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Simulation of lumbar and neck angle flexion while ingress of paratransit (angkot) in Indonesia as a preliminary design study

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Abstract

This is the preliminary finding of a study to simulate lumbar and neck flexion while ingress to the paratransit. The result of simulation will determine design aspect criteria as a preliminary step before ideation and implementation design steps. Biomechanics of Bodies (BoB) is software that used to represent passenger task during paratransit ingress simulation, with skeleton model that used is height 165 cm and weight 65 kg. Environment to represent this simulation is measured Suzuki Carry SS 2013 as a private car that has been modified into a public transportation in accordance with the Indonesian government road-worthy test. Due to the low height of the entrance and the high ground clearance, lumbar and neck joint angle was a focus of this ingress simulation. The peak angle at the neck joint is 40° when 2 s skeleton nod in the door limitation ingress and lumbar flexion is 70° when 5 s skeleton is walking while bend over that will increase the load on that area. Based on biomechanical simulation approach, we may suggest the dimension of public transportation design framework developments, especially paratransit.

Keywords: paratransits ingress; angkot; product design process; biomechanical simulation.

I. Introduction

Paratransits, which is called Angkot in Indonesia are the connector of larger public transportation vehicle such as bus and train, are very common in developing countries in Asia and Africa. Figure 1 shows the example of paratransit in Bandung, Indonesia, the city that in 2014 has total number 5521 units of paratransit, 39 different routes, and distances between 7 – 24.35 km [1]. The attraction of paratransit to passengers is decreasing due to the increasing number of private vehicles [2], [3]. There are various issues on paratransits in such as limited access for the elderly and passengers with a disability. These vehicles have fixed routes without fixed schedule trip and stop on demand from the passengers; nevertheless paratransits still stand to be a public transportation due to the other factors such as, affordable of the payment rates, individual ownership that allows the development of

Figure 1. Suzuki SS 2014 as one of Bandung paratransit

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small entrepreneurship, as well as the dispersed urban planning spaces for such vehicle to operate. The aspects that are necessary to be given attention in order to improve paratransits systems in many countries are the quality of services, the role of government, the promotion of electric paratransits and integration with mass transit systems and the concept of human mobility as a whole [4], [5].

Existing paratransit standardization refers to the terms of the road-worthiness test according to the Indonesian government rules [6], [7]. In our research centre, there are efforts to improve the paratransits by performing modifications on an existing angkot driven by both environmental and ergonomics issues. The efforts were performed by converting the propulsion system from internal combustion engine into an electric propulsion system and modification of passenger cabin dimension, especially the cabin height to make it more comfortable for ingress and egress [8]. However, it was constrained by the floor of the passenger cabin that was too high due to the light truck basic chassis of the vehicle [8]. It is possible to change the conventional combustion engine paratransit becomes an electric vehicle (EV) with estimating the total energy consumption and demand at each charging station [9]. Mock up scale of future electric paratransit concept has been done with features include folding seat, accommodation of disabilities passenger, priority seat and standing positions. Nevertheless, the concept still used existing high ground clearance without considering standardization measurement through systematic human factor study [10]. In a previous study that can be used as a reference, an automated urban mobility system with low floor concept is able to accommodate 12 standing passengers and 12 seats, and an allowance for 1 wheelchair space inside of a compact vehicle of only 5 meters long [11]. In another study, the design concept of paratransits transportation payment was introduced [12]. It was using an integrated payment system based on the distance that recorded from the time when the passenger passes the entrance door and to the time when the passenger leaves the exit door, this effort was performed to speed up the payment process and to reduce traffic congestion [12].

Study of activities that related to the paratransit either the vehicles, facilities, infrastructures, and users, both direct and indirect are the reference for a designer to improve paratransit design [13]. The definition of good designs are designs that can accommodate the needs of users through an empathic designing approach [14]. In this case, those public transportations must accommodate users with special needs such as an elderly user or people with disabilities, and parents with a baby stroller. Thus paratransit design must fulfill "design for all" criteria according to the particular posture, not limited to separated design for the small, mean, or for the tall users [15].

One critical point in passengers' activities while using a paratransit is walking to enter the vehicle or ingress. During ingress, the passenger should flex the trunk and the knee, followed by lifting the foot onto the vehicle entrance. Because of the low height of the entrance and the high ground clearance, ingress can be considered the most uncomfortable activity in the paratransit. The neck flexion degree positions are significantly affecting neck pain cause [16]. Fear of falling as injury factor is the one of elderly risk on mobility activities including stairs issues and walking without assistance [17]. The Biomechanics simulations ingress and egress as a driver scene have conducted to predict an effective motion analysis [18]–[23]. However, behaviours of elderly people and people with an impairment may be difficult to classify in a simulation [24]. We did not find any specific reference with regard to biomechanical study on angkot ingress. However, previous studies have reported the greater low back muscular load during trunk flexion both in static [25] and dynamic [26] condition.

The purpose of this study is to determine and assess biomechanical aspect during ingress of angkot especially to explore the risk of lower back injury, the eligibility of empathic design approach and to provide a preliminary research design to improve the paratransits design in Indonesia by means of computer biomechanical simulation.

II. Research Method

The study plan consists of four main phase process as follows: inspiration, preliminary, ideation and implementation as shown in Figure 2. First step is inspiration process that consists of literature study to make a better paratransit design from the state of the art findings. Design aspect study which consists of ergonomic approach study by performing Biomechanics of Bodies (BoB) simulation is the part of the second phase that is a preliminary phase. Thus, the result of simulation will determine design aspect criteria as a preliminary step for the design improvement. The third step is ideation that consists of design product process; this process is conducted before the final step that is an implementation to make a product, mock-up and prototyping. In this article, we will describe the first two phases of the study plan.

Variables of biomechanical measurement and assessment methods, especially in transportation field could be conducted with some measuring tools i.e. load cell, force plate, pressure sensor, motion analysis,

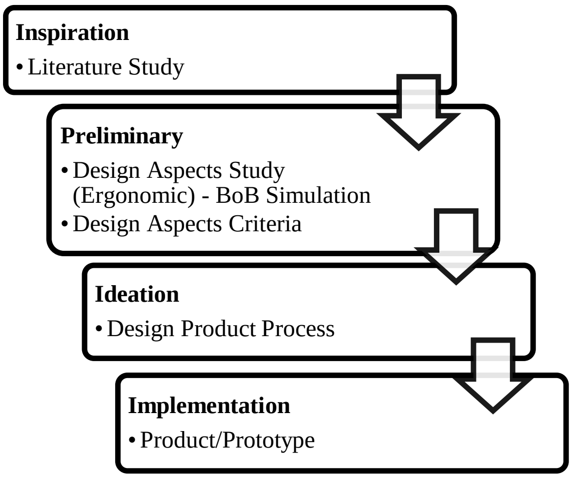

Figure 2. This study methodology

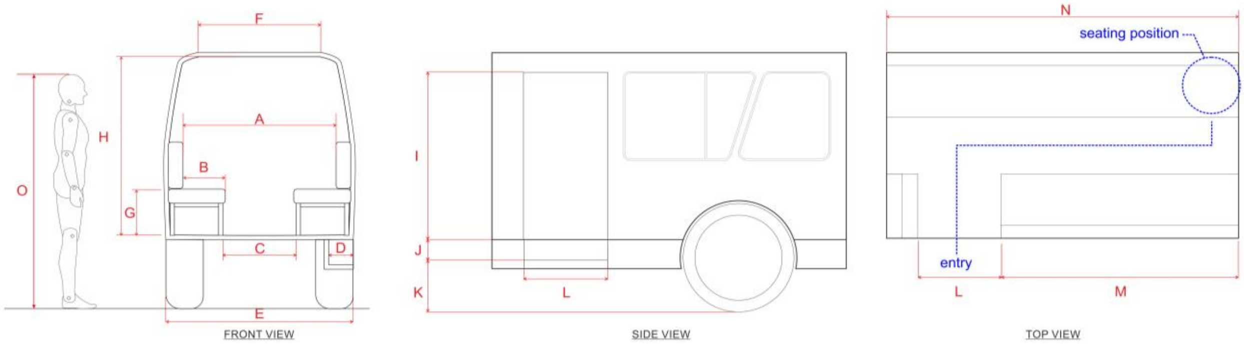

Figure 3. Paratransit and stature of human model measured variables

electromyography, and many more [27]. The study was conducted by measuring some parameters and learn about how to measure time, movement and biomechanics skeleton model when entering paratransit. Computer simulation is used to represent the movement when the passenger takes a step into the paratransit toward the passenger seat. Biomechanics of Bodies software by James Shippen which is usually combined with a motion capture system is used to quickly answer biomechanics issues like dancing, vehicle egress, ingress and many more. Skeleton model has major anatomical components that are representing 31 segments that were connected with 35 joints, 666 locomotor muscle units and maximal isometric load that is characterized [28]–[33].

In this study, we also measured paratransit that was based on Suzuki Carry SS 2013 which is one of the privately owned vehicles that has been operated to be a paratransit in Indonesia, with the aim is to use it as the reference for the environment of biomechanical study simulation. Measurement of body segments movements and joint motion angles are examined with regard to time/second (s), and through the simulation, we determine the peak angle of lumbar and neck angle flexion during paratransit ingress. The data of skeleton and paratransit entrance dimension were used to determine the limit points between the entrance door and head clearance of paratransit cabin ceiling, the height of footstep, the height of the seat cushion and another environment on paratransit as shown in Figure 3. There are anatomical body landmarks that are specifically calculated based on time, axis, transition and rotation which include head, neck, shoulder, elbow, hip, pelvis, lumbar, knee and ankle.

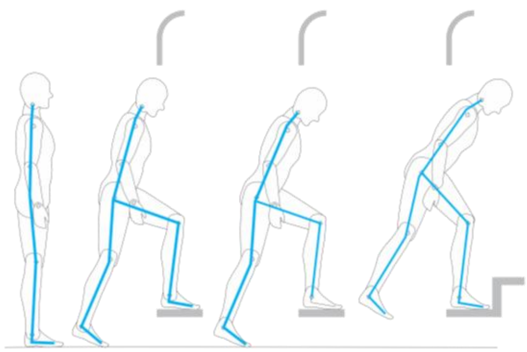

Figure 4. Paratransit ingress joint angle points

The components of paratransit dimension that related to ingress activity were also measured as shown in Figure 4. The components include inner width between back cushion, depth of seat cushion, inner width between base cushion, width of entrance sidestep, vehicle width, interior ceiling width, seat height, height of passenger cabin, height of door from cabin deck, height of entrance sidestep, sidestep height from ground, width of entrance door, length of left base seat and length of right base seat. The measurement was intended to know spatial limitations in simulating body movements as shown in Table 1.

Figure 5 shows that for this study, the simulation was using the Biomechanics of Bodies, custom-built software which was developed within Matlab® (The MathWorks Inc™) environment. Skeleton model that was used in the simulation assumed with height 165 cm and weight 65 kg without age specification option provided, which represents 50th percentile of Indonesian anthropometric [34]. The direction of rotation and axis displacement of the human body model was simulated according to the coordinates in the three axes of X, Y, and Z. Red arrow is X-axis, the green arrow is Y-axis, and blue arrow is Z-axis. For joint angles articulation in non-translation movement,

Table 1.
The dimension of Suzuki Carry SS 2013 paratransit and human model

Variable	Measured Variable	Dimension (cm)
A	Inner width between back cushion	103,5
B	Depth of seat cushion	31
C	Inner width between base cushion	72,7
D	Width of entrance sidestep	19,5
E	Vehicle width	139
F	Roof width	90
G	Seat High	28
H	Height of passenger cabin	129
I	Height of door from cabin deck	107
J	Height of entrance sidestep	25
K	Sidestep height from ground	37,5
L	Width of entrance door	69,5
M	Length of left base seat	144
N	Length of right base seat	230
O	Stature of BoB model	165

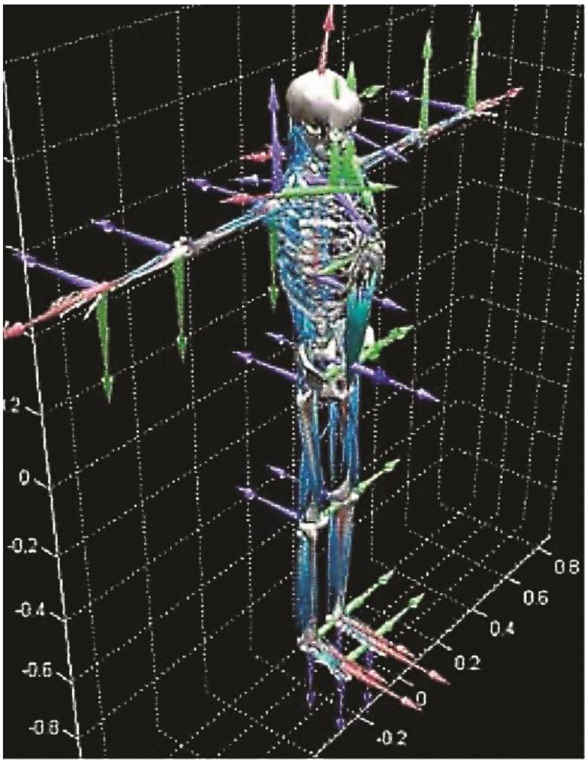

Figure 5. BoB skeleton model axis [30]

red arrow represents axis 3, green arrow represents axis 2, and blue arrow represents axis 1.

The ingress of paratransit period used in the simulation was that it was conducted within 12 seconds (s) duration. The commands and movements were customized with regard to the time axis, coordinate transitions and joints angle rotation that makes the skeleton model of the body able to represents the movement in the paratransit ingress more realistically. We consider the dynamic postures during movement can be calculated by a series of static postures during certain time references.

III. Result and Discussion

Figure 6 illustrates the overall neck joint angle while paratransit ingress movement for the period 12 s while entering the paratransit. Neck angle peak achieved in the first 2 s that is 30° and withstand up to 3 s that is beginning to enter the paratransit passenger cabin door. Afterward, a slight reduction to 20° was occurred on the last 4 s and then stable up into 11 s when walking into the inside of paratransit and eventually fell back down to 10° in 12 s, i.e. while sitting in the vehicle. This data suggest that the greatest neck flexor muscles load occurs at the earliest stage of ingress. Neck flexion or cranio-cervical flexion among people with chronic neck pain has been reported to affect postural control and proprioception [35]. Cranio-cervical flexion also affects gaze. Thus, the awareness of head position is also affected, which may be hazardous during entering a narrow place like the paratransit. The condition of pressure and isometric strength of neck flexors and extensors muscles are also reported to be closely related to certain type of a headache [36], [37]. The difficult situation in ingress is

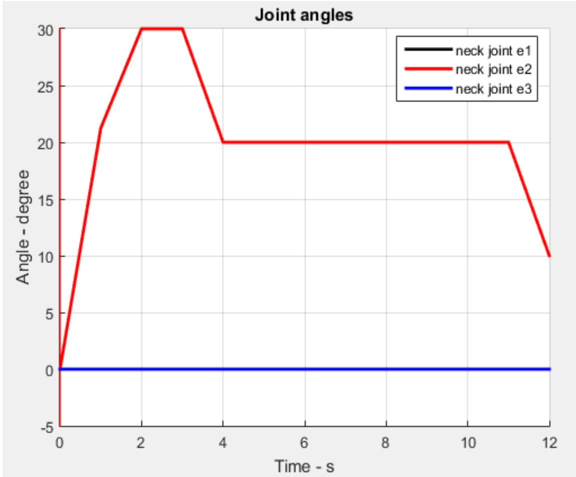

Figure 6. Neck joint angle flexion Axis-2 (red) while ingress paratransit results

not only faced by subjects with chronic neck pain, but also by healthy subjects with neck flexor muscles fatigue [38]. We speculate that the narrow design of the paratransit ingress can be harmful to users with the limitation on neck muscles condition as well as the subject with the larger size of anthropometry.

Figure 7 shows that the lumbar joint angle flexion was increasing from 0° to 30° in 3 s during the early stage of entering the paratransit, when the body is positioned to start to take a step into the side steps of paratransit. The position of other body landmarks are: left ankle axis1 (-10°), left hip axis2 (15°), right hip axis2 (-60°), left hip axis2 (15°), left shoulder axis1 (90°), left shoulder axis2 (-30), right shoulder axis1 (-90°), right shoulder axis2 (15°), left elbow axis1 (-60°), right elbow axis1 (-60°), neck joint axis2 (30°), left front head axis2 (15°), and pelvis transition-x (0.3°). At the 5 s time point, the peak of the lumbar joint angle flexion is up to 70° where the position of pelvis translation-x (0.5°), pelvic transition-z (0.4°) and pelvic rotation-z (-90°), which means that the body orientation was turned to the right with the turning radius 90° toward the seating position. Lumbar joint angle began to decline dramatically in the last two seconds after the time point of 10 s which is the body orientation was

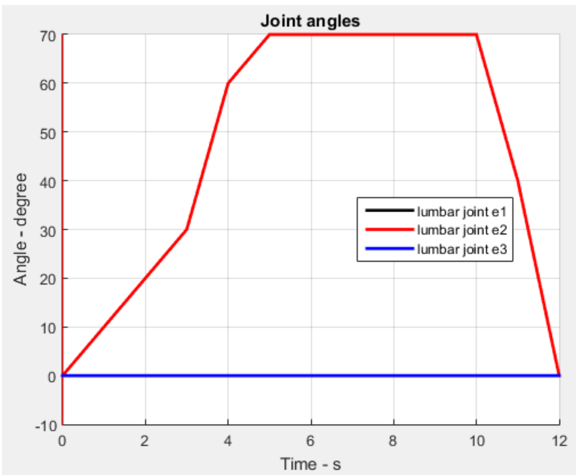

Figure 7. Lumbar joint angle flexion Axis-2 (red) while ingress paratransit results

rotated to 180°, preparing to sit down after turn, and adjusting the direction of seat position, with joint motion data as follows: lumbar joint axis2 (70°), left hip axis2 (-10°), right hip axis2 (20°), right knee axis2 (20°), left knee axis2 (20°), left shoulder axis1 (90°), left shoulder axis2 (-30°), right shoulder axis1 (-90°), right shoulder axis2 (-30°), pelvis trans-x (0.7°), pelvis trans-y (-0.7), pelvis rot-z (-180°), neck joint axis2 (20°), left ankle axis1 (-10°), and right ankle axis1 (-10°). Lumbar position at the time point of 12 s is the last lumbar position to 0° that have been in seating position on paratransit seat, with the joint motion data as follows: right hip axis2 (-120°), right knee axis2 (120°), left knee axis2 (120°), left shoulder axis1 (90°), left shoulder axis2 (0°), right shoulder axis1 (-90°), right shoulder axis2 (0°), pelvis trans-X (1.2°), pelvis trans-Y (-0.7°), pelvis trans-Z (-0.2°), pelvis rot-Z (-180°), neck joint axis2 (10°), and left hip axis2 (-120°). Meanwhile, the angle of both of knees axis are flexed up to (120°), both hips (-120°) and both ankles (-40°) while seated and trip with paratransit.

In a previous study on static postures, lumbar flexion angles were found to be linear with lumbar erector spinae muscular activation up to 45° [25]. Erector spinae muscle is responsible for maintaining body posture with regard to balance during locomotion [26], [39]. The data of this simulation study may suggest that the greatest muscle load occurs right after the entrance to right before taking a seat.

In a coordinated movement, a movement of one part of the body will affect the other part. The spinal condition has been reported to interact with both upper and lower limb muscle with regard to fatigue [40]. Gait characteristics also affect lumbar muscular load [41], [42]. Step width was also reported to be related to flexion-relaxation phenomenon of the lumbar muscles [43]. Therefore, the narrow width of the entrance provides another challenge for the passengers. As both lumbar and neck flexor-extensor muscles are very crucial for maintaining balance, walking while stooping inside the paratransit should require greater work from those muscles. Moreover, the anthropometry data of many subjects with distinctive characteristics, like Indonesia as a country of angkot user, should be measured on every particular body parts [44].

IV. Conclusion

This study shows that it is possible to make a simulation using software Biomechanics of Bodies to measure ingress lumbar and neck angle flexion while ingress of paratransit in Indonesia. The data show that the largest angle at the neck joint for cervo-cranial flexion is 30° which occurs between the 2 s to 4 s due to narrow entrance and lumbar flexion is 70° started at 5 s from the start of walking due to bending the trunk over that increases the lumbar muscular load.

Based on this biomechanical simulation, we may suggest that the dimension of the entrance of the existing paratransit is very narrow and may lead to greater musculoskeletal load for the passengers. As a preliminary study, we have suggested that the dimension of the entrance and passenger cabin on public transportation design development especially angkot should be enlarged so that the passengers do not have to flex their body parts excessively.

Biomechanical simulation allows the consideration to improve the paratransit design based on human factors data in a more rapid and efficient way. However, as this study is still at the preliminary stage, further studies are required. In the future, we will enhance more simulation of various anthropometry data followed by laboratory experiment using motion capture system and electromyography (EMG) analysis to makes more accurate analysis. As the software of BoB is still under development, its quality will be improved by comparison between simulation and laboratory experiment.

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