

# **An Ergonomic Design of Motorized Tricycle in the Philippines**

**Ma. Janice J. Gumasing and Jonas Liao**

School of Industrial Engineering and Engineering Management

Mapua University

Intramuros, Manila, Philippines

[mjgumasing@mapua.edu.ph](mailto:mjgumasing@mapua.edu.ph), [jliao@mymail.mapua.edu.ph](mailto:jliao@mymail.mapua.edu.ph)

## **Abstract**

Motorized tricycles are local form of auto rickshaw in the Philippines. These are a common means of public transport in the country that transport in small towns and cities, especially in the rural areas. Motorized tricycles are built in a variety of styles, which differ from city to city, and are usually made locally by building a sidecar and affixing it to a motorcycle. Passenger tricycles can accommodate from four passengers to as many as six excluding the driver. However, the passengers of tricycles are commonly subjected to awkward postures and uncomfortable environment that can cause discomfort and musculoskeletal disorders. According to Philippine Statistics Authority, there are 4,488,507 registered motorized tricycles in the country. 853,075 of these are operating in National Capital Region. The increasing number of tricycles are brought about by increasing volume of commuters in the country. This also translated into higher number of passenger complaints on their experience of discomfort and musculoskeletal disorders when riding the tricycle. Given these conditions, the paper aims to assess the current design of motorized tricycle in the country, identify factors that affect the discomfort level of passengers in riding the tricycle and come up with an ergonomic design of motorized tricycle that would be a standard blueprint in the Philippines. Although passenger comfort is a crucial indicator of service quality, existing studies tend to focus only on the design of cabin or vehicle body that takes into account the postural condition of passengers. Therefore, the researchers have conducted review of related literature, direct observation, surveys, interview, and use of ergonomic assessment tools in order to examine factually and accurately the passengers' discomfort level based on numerous factors such as postural condition, environmental condition, road condition and health condition of passengers. Statistical analyses such as correlation, stepwise regression technique, and residual analysis were performed in order to determine the factors affecting the discomfort level of passengers. Finally, quality function deployment matrix was used to determine customer requirements that will be considered in the ergonomic design of motorized tricycle. Key findings in the study revealed that factors that affect the discomfort level of passengers in riding the tricycle are the following: sitting height, hip height, hip breadth, buttock-popliteal length, popliteal height, noise level, heat index, vibration level, and travel duration. The authors were able to come up with an ergonomic design of motorized tricycle that considered all the factors the appeared significant in the study. The researchers applied the principles of anthropometry in the design in order to match the critical dimensions of the tricycle to the body dimensions of passengers.

## **Keywords**

Motorized tricycle, ergonomic design, musculoskeletal disorder, discomfort

## **1. Introduction**

Commuting in the Philippines is very much a part of the Filipino lifestyle. Riding motorized tricycles is a common mean of passenger transport everywhere in the Philippines. They transport in small towns and cities especially in the rural areas. Motorized tricycles are built in a variety of styles, which differ from city to city, and are usually made locally by building a sidecar and affixing it to a motorcycle. Passenger tricycles can accommodate from four passengers to as many as six excluding the driver. Due to its small size, structure and capability to drop passengers off a specific point, it is one of the most preferred vehicle of passengers (Dorado, Fabros and Rupisan, 2015). According to Philippine Statistics Authority, there are 4,488,507 registered motorized tricycles in the country. 853,075 of these are operating in National Capital Region. The increasing number of tricycles are brought about by increasing volume of commuters in the country. Unfortunately, the increased volume of commuters has also translated

into higher number of complaints from passengers on experiencing discomfort and musculoskeletal disorders (Gumasing and dela Cruz, 2018).

Comfortability is one of the main aspects in the field of ergonomics and a thriving application of this study is on public utility vehicles where most of the population is affected. Passenger comfort is an important index that can be used to measure the quality of public transport services and a crucial factor in residents' choice of traffic mode (Dell'Olio et al. 2011; Eboli and Mazzulla 2011). Comfort is one of the key factors leading to high service quality and significantly influences passenger satisfaction with public transportation. (Eboli and Mazzulla 2007, 2009; Gumasing).

Comfort of public transport is mainly controlled by worldwide accepted quality standards. One of these standards is EN 13816, accepted by the European Union, it is a service standard in public transportation which evaluates the satisfaction level of passengers over a range of factors such as convenience, accessibility, time/duration, customer care, ride comfort, security and environmental effects. Ride comfort is defined as usability of facilities, riding comfort, ambient conditions, complementary facilities, and ergonomics. Another standard, ISO 2631-1 is related to mechanical vibration and knock, and is interested in investigating the vibration of human body. This standard is generally the basis of comfort indexes used in technical design studies (Imre and Celebi, 2016).

The design of public transport vehicle has progressed considerably in the last two decades, mainly in the area of the comfort and security of the passengers. In European countries, USA and many other countries, there are standards and regulations in order to prevent accidents and to assure the minimum conditions of comfort and safety of users (Marquez and Garcia, 2004). However, in the Philippines, there is an absence of comprehensive policies regarding the standard design of public vehicles. These lack of policies and regulations result to varying design and sizes of public vehicles in the country. Therefore, several factors must be considered in order to satisfy the passenger's requirements such as age, gender, stature, weight and mobility. The population of passengers varies in terms of these factors especially for individuals with physical limitations and disabilities and population segments of elderly and children, who are naturally susceptible to musculoskeletal disorders and discomfort. (Marquez and Garcia, 2004; Gumasing et al., 2020).

There have been many published studies that dealt with improving tricycle design in an ergonomic approach. However, exposure data are minimal. Majority of the studies focused only on the design of cabin or vehicle body that takes into account the body postures and dimensions of passengers. However, none of the studies dealt with the overall improvement of the tricycle design that takes into consideration other risk factors such as environmental conditions, health conditions and road conditions.

Dorado, Fabros and Rafanan (2015) studied the factors that contribute to discomfort of passengers in riding tricycle during 3 phases: embarking, riding and disembarking. However, the factors considered in the study are only anthropometric measurements of passengers. Using multivariate analysis and logistic regression, the correlation between anthropometric measurements and perception of discomfort were determined. The results showed that the two significant factors in passenger discomfort were sitting height and popliteal height of passengers.

Godoy (2015) also developed a study to analyze the variability in design of the tricycles in Lipa City, Philippines and proposed a standard ergonomically designed tricycle sidecar seat for the greater population. Using the design for the average and design for the extremes, it was found out that most of the tricycles in the area have inappropriate inclined seat and lowered sidecar seat pan height which resulted to leg and abdominal pain of passengers. Narrowed seat pan depth also caused pressure on buttocks and legs; narrowed backrest width caused upper and lower back pain while low backrest height caused upper back pain and neck pain due to inappropriate cabin dimension. Therefore, the researcher proposed a sidecar seat design standard, however, the study only focused on the anthropometric measurements of passengers and failed to consider other factors that may affect comfortability of passengers.

Based from the review of related studies, various sub-factors can affect the comfortability of passengers when riding a transport vehicle. The sub-factors for environmental conditions include noise, illumination, temperature, vibration, travel duration and travel frequency. Similarly, sub-factors for health conditions include age, gender, body-mass index, blood pressure and smoking habits. And sub-factors for road conditions include type of roadway, road character, speed, time of day, weather and traffic. However, the identified sub-factors were not yet considered and verified as significant contributors to the comfortability of passengers in riding the motorized tricycle in the study. That is why the researchers intended to examine passengers' discomfort level in riding motorized tricycle based on the identified

sub-factors, which are classified under major factors such as (1) postural condition, (2) environmental condition, (3) road condition and (4) health condition.

### **1.1 Objectives**

Based from identified factors, the researcher proposed to design an ergonomic motorized tricycle for Filipino population in order to reduce the discomfort level of passengers and minimize risks for musculoskeletal disorders. The paper initially intended to assess the current design of tricycle in the country in terms of the following: foot step height, seat height, seat depth, seat width, roof height, leg clearance and overall dimension. Furthermore, the paper aimed to determine the discomfort and musculoskeletal disorders experienced by passengers in riding the motorized tricycle using ergonomic assessment tools. The study also intended to determine significant factors affecting the discomfort level of passengers in terms of the following factors: (1) postural condition: body postures during embarking, riding and disembarking; (2) environmental condition: noise, illumination, temperature, vibration, travel duration and travel frequency; (3) health condition: age, gender, body-mass index, blood pressure and smoking habits; and (4) road condition: type of roadway, road character, speed, time of day, weather, and traffic. Finally, the paper proposed to come up with an overall ergonomic design of motorized tricycle based on significant factors identified in the study using statistical analyses and quality function deployment tool.

## **2. Methods**

The researchers conducted the study among the different areas in Metro Manila wherein large numbers of tricycle operators were located. The participants of the study included tricycle drivers, tricycle operators and passengers. A total of 300 participants were involved in the study including 200 passengers, 22 operators and 78 drivers.

To carefully process and select the factors that will be considered in the study, the researchers conducted a thorough investigation and analysis from previous researches and studies. Moreover, survey forms and questionnaires were administered such as Cornell Musculoskeletal Discomfort Questionnaire (CMDQ) and Nordic Musculoskeletal Questionnaire (NMQ). These tools were used to determine the discomfort location and common types of MSDs among passengers and were used to assess the frequency and extent of pain felt in each body segment during their ride in the motorized tricycle. Next, an onsite observation was done in the study for Rapid Upper Limb Assessment (RULA) to investigate the exposure of the passengers to ergonomic risk factors associated with work-related upper extremity MSD. The blood pressure of each of the respondents and body-mass index ratio were also collected. All other data like noise, illumination, temperature and vibration level were gathered using the apparatuses, devices and instrumentation. Finally, frequency count and rubrics scaling was used to standardize the interpretation of the collected data.

### **2.1. Statistical Analysis**

Descriptive measures were used to provide an analysis of summary of collected data. This helped the researches to come up with analysis and draw appropriate conclusions without bias. Collected data from survey, interview and observations were arranged in a manner of which the data can be easily interpreted through the use of frequency count and percentage distribution.

In addition, the gathered data for factors and sub-factors considered in the study were statistically treated and analyzed using correlation analysis and stepwise regression method. Correlation analysis was used to establish the possible connections between the factors considered in the study to the discomfort level of passengers. Moreover, the significant factors identified were further analyzed using multiple regression analysis to identify the relationship of the predictors and how they affect the discomfort level of passengers. Stepwise backward elimination procedure was also done to simplify the multiple regression equation formulated in the study. This technique was used to identify the true significant risk factors as predictors for the discomfort level of passengers.

### **2.2. Ergonomic Design**

Finally, an overall ergonomic design of motorized tricycle was developed based on the significant factors identified in the study. The authors applied the principles of anthropometry in order to match the dimensions of the proposed design to the anthropometric dimensions of the users. The authors used the data for Filipino manufacturing workers published by del Prado-Lu (2007). Similarly, the authors also used quality function deployment tool in order to determine the immediate needs and requirements of the passengers for the new design of motorized tricycle.

### 3. Results and Discussion

#### 3.1. Summary of CMDQ Scores

The table 1 showed the overall summary of results of the CMDQ from the 300 respondents and ranked from the highest to lowest percentage of risk.

Table. 1. CMDQ Score

Body Part	Ave. Discomfort Score	Risk Level	Percentage (%)	Cumulative Percentage
Hip Buttocks	53.39	Severe	26%	26%
Lower Back	32.8	Severe	16%	42%
Thigh (right)	22.8	Severe	11%	53%
Neck	18.9	Severe	9%	62%
Upper back	11.2	Moderate	5%	68%
Shoulder (right)	10.89	Moderate	5%	73%
Lower leg (left)	8.9	Moderate	4%	78%
Upper Arm (right)	8.9	Moderate	4%	82%
Forearm (left)	7.1	Moderate	3%	85%
Thigh (left)	6.5	Moderate	3%	89%
Shoulder (left)	5.2	Moderate	3%	91%
Forearm (right)	4.3	Mild	2%	93%
Knee (left)	3.8	Mild	2%	95%
Lower Leg (right)	2.8	Mild	1%	96%
Upper arm (left)	2.3	Mild	1%	98%
Knee (right)	1.8	Mild	1%	98%
Wrist (left)	1.6	Mild	1%	99%
Wrist (right)	1.6	mild	1%	100%

Based on the results of CMDQ, the most affected body parts of passengers in terms of discomfort when riding the tricycle are: hip/buttocks, lower back, thigh, neck and upper back. This is due to the sedentary posture of passengers when riding and unsuitable cabin dimension of existing tricycle design.

The researches also evaluated the sitting posture of the passengers to determine their exposure to risk factors associated with work-related upper limb disorders. In this study, the sitting postures were observed using Rapid Upper Limb Assessment (RULA) tool.

#### 3.2. Results of Rapid Upper Limb Assessment (RULA)

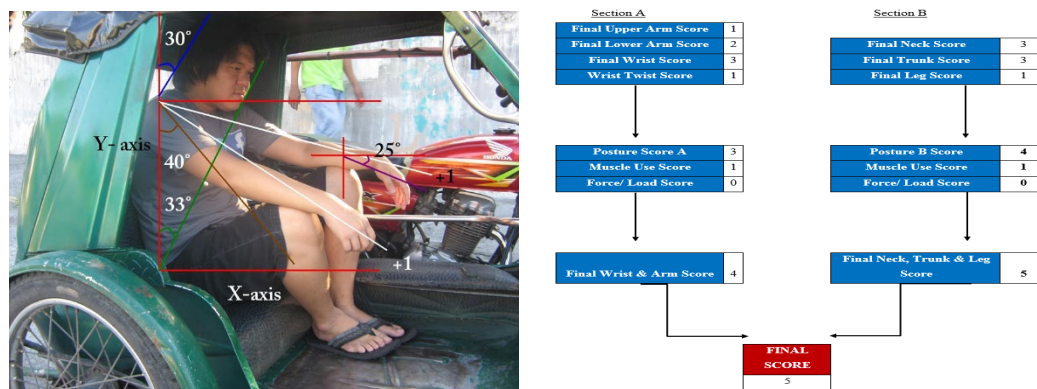


Figure 1. RULA for Cabin Seat Ride

The result of the RULA for cabin seat of tricycle indicated that the current riding posture as shown in Figure 1 pose a medium risk to the passengers and needed further investigation and change in the cabin design soon.

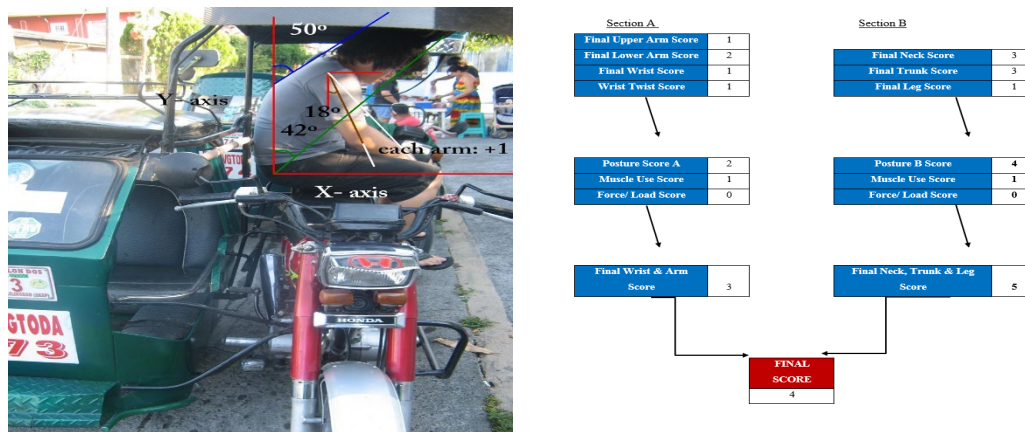


Figure 2. RULA Posture for Backseat Ride

Similarly, the result of RULA for backseat ride indicated that the current riding posture pose a moderate risk to the passengers and further investigation and change are needed as shown in Figure 2.

Table. 2. Overall Summary of RULA Score

RULA Score	Risk Level	Frequency	Percentage	Cum. Percentage
6	medium risk	53	27%	27%
5	medium risk	48	24%	51%
3	low risk	44	22%	73%
4	low risk	23	12%	84%
7	very high risk	12	6%	90%
1	negligible risk	12	6%	96%
2	negligible risk	8	4%	100%

The overall summary of RULA score of 200 passengers reflected in Table 2 showed that majority of the passengers pose medium risk for MSD while riding the motorized tricycle.

All the data gathered from the initial assessment were used by the researchers to analyze the major factors and sub-factors that were considered in the study in order to determine the factors affecting the discomfort level of passengers in riding the motorized tricycle. The summary of the results is shown in the Table 3.

Table. 3. Summary of Frequency Distribution and Rubrics Score for Factors

Postural Condition		
Factors	Rubrics Scale	%
Sitting height (cm)		
< 70	1	9.30%
71-85	2	73.40%
86-100	3	17.30%
Eye height (cm)		
<60	1	5.40%
61-70	2	82.20%
71-80	3	12.40%
Elbow height (cm)		
<15	1	12.40%
16-21	2	63.20%
22-28	3	24.40%
Waist height (cm)		
<15	1	11.80%
16-21	2	68.90%
22-28	3	19.30%
Hip height (cm)		
<10	1	13.60%
11-15	2	73.20%
16-20	3	13.20%
Hip breadth (cm)		
<30	1	12.60%
31-39	2	69.30%
40-48	3	18.10%
Thigh clearance (cm)		
<10	1	8.60%
11-14	2	78.90%
15-18	3	12.50%
Buttock knee length (cm)		
<45	1	6.40%
46-54	2	87.90%
55-63	3	5.70%
Buttock popliteal length (cm)		
<40	1	8.10%
41-47	2	84.20%
48-54	3	7.70%
Knee height (cm)		
<40	1	10.10%
41-48	2	75.40%
49-56	3	14.50%
Popliteal height (cm)		
<35	1	12.80%
36-42	2	81.40%
43-49	3	5.80%
Buttock width (cm)		
<35	1	11.10%
36-48	2	79.30%
49-61	3	9.60%
Length of upper leg (cm)		
<25	1	9.80%
26-36	2	81.50%
37-47	3	8.70%
Length of lower leg (cm)		
<35	1	7.50%
36-45	2	83.40%
46-55	3	9.10%
Thumbtip reach (cm)		
<55	1	21.20%
56-68	2	63.60%
69-81	3	15.20%
Overhead fingertip reach (cm)		
<105	1	18.90%
106-121	2	67.80%
122-138	3	13.30%

Environmental Condition		
Factors	Rubrics Scale	%
Noise level (dB)		
<70	1	3.20%
71-90	2	18.50%
91-100	3	78.30%
Illumination level (fc)		
<100	1	18.00%
101-5000	2	63.50%
5001-10000	3	18.50%
Heat Index (°C)		
<25	1	4.90%
26-35	2	38.40%
36-45	3	56.70%
Vibration level (hz)		
<10	1	0.00%
11-635	2	31.40%
636-1255	3	68.70%
Travel duration (mins)		
<10	1	12.30%
11-30	2	74.20%
>30	3	13.50%
Travel frequency (times/day)		
1	1	54.30%
2-3	2	38.90%
>3	3	6.80%

Health Condition		
Factors	Rubrics Scale	%
Age		
<10	1	6.70%
11-25	2	34.50%
26-40	3	31.20%
41-55	4	19.80%
>56	5	7.80%
Gender		
Female	1	56.00%
Male	2	44.00%
BMI		
Underweight	1	8.20%
Normal weight	2	67.90%
Over weight	3	21.40%
Obese	4	2.50%
Blood Pressure		
Low blood	1	10.80%
Normal	2	75.80%
High blood	3	13.40%
Smoking habits (times/day)		
0-1	1	75.70%
2-3	2	12.40%
>3	3	11.90%

Road Condition		
Factors	Rubrics Scale	%
Roadway		
One-way	1	23.20%
Two-way	2	41.20%
Multiple ways	3	35.60%
Road Character		
Straight	1	56.10%
Inclined	2	12.80%
Curved	3	31.10%
Speed		
<20	1	20.00%
21-40	2	48.90%
>40	3	31.10%
Time of Day		
Morning	1	54.10%
Afternoon	2	23.10%
Evening	3	20.70%
Midnight	4	2.10%
Weather		
Sunny	1	79.80%
Cloudy	2	11.20%
Drizzle	3	2.30%
Moderate Rain	4	5.30%
Heavy Rain	5	1.40%
Traffic		
No vehicle	1	3.20%
Light traffic	2	12.50%
Moderate traffic	3	53.80%
Heavy traffic	4	30.50%

The result of the descriptive data from the subjects indicated that for postural condition factors, majority of the subject have sitting height of 71-85 cm, eye height of 61-70 cm, elbow height of 16-21cm, waist height of 16-21 cm, hip height of 11-15 cm, hip breadth of 31-39cm, thigh clearance of 11-14cm, buttock knee length of 46-54 cm, buttock popliteal length of 41-47 cm, knee height of 41-48 cm, popliteal height of 36-42 cm, buttock width of 36-48 cm, upper leg length of 26-26 cm, lower leg length of 36-45 cm, thumb tip reach of 56-68 cm and overhead fingertip reach of 106-121 cm. Similarly, data for environmental condition factors showed that majority of passengers are exposed to noise level of 91-100 dB, illumination level of 101-5000 lux, heat index of 36-45°C, and vibration level of 636-1255 hz. They travel on the average of 11-30 minutes once a day. Additionally, for road condition factors, majority of the data showed that passengers travel on two-way road, which is straight having a speed of 21-40 kph. Majority of the passengers travel during the morning in a sunny weather with moderate traffic. Data also showed that for health

condition factors, average age of passengers is 11-25 followed by 26-40, there are more female passengers than male, majority of them have normal weight and normal blood pressure and they smoke 0-1 time a day.

### 3.3. Results of Statistical Analysis

All major factors and sub-factors considered in the study were statistically treated using statistical analysis. The result of correlation analysis showed the relationships of factors to the discomfort level of passengers in riding the motorized tricycle. The Pearson correlation measured the strength and direction of relationship between factors identified in the study. The summary of correlation result is presented in the Table 4.

Table. 4. Results of Correlation Analysis

Postural Condition		Environmental Condition		Road Condition		Health Condition	
<b>sitting height</b>		<b>noise</b>		<b>speed</b>		<b>age</b>	
<i>Pearson correlation</i>	0.857	<i>Pearson correlation</i>	0.951	<i>Pearson correlation</i>	0.834	<i>Pearson correlation</i>	0.657
<i>p-value</i>	0.002	<i>p-value</i>	0.000	<i>p-value</i>	0.003	<i>p-value</i>	0.039
<b>hip height</b>		<b>heat index</b>		<b>time of day</b>		<b>BMI</b>	
<i>Pearson correlation</i>	0.728	<i>Pearson correlation</i>	0.974	<i>Pearson correlation</i>	-0.845	<i>Pearson correlation</i>	0.845
<i>p-value</i>	0.017	<i>p-value</i>	0.000	<i>p-value</i>	0.002	<i>p-value</i>	0.002
<b>hip breadth</b>		<b>vibration level</b>		<b>weather</b>			
<i>Pearson correlation</i>	0.99	<i>Pearson correlation</i>	0.983	<i>Pearson correlation</i>	0.823		
<i>p-value</i>	0.000	<i>p-value</i>	0.000	<i>p-value</i>	0.003		
<b>buttock popliteal depth</b>		<b>travel duration</b>		<b>traffic</b>			
<i>Pearson correlation</i>	0.972	<i>Pearson correlation</i>	0.967	<i>Pearson correlation</i>	0.717		
<i>p-value</i>	0.000	<i>p-value</i>	0.000	<i>p-value</i>	0.02		
<b>popliteal height</b>							
<i>Pearson correlation</i>	0.981						
<i>p-value</i>	0.000						

Based on the results of the analysis, sub-factors that have positive correlation to discomfort level of passengers are sitting height, hip height, hip breadth, buttock-popliteal depth, popliteal height, noise level, heat index, vibration level, travel duration, speed, weather, traffic, age and BMI, which explained that as the values of these factors increased, the level of discomfort of passengers also increased. On the other hand, time of day sub-factors have negative correlation to the comfortability level of passengers, which explained otherwise.

The sub-factors were further analyzed and treated using stepwise regression analysis to verify the true predictors for discomfort level of passengers. Moreover, the equation formulated in the analysis served as the basis for the researcher in developing a new design of motorized tricycle. The Equation 1 showed the general predictive model for the discomfort level of passengers.

$$(1) \\ \text{CMDQ} = 7.4 + 1.381 \text{ sitting height} + 3.991 \text{ hip width} + 1.646 \text{ hip breadth} + 0.5608 \text{ buttock popliteal length} \\ - 3.051 \text{ popliteal height} + 4.125 \text{ noise} - 0.3208 \text{ heat index} + 4.0640 \text{ vibration level} - 0.7033 \text{ travel duration}$$

The model summary for the stepwise regression model incurred an adjusted  $R^2$  of 87.62% that gives a coefficient of correlation (R) value of 0.912, which explained that independent variables in the equation are strong predictors of the discomfort level of passengers. This served as the focus of the researchers in the development of new design for motorized tricycle in the country.

In addition, the researchers validated if the values used in the analyses are normally distributed even after eliminating all the outliers. Figure 3 showed that the residuals CMDQ are normally distributed and the points are randomly scattered around the line, which indicated that there was no violation in terms of normality, which is a requirement for multiple regression analysis.

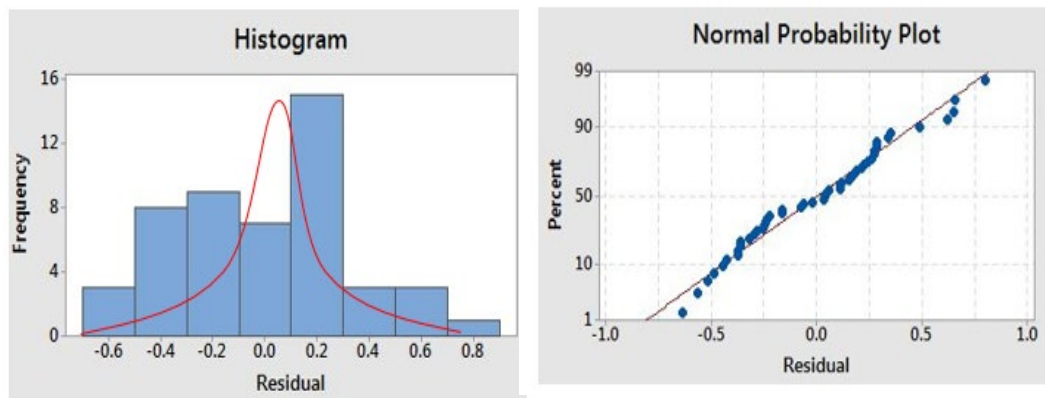


Figure 3. Results of Normality Test

## 4. Proposed Improvements

### 4.1. Ergonomic Assistive Tool for Motorized Tricycle Design Dimension

In order to come up with an ergonomically designed motorized tricycle, the researchers applied the principles of anthropometry and used the data gathered from anthropometric measurements of the passengers. Based from the evaluation, the current design dimensions of the tricycles did not match the anthropometric dimensions of the passengers since tricycle design dimensions are only set by the operators based on their preference and there is no standard design dimension for motorized tricycle set by the Department of Transportation (DoTC). As such, these discrepancies caused discomfort and musculoskeletal disorders on the passengers.

It was also observed that seat height and roof height of the tricycles are too low and are not matched with the sitting height and popliteal height of the majority of the passengers. These mismatch caused discomfort for the passengers especially during embarking and disembarking phase that led to back pain and neck pain of riders. Similarly, seat depth, seat width and leg clearance of tricycle are too narrow especially if the capacity of the inside cabin of tricycle is for three passengers. It was also observed that dimensions are not matched with the elbow-elbow breadth and buttock popliteal depth of the majority of the passengers. These mismatched caused awkward posture for the passengers. These also explained that majority of the passengers are experiencing pain in their hips/buttock, lower back and thigh in riding the tricycle.

Given these conditions, the authors proposed to develop a new design dimension for tricycle based on the postural sub-factors that appear significant to the discomfort level of passengers such as sitting height, hip height, hip breadth, buttock popliteal depth and popliteal height. The following are the proposed design dimension as shown in Table 5.

Table. 5. Anthropometric Measurement of Current and Proposed Dimension of Tricycle

Tricycle Design Dimension	Existing Measurement (cm)	Recommended Anthropometric Measurement (based on published anthropometric data of Filipino population)			
		Body Part	Gender	Percentile	Measurement
Step height	26.1	step height	female	5th %	14.58
Seat height	20.2	popliteal height	female	5th %	36.0
Seat depth	40.4	buttock-popliteal depth	female	5th %	40.0
Seat width	31.3	elbow-elbow breadth	male	95th %	48.0
Roof height	77.9	sitting height	male	95th %	92.0
Backrest height	34.1	shoulder height - popliteal height - buttock popliteal depth	female	5th %	42.0
Leg clearance	63.6	(buttock popliteal depth + popliteal height) - seat depth	male	95th %	59.0



The recommended design dimension is based from the seating design guidelines of American National Safety Institute (ANSI). Based on the guidelines, step height and seat height should be designed for the minimum users and should be low enough so as to reduce pressure on the underside of the thigh. For public seating, seat depth should be designed for the minimum while the width should be designed for the maximum. Seat back should have inclination of 10-30 degrees and seat pan should slope back slightly for weight distribution. There should also be seat cushion of 1.5 to 2 inches thick to support the buttocks and back of the passengers. Roof height should be designed for the maximum in order to minimize bending of neck of passengers and leg clearance should also be designed for the maximum users to avoid pain and numbness of thigh and lower legs. The proposed design of tricycle is illustrated in the Figure 4.

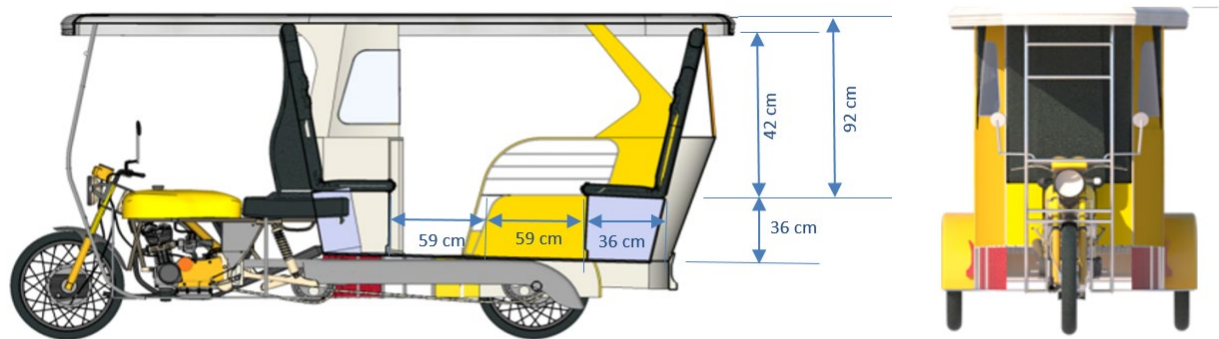


Figure 4. Proposed Design of Motorized Tricycle

#### 4.2 Motorcycle Noise Emission Regulation

Based on the result of statistical analysis, noise level have strong positive correlation to the comfortability of passengers with Pearson value of 0.951. Similarly, it is also considered as good predictor for estimating the comfortability level of passengers having coefficient value of 1.125, meaning an increase of 1dB in noise level will result to 1.125 increase in the CMDQ score of passengers.

It was observed that the majority of passengers of tricycle are exposed to noise level of 91-100dB which is beyond the manageable noise level of 80dB. This is caused by several factors such as motorcycle engine, motorcycle speed, road surface on which it travels, defective and improper use of mufflers and other environmental factors. Such noise levels not only caused discomfort to passengers, but also lead to hearing loss. Unfortunately, Philippines doesn't have an existing noise limit for motorcycles. The best that we have is an obsolete 1977 law that deals with noise regulation for industrial establishments and does not include motorcycles. A recently filed bill dubbed as Muffler Act of 2016 seeks to ban motorcycles and all sorts of vehicles, both public and private, from using modified form of muffler. The bill also sets a noise limit for the vehicles, requiring them to be no louder than 70 dB. However, the bill is not yet approved and still in the process of review and deliberation.

Given these conditions, the authors proposed to develop regulations for tricycle noise emission which governs exhaust system, mufflers and noise control. The proposed regulation will require all motorized tricycle to be equipped with a muffler or other effective noise suppressing system in good working order and will prohibit riders to modify their mufflers and exhaust system. To ensure compliance, authors proposed to Land Transportation and Franchising Regulatory Board (LTFRB), to conduct inspection of the motorized tricycle on a regular basis and implement fines and penalties for violators.

The authors also proposed the adoption of tire rolling noise regulation based on Current Framework of Vehicle Noise Regulation, Ministry of Environment, Japan (2012). Tire rolling noise is mainly divided into the noise owing to tread pattern, such as groove resonance and pattern vibration noise, and the noise owing to other elements, such as vibration noise by irregular road surface and friction. The use of appropriate tire type for motorized tricycles are proven to reduce tire rolling noise to 1 or 2 dB.

#### 4.3. Vibration Reduction for Motorized Tricycle

Vibration level is also considered to have strong positive correlation to the comfortability level of passengers with Pearson value of 0.983 and coefficient value of 0.068. Based on data, majority of the passengers are exposed to 636-

1255 hz of vibration level when riding the motorized tricycle. Exposure to vibration may cause psychological and physical effect on passengers and may cause discomfort and injuries. The vibration are caused by improper engine mounting to the chassis, poor chassis design, inappropriate use of tire type, lack of seat cushion and other environmental factors. Therefore, the authors proposed to LTFRB to conduct regular inspection on the maintenance of engine and chassis of motorized tricycle. Similarly, strict implementation on the appropriate use of tire type for tricycles are also encouraged. Providing cushion on cabin seats are also proposed to support the lumbar spine of passengers. The effectiveness of the seat cushion was qualitatively validated in reducing whole body vibration and musculoskeletal disorders of passengers (Makhssous et al., 2005).

Marul and Karabulut (2012) made a study about the vibration effects of cushions used on tractor driving seat. In their research, three different cushions on driver's seat have been used: wool, sponge and cotton. Pad accelerator receiver is put on seat to record vibration data. It was proven in the study that vibration rate varies on material property of cushion. In three cushions used in the research, wool is the best isolation material because it is more elastic and has energy-absorbing properties. It was verified to decrease vibration intensity of vehicle seat and improve comfortability of riders. Therefore, the authors proposed the use of wool cushion in the cabin seat of motorized tricycle with cushion thickness of 1.5 to 2 inches thick to support the buttocks, lumbar area and back of the passengers.

#### **4.4. Providing Heat Insulation for Motorized Vehicle**

Heat index is also a factor that affects the comfortability of passengers based on the result of statistical analysis. Heat index is defined as the human discomfort index that gives apparent temperature of what human perceive or feel as the temperature affecting their body. It is the temperature which people feel, which is different from the actual temperature of the environment they are in. Based on the data gathered by the reserachers, majority of the passengers are exposed to heat index of 36-45 degrees Celsius. Philippine Atmospheric Geophysical and Astronomical Service Administration (PAGASA) considered the heat index "extreme caution" when the temperature reaches 32 to 41 degrees Celsius. Our body may possibly experience cramps and exhaustion due to heat. People might also experience dizziness, feelings of confusion and loss of consciousness when cramps and exhaustion persist.

Passengers comfort on temperature is assured by factors that depend on the heat exchange between the human body and the ambient environment. As many passengers spend several minutes in tricycles, it is important to provide good thermal environment, which gives comfort and optimizes performance for both drivers and passengers.

One of the commonly used heat reduction method for vehicles is automotive thermal insulation. Currently, there are many types of heat insulators in the market. One of them is the conventional heatshield. It works by deflecting heat away from the affected area. Such shields are usually made of fiberglass, mineral wool, cellulose, styrofoam, polyurethane foam and polystyrene. The materials differ in terms of cost, conductivity, installation, flammability and environmental impact. In the Philippines, styrofoam remains one of the most popular thermal insulation since it is the cheapest compared to other types of materials. It is also lightweight, reusable and versatile. Thus, the author propose the use of styrofoam material for heat insulation for the tricycle cabin. It is more readily available in the market, hence, styrofoam insulators are more affordable. Moreover, the lightweight properties of styrofoam insulators makes it an ideal candidate for tricycle use.

### **5. Conclusion**

From the result of the analysis in the data obtained from 300 respondents of the study, the following conclusions were drawn:

- (1) Using Cornell Musculoskeletal Disorder (CMDQ) questionnaire, it was determined that the passengers experienced pain and discomfort during their ride in motorized tricycle. The most affected body parts of passengers in terms of discomfort when riding the tricycle are: hip/buttocks, lower back, thigh, neck and upper back. This is due to the sedentary posture of passengers when riding and unsuitable cabin dimension of existing tricycle design. It was also validated through Rapid Upper Limb Assessment (RULA) that the sitting posture of passengers using current design of tricycle pose moderate risk for musculoskeletal disorders and must be investigated and changed soon.
- (2) All major factors and sub-factors considered in the study were statistically treated using statistical analysis. Based on the results, sub-factors that have positive correlation to the discomfort level of passengers are sitting height, hip height, hip breadth, buttock-popliteal depth, popliteal height, noise level, heat index, vibration level, travel duration, speed, weather, traffic, age and BMI, which explains that as the values of these factors

increase, the level of discomfort of passengers also increase. On the other hand, time of day sub-factors has negative correlation to the discomfort level of passengers, which explains otherwise.

- (3) The sub-factors were further analyzed and treated using stepwise regression analysis to determine the true predictors for discomfort level of passengers and the following factors were identified: sitting height, hip height, hip breadth, buttock popliteal length, popliteal height, noise, heat index, vibration level and travel duration. The identified factors will serve as the basis for the researchers in developing a new design of motorized tricycle.
- (4) For the ergonomic evaluation of current design of tricycle, it was also concluded that seat height and roof height of the tricycles are too low and are not matched with the sitting height and popliteal height of the majority of the passengers. These mismatch caused discomfort for the passengers especially during embarking and disembarking phase and may lead to back pain and neck pain. Similarly, seat depth, seat width and leg clearance of tricycle are too narrow especially if the capacity of the inside cabin of tricycle is for three passengers. It was also observed that dimensions are not matched with the elbow-elbow breadth and buttock popliteal depth of the majority of the passengers. These mismatched caused awkward posture for the passengers. These also explains that majority of the passengers are experiencing pain in their hips/buttock, lower back and thigh in riding the tricycle.
- (5) The authors were able to come up with an ergonomic design of motorized tricycle that considered all the factors that appeared significant in the discomfort level of passengers. The researchers applied the principles of anthropometry in the design in order to match the critical dimensions of the tricycle to the body dimensions of passengers. In addition, the authors also proposed to implement noise emission and vibration reduction regulations in order to minimize the discomfort level of passengers when riding motorized tricycle. Similarly, the authors also proposed the use of thermal insulators for the tricycle cabin in order to provide good thermal environment for the passengers.

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## Biographies

**Ma. Janice J. Gumasing** is a Professor of the School of Industrial Engineering and Engineering Management at Mapua University, Philippines. She has earned her B.S. degree in Industrial Engineering and a Master of Engineering degree from Mapua University. She is a Professional Industrial Engineer (PIE) with over 15 years of experience. She is also a professional consultant of Kaizen Management Systems, Inc. She has taught courses in Ergonomics and Human Factors, Cognitive Engineering, Methods Engineering, Occupational Safety and Health, and Lean Manufacturing. She has numerous international research publications in Human Factors and Ergonomics.

**Jonas Liao** graduated from Mapua University with B.S. degree in Industrial Engineering. He is a member of Philippine Institute of Industrial Engineers (PIIE) Mapua Chapter and also an active member in Operation Research Society of the Philippines (ORSP) Mapua Chapter. His research interest includes Risk Management, Ergonomics and Human Factors.