B8	60	42	16	30	10	17	70	84	99	103
B9	32	68	38	13	10	18	70	86	95	108
B10	45	45	27	27	3	19	68	68	102	102
B11	60	50	18	27	10	18	69	86	101	114
B12	55	37	21	32	14	20	73	83	92	101
B13	51	51	22	22	4	14	81	81	110	110
B14	53	47	26	30	3	19	80	100	108	118
B15	29	67	32	15	6	20	85	94	112	117
B16	57	57	26	26	9	10	83	83	108	108
B17	46	63	32	14	10	17	80	86	105	104
B18	43	36	29	36	15	14	82	88	106	111
B19	56	56	18	18	9	18	62	62	106	106
B20	66	49	19	35	16	16	83	88	102	113
B21	45	66	32	17	13	11	81	86	110	115
B22	73	73	20	20	21	16	76	76	106	106
B23	74	55	19	38	24	18	76	88	102	114
B24	75	60	33	20	24	18	76	85	101	102

	Road type	Load	Speeds (km/s)/h	Motion		Road type	Load	Speeds (km/s)/h	Motion
B1	Bitumen	Empty	4	Straight	B13	Farm road	Empty	4	Straight
B2	Bitumen	Empty	4	Turn 45^{O}	B14	Farm road	Empty	4	Turn 45^{O}
B3	Bitumen	Empty	4	Turn 90^{O}	B15	Farm road	Empty	4	Turn 90^{O}
B4	Bitumen	Empty	6	Straight	B16	Farm road	Empty	6	Straight
B5	Bitumen	Empty	6	Turn 45^{O}	B17	Farm road	Empty	6	Turn 45^{O}
B6	Bitumen	Empty	6	Turn 90^{O}	B18	Farm road	Empty	6	Turn 90^{O}
B7	Bitumen	Full	4	Straight	B19	Farm road	Full	4	Straight
B8	Bitumen	Full	4	Turn 45^{O}	B20	Farm road	Full	4	Turn 45^{O}
B9	Bitumen	Full	4	Turn 90^{O}	B21	Farm road	Full	4	Turn 90^{O}
B10	Bitumen	Full	6	Straight	B22	Farm road	Full	6	Straight
B11	Bitumen	Full	6	Turn 45^{O}	B23	Farm road	Full	6	Turn 45^{O}
B12	Bitumen	Full	6	Turn 90^{O}	B24	Farm road	Full	6	Turn 90^{O}

Observing the analysis results from the motion ergonomics perspective for operator B on the pivot type trailer operation, it is seen that that upper body segments, which include elbows (EF), shoulders (SF), back (BF) and neck (NF), of the operator were safe and comfortable while he was controlling the tractor. Meanwhile, the lower body segments, which include the thighs (HF) and knees (KF), were uncomfortable because the knees tend to bend.

To detect operator discomfort while working, the ROM method is applicable (Table 3). Therefore, for all operators (A, B, C, and D), the distribution of the operator's Range of Motion is summarized in Table 4.

Table 3

Range of Motion on several zones

	Movement	Range of movement zone (in°)			
		Zone 0	Zone 1	Zone 2	Zone 3
Neck (NF) *	Flexion	0 – 9	10 –22	23– 45	46+
Shoulder (SF) *	Flexion	0 –19	20 – 47	48– 94	95+
Elbow (EF) **	Flexion	0–28	29–62	63–124	125+
Back (BF) *	Flexion	0 – 10	11 –25	26– 45	46+
Thigh (HF) **	Flexion	0–22	23–50	51–99	100+
Knee (KF) **	Flexion	0–21	22–48	49–94	95+

*Source: *) Chaffin (1999) and Woodson (1992) referred to in Openshaw (2006)*
***) Processed based on data sourced from Houy 1983 referred to in Sanders and McCormick (1993)*

Table 4

The results of operator ROM analysis on pivot type trailer operation

Parts of body	Movement	Summary of ROM values			
		A	B	C	D
Neck	Flexion (NF)	8 – 24^{O}	10 – 20 ^{O}	15 – 42^{O}	10 – 49^{O}
Shoulder	Flexion (SF)	11 – 59^{O}	11 – 55^{O}	6 – 53^{O}	5 – 70^{O}
Elbow	Flexion (EF)	21 – 113^{O}	17 – 90^{O}	11 – 78^{O}	8 – 95^{O}
Back	Flexion (BF)	0 – 32^{O}	3 – 24^{O}	0 – 17^{O}	8 – 31 ^{O}
Thigh	Flexion (HF)	43 – 80^{O}	62 – 100^{O}	57 – 93^{O}	51 – 84^{O}
Knee	Flexion (KF)	29 – 92^{O}	92 – 118^{O}	79 – 118^{O}	76 – 115 ^{O}

Tables 3 and 4 show the results of the analysis of potential risks of operator motion. The Range of Motion (ROM) analysis shows that in general, the upper body segments such as the neck (NF), shoulders (SF), elbows (EF) and back (BF) are in the safe zone for operators A, B and C. This implies that the upper body segment of the pivot-type trailer operation makes the operator comfortable while controlling the tractor.

However, operator D was an exception since the neck (NF) is often in the danger zone. This is because it is necessary to look down when turning to get the position of the auxiliary wheel which assists in turning and the D operator needs to adjust it longer for the use of this pivot type trailer. Therefore, some exercises and adjustments are needed for the operator in using this pivot type trailer.

Furthermore, the lower body segments of operator A such as thighs and knees (which represent the 5th percentile) were shown to be in a comfortable state, because the foot was well rested on the footrest and the knee was not bent. Meanwhile, operators B, C and D were generally in an uncomfortable condition, due to the tendency of the knee to bend during operation, especially for operator B (representing the 90th percentile) that always need to bend the knee during trailer operation because it has a different longer leg size.

The lower part of the body was influenced by the operator's seat height and foot seat. This is because when it is too high, it causes the foot to not tread properly and hang, while when it is too low, it causes the knees to bend and feel uncomfortable. Therefore, a mechanism capable of adjusting the operator's seat height (seat) is needed.

Operators Subjective Analysis Results

Subjective assessment was carried out in the form of filling out a questionnaire to obtain the complaints of the operator on body parts, pain, or discomfort, which is mostly felt when operating a pivot type trailer.

Figure 5 shows the distribution of musculoskeletal discomfort, and it was discovered that the operator experienced fatigue or musculoskeletal discomfort especially in the upper limbs which include the hands, forearms and upper arms by 42%. Furthermore, it was discovered that all operators felt pain in the right and left hands. According to the information obtained from the operators, these pains were due to the stiffness of the clutch lever, which consequently requires a lot of force to press it. Therefore, it is necessary to repair and maintain the clutch in order to solve the problem.

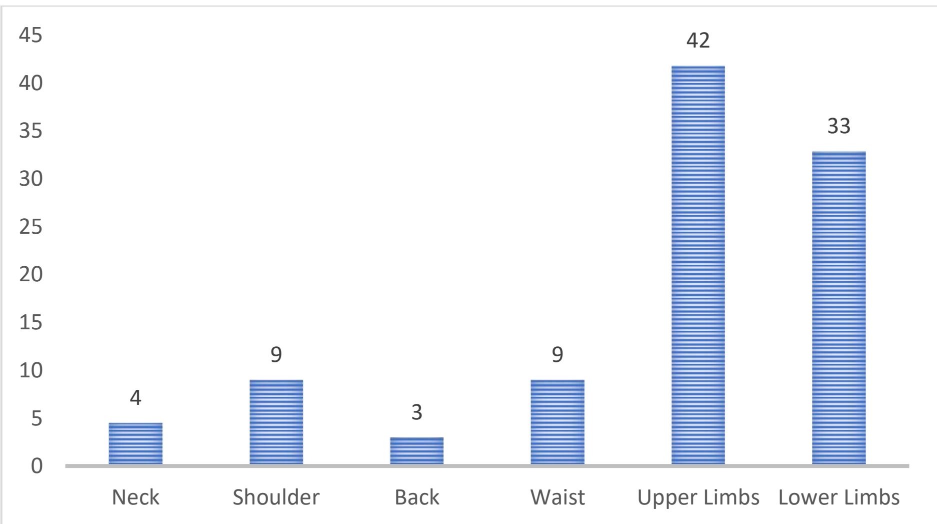

Fig. 5 - Operators subjective perception of complaints on body parts on the pivot type trailer operation

For the lower limbs, which include the thighs, knees, calves and feet, the percentage of discomfort felt by the operators was 33%.

Meanwhile, operator A did not experience any feeling of discomfort, while operators B, C and D experienced it, which may be due to the bending of the knee in other to adjust the seat height. However, this relatively short seat height was comfortable for Operator A, which represents the 5th percentile.

For the limb (waist) which includes the waist, and buttocks, the percentage of discomfort felt was 9%. This was due to the twisting motion on the back when the trailer is in a turning motion. Furthermore, the discomfort felt at the neck and back was 4 and 3%, respectively, due to the turning movements.

In general, the operators had the correct perception of the most uncomfortable body parts. Therefore, it can be used as a basis for making ergonomic interventions to reduce work risks which leads to increased productivity.

Ergonomic Intervention

According to Syuaib *et al*. (2015), ergonomic interventions is carried out to reduce work risks and also increase productivity, by improving work procedures, improving tool design and using personal protective equipment/clothing.

Therefore, based on the analysis of motion and subjective perceptions above, to improve safety and comfort in operating a *pivot type trailer*, some ergonomic interventions are needed, namely:

1. Repairing and maintaining the clutch rotary lever to make it more comfortable for use.
2. Operator seat height (seat)

To increase the comfort during *pivot type trailer* operation, the seat height should be adjustable to the operators' anthropometry because of their different sizes. Therefore, an adjustable seat height mechanism is needed.

According to *Nurmianto (2008)*, seat height based on anthropometric measurements of knee height (*popliteal*), is carried out by adding up the height of the shoes. According to *Bendix (1987)*, the recommended seat height is about 30 to 50mm above the *popliteal* height. Therefore, the recommended adjustable seat design based on Table 5 is a minimum and maximum height of 410 and 490, respectively.

Table 5

Fold height in knee (*popliteal*) and height seat design

Description	High(mm)	
	Fold height in knee (*popliteal*)	High seating design
Percentile 5	365	410
Percentile 50	405	440
Percentile 95	445	490

The recommended adjustment mechanism is shown in Figure 6. The mounting posts were connected to the mounting frame, while the fastener was fixed at the meeting point of the mounting post and frame. Furthermore, to adjust the seat height, the lock lever was relaxed. Therefore, it is possible to pull or press the seat posts axially with the seat frame to adjust the height as desired.

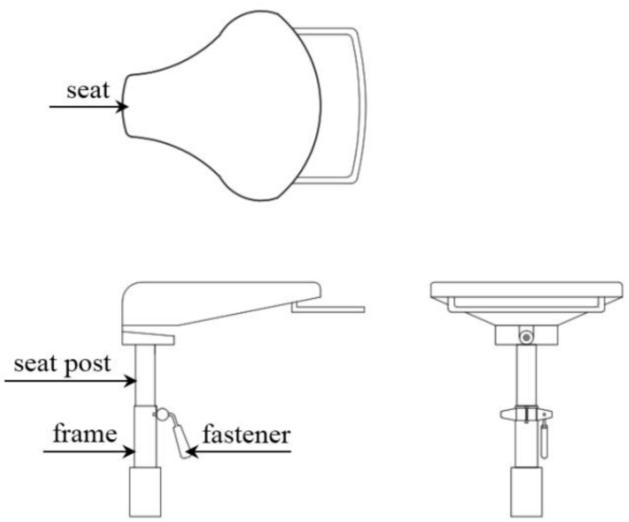

Fig. 6 - Adjustable mechanism on the operator's seat

CONCLUSIONS

1. The results of the motion hose operator analysis showed that in general the operation of the pivot type trailer for the upper body segment, namely neck, shoulder, elbows and back, is in a safe zone for all operators. Meanwhile, for the lower body segment, operators B, C and D's thighs and knees were uncomfortable, while operator A, representing the 5th percentile, was in a comfortable area.
2. The results of the subjective perception of the operators regarding complaints on the most uncomfortable pivot type trailer operating body parts were 42% and 33% for the upper and lower limb, respectively.
3. Ergonomic interventions that are capable of increasing safety and comfort during the operation of the pivot-type trailer include improving the clutch rotating lever, as well as the addition of a mechanism capable of adjusting to the seat height settings of operators.

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