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Establishment of Baseline Conditions for Tricycle Research in Tuguegarao City, Philippines

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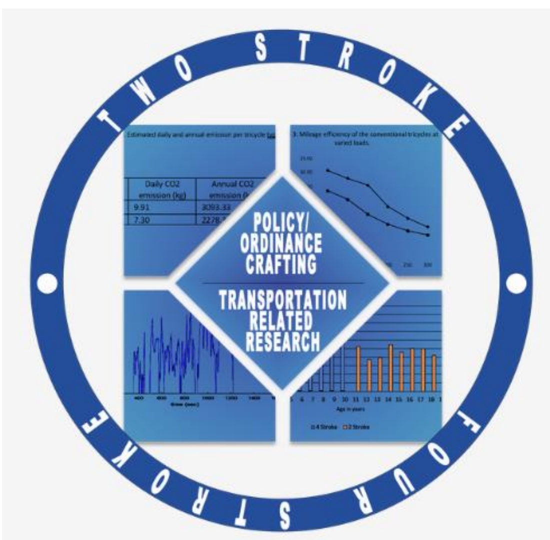
Graphical abstract



Abstract

There are a lot of initiatives to reduce the effect of global warming. In the Philippines, in the sector of transportation, shifting to a modernized mode of transportation (EVs), development of mass transport, and the like are being pushed. However, the effectiveness of each solution cannot be quantified without established baseline information. The objective of this study is to provide baseline information on 2-stroke and 4-stroke tricycles in Tuguegarao City. Experimental test runs are conducted to determine the effect of the general terrain, weight, road gradient, and age on the mileage efficiency of the tricycles. For general mileage efficiency, ten 2-stroke and ten 4-stroke tricycles are deployed on the same routes. Results show that the average mileage efficiency of the 2-stroke is 23.4 km/L, while that of the 4-stroke tricycle is 31.77 km/L. On a flat road, an additional load of one (1) kg on the tricycles decreases the mileage efficiency by an average of 0.4131% and 0.4095% on the 2-stroke and 4-stroke tricycles, respectively. The 4-stroke tricycle is 30% more efficient when tested on inclined roads. There is no direct relationship between the age of the tricycles tested and their corresponding mileage efficiency. A representative drive cycle for each type of tricycle is developed using a microtrip-based cycle construction. A load cycle is also developed based on the representative drive cycles constructed. The results of this paper will be a good input for future transportation-related studies in the city. This could also be the basis of Local government unit (LGU) and other lawmaking bodies in drafting policies related to transportation and environment.

Keywords: *tricycle, drive cycle, microtrip, emission and mileage efficiency*

1.0 INTRODUCTION

The world's population is growing at an exponential rate. To comply with the increasing demand brought about by this population growth, millions of vehicles are assembled and manufactured each year to accommodate these transportation needs. Most vehicles traveling on roads use gasoline or diesel derived from fossil fuel deposits. These fuels are classified as nonrenewable resources and are expected to be depleted soon with the current utilization rate. The increase in demand for mobility also increases air pollution caused by vehicle emissions. The burning of fossil fuels emits pollutants such as carbon dioxide (CO_2), nitrogen oxides (NOx), and hydrocarbons (HC), which are considered major greenhouse gases (GHGs) that cause global warming and eventually lead to climate change.

Several countries have taken actions to mitigate the effects of climate change. [1] Several studies have been conducted to quantify emissions as a basis for environmentally responsible decisions. [2] An initial step to minimize the harmful effects of vehicle emissions on health and the environment is to measure baseline conditions. [3] These baseline conditions can be used to compare and assess the effectiveness of the possible solutions that can be implemented. The first step in the quantification of this baseline condition is to develop the drive cycle, also known as the driving schedule, at the location of the study. A drive cycle is typically a series of speed-time trajectory data points. [4] The driving cycle provides a representative speed-time profile of driving behavior in a specific area or city, which is used to quantify vehicular emissions, fuel consumption, and vehicle driving range. [5,6,7,8] The estimated fuel economies of measured vehicles can be used in the creation of emission inventories and the evaluation of the impact of the use of alternative fuel. [9] Drive cycles had also been used to determine traffic-related parameters. [10] These drive cycles can also serve as a basis for optimization of the design, manufacturing, and assembly of vehicles. [11,12].

City size, road topology, traffic conditions, vehicle ownership, vehicle types, economics, cultures, and geographical features present in each country contribute to the uniqueness of the characteristics of driving cycles in cities and regions. [13] This implies that the location where the study is conducted must have its own drive cycle.

Tuguegarao City is the capital of the province of Cagayan, Philippines, where the regional offices are located. It has a land area of 113.95 square kilometers and a population of 153,502 as of 2015. The city took advantage of its location and the rapidly expanding intellectual and knowledge economy, and as a result, it has been recognized as a digital city in Region 2. [14]

In Tuguegarao City, tricycles are the most prevalent transport vehicle used, and there are 7,067 registered tricycle units. [15] Among these, around 50% are 2-stroke tricycles. Tricycles are modified motorcycles with an attached sidecar used to carry passengers. They are one of the top contributors to air pollution and one of the most inefficient users of gasoline fuel. [16] Tricycles and other gas-powered vehicles' emissions pose a health concern, especially for people who have respiratory ailments.

This paper aims to establish a baseline for assessing the performance of conventional gas-fed tricycles in Tuguegarao City. The objectives of the study are to:

- assess the mileage efficiency of 2-stroke and 4-stroke tricycles under different conditions.
- develop a representative drive cycle of Tuguegarao City.
- estimate the emissions produced by each type of tricycle.

This study will be a good input for local legislators and system planners. The output of the study will be needed in the evaluation of the effectiveness of the proposed transportation modernization plan for the city.

2.0 METHODOLOGY

2.1 Assessment of Fuel Economy

Some factors affecting mileage efficiency are road terrain, driver behavior, and motorcycle specifications such as the size of the engine, year model, weight, and type of gasoline. Testing and data gathering are conducted to determine the effects of 1) the general terrain, 2) the weight carried by the tricycles, 3) the gradient of the road, and 4) the age of the tricycles on mileage efficiency.

To acquire reliable data, ten 2-stroke and ten 4-stroke tricycle drivers from the same Tricycle Operators and Drivers Association (TODA) are requested to take part in the data gathering for the determination of the mileage efficiency of conventional tricycles in Tuguegarao City.

A GPS mobile application is used to record the distance traveled by tricycles for the duration of data gathering. To measure the mileage efficiency of the tricycles accurately, drivers should have their tricycle gasoline tank at full capacity at the start of the data gathering. The amount of gasoline needed to fill the tank at full capacity at the end of data gathering is the total amount of fuel spent.

For the succeeding experiments, one 2-stroke and one 4-stroke tricycle whose mileage efficiency is closest to the calculated average mileage efficiency of the ten previously tested tricycle units of each type are chosen. A flat road section is selected as the location for the testing to verify the effect of weights on the tricycle. The testing site to determine the effect of road gradient on mileage efficiency is composed of three road sections with long, steadily inclining slopes. For each test, the tank of the tricycle is filled until it is full at the starting point. A graduated cylinder is used to fill the tank to full again at the end of the experiment. The amount of gasoline filled at the endpoint is the fuel consumption. Gear shifting and speed during the tests are kept the same as much as possible for consistent results.

The mileage efficiency in kilometers per liter (km/L) is the total distance covered over the total gasoline consumed.

$$ME = \frac{d}{L} \quad (1)$$

Where:
ME : *is the mileage efficiency in km/L*
d : *is the distance traveled in km*
L : *is the gasoline consumed in L*

2.2. Data Gathering for Drive Cycle

Table 1 shows the specifications of the two chosen conventional gas-fed tricycles that are deployed to determine Tuguegarao City's drive cycle. To gather enough data, a six-month deployment is planned. A GPS data logger application is installed on smartphones for data gathering. This device can record instantaneous speeds at one-second intervals over the designated period and route.

Table 1 Specifications of the tricycles deployed.

Parameter	Tricycle Type	
	2-stroke	***4-stroke***
Make Model	Yamaha	Haojue
Years in Service	35 years	7 years
Engine Displacement	100 cc	125 cc
Weight	310 kg	350 kg
Frontal area	2.18 m^2	2.21 m^2
Fuel	Unleaded	premium

2.3 Drive Cycle Methodology

Various approaches are used in driving cycle development based on time constraints, resource availability, and information accessibility. [17]

The microtrip-based drive cycle is used for a better representation of fuel consumption and emissions. [18] A microtrip is defined as a sequence of speed profiles between two successive stops. [19] It is used to break down long trips into smaller segments. These segments are concatenated to produce the drive cycle, whose parameters closely resemble the driving data gathered in a specific region. Figure 1 shows the process flow in the determination of the candidate drive cycle.

The daily data gathered are extracted from mobile phones and stored on a computer. Instantaneous acceleration cannot be obtained directly from the GPS application. The relationship between velocity and acceleration is assumed to be linear between two consecutive data points since the interval is very short. Then the acceleration is computed as:

$$a_{i+1} = \frac{v_{i+1}-v_i}{t} \tag{2}$$

Where:

a : is acceleration in (m/s^2)
v : is the velocity in (m/s)
t : is the time in (s)

Raw data obtained are filtered to remove noise and outliers by adapting the methods described in past research [20]. The filtered data is referred to as the population data set.

The parameters of the population data set are computed and used to validate the generated drive cycles. These parameters are:

a) percent idle
b) maximum velocity
c) minimum velocity
d) average speed
e) average positive acceleration
f) average negative acceleration
g) average running speed
h) speed-acceleration frequency distribution (SAFD)

Percent idle is the percentage of the data set that has zero speed and acceleration values. Maximum and minimum values are obtained by looking at the extreme values of velocity. Average values are the sum of all the data on each parameter divided by the total number of samples. The data included in the computation of average running speed are non-zero speed values. SAFD is a three-dimensional matrix that shows the frequency distribution of speed and acceleration values for a specified range.

Microtrips are generated from filtered data. The first microtrip starts at the beginning of the trip and ends when the speed decreases to zero. These microtrips are concatenated and sorted from shortest to longest until a minimum of 1200-second speed data is reached. Based on the literature, the 1200-second speed data is sufficient to account for an adequate number of microtrips that will reflect the actual driving pattern in a region and is practical to use on dynamometers. [9] The number of microtrips concatenated determines the maximum number of microtrips used to create a drive cycle.

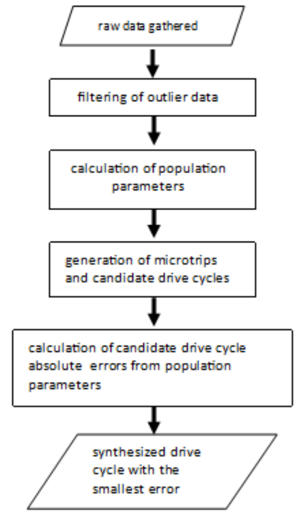


Figure 1 Flowchart for drive cycle development model.

A random number of microtrips based on the maximum number of microtrips identified are performed to generate candidate drive cycles. The parameters of this candidate drive cycle are computed and compared to the parameters of the population data set. The candidate drive cycle with the least summation of absolute error is the final drive cycle.

2.4. Load Cycle Development

The generated drive cycle for each type of tricycle will be used to generate the load cycle. The power needed to be exerted by the tricycle's engines arises from rolling resistance, aerodynamic drag, gravity, and vehicle acceleration. They are computed as follows:

$$F_{total} = F_{Acceleration} + F_{Rolling} + F_{AirDrag} + F_{Gradient} \tag{3}$$
$$F_{Acceleration} = mxa \tag{4}$$
$$F_{Rolling} = mgf_r cos\theta \tag{5}$$
$$F_{AirDrag} = 0.5\rho A_f c_d v^2 \tag{6}$$
$$F_{Gradient} = mgsin\theta \tag{7}$$

Where:

m : mass of the vehicle (kg)
a : vehicle acceleration (m/s^2)
g : gravitational acceleration (m/s^2)
f_r : rolling resistance coefficient
c_d : drag coefficient
θ : angle of inclination
ρ : density of air (kg/m^3)
A_f : frontal area
v : vehicle speed (m/s)

Vehicle speed data and road inclination is obtained from the generated drive cycle.

2.5. Emission Levels

For emissions, laboratory testing using a dynamometer is a commonly used method by researchers. [21] This requires the drive cycle as an input. Remote sensing devices (RSD) and other additional measurement devices were used to measure on-road emissions. [22] On-board instrumentation with the use of a portable emissions measurement system (PEMS) was also available to gather data under real-world conditions at any location and under any weather condition. [23-24]

The pollutant calculated in this study is carbon dioxide (CO_2). Carbon dioxide is a major greenhouse gas that traps heat close to the Earth's surface. Known as global warming, excessive greenhouse gases in the atmosphere will enhance the natural warming of the planet and increase its average temperature.

The researchers have no emission testing equipment and no available local data on the emission factors of 2-stroke and 4-stroke tricycles. The researchers resorted to the use of an emission factor in kilograms of CO_2 per liter of gasoline consumed (kg/L). To have an estimate, the average fuel efficiency of each type of conventional tricycle determined from the ten 2-stroke and ten 4-stroke tricycles described previously is used. The usual distance traveled by tricycles was obtained from the survey.

The daily emission of each type of tricycle in kilograms is computed as

$$emission = \frac{EF \ x \ d}{ME} \quad (8)$$

Where:

EF : is the Emission Factor in (kg/L)
d : is the distance travelled (km)
ME : is the Mileage Efficiency in (km/L)

3.0 RESULTS AND DISCUSSION

3.1 Fuel Economy

3.1.1. Effect of the General Terrain of Tuguegarao City

Tuguegarao City has a relatively flat terrain. In this study, we determine the mileage efficiency of both 2-stroke and 4-stroke tricycles, considering the general terrain of Tuguegarao City. The participants in the data gathering are selected from Carig TODA. Carig TODA is chosen because it covers a more diverse terrain available in Tuguegarao City.. Figure 2 shows the route traveled by the tricycles. All the 2-stroke tricycles that participated in the data gathering use Yamaha RS100 motorcycles. Different models, such as the Kawasaki Barako (175 cc) and Honda TMX (125 and 155cc), participated in the deployment of 4-stroke tricycles. Based on the data gathered shown in table 2, the 2-stroke tricycle has an average mileage efficiency of 23.4 km/L, while the 4-stroke tricycle has an average of 31.77 km/L. Results show that 4-stroke tricycles are 35.76% more efficient than 2-stroke tricycles.

Table 2 Mileage efficiency of the deployed 2 and 4-Stroke Tricycles

Tricycle	Tricycle	Tricycle	Distance	Mileage
	1	1	109.30	23.39
	2	5	80	27.34
	3	5	118.90	31.91
	4	7	117.90	23.75
	5	7	113	34.91
4 Stroke	6	7	106.90	35.46
	7	7	94.60	43.86
	8	10	64.50	32.72
	9	16	89.70	31.62
	10	20	94.90	32.72
	Average	**8.5**	**98.97**	**31.77**
	1	21	82.8	26.33
	2	22	74.5	18.84
	3	22	59.3	19.87
	4	22	103.5	27.42
	5	23	87	23.07
2 Stroke	6	23	107.2	25.28
	7	25	87.2	24.95
	8	27	111.3	21.35
	9	30	116.9	23.54
	10	32	83.4	23.21
	Average	**24.7**	**91.31**	**23.39**

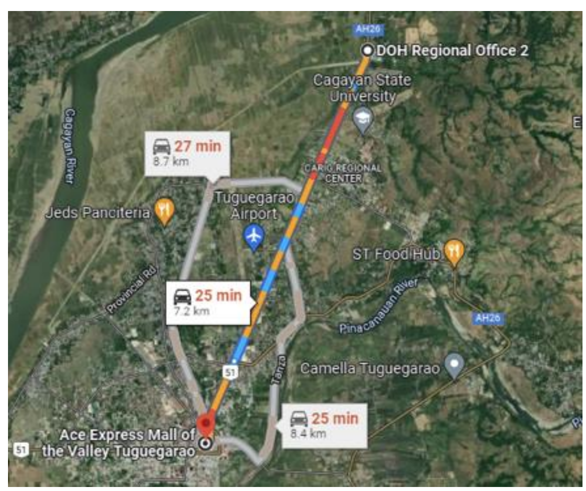


Figure 2 Main route traveled by deployed tricycles.

The calculated mileage efficiency for Tuguegarao City is lower for 2-stroke and higher for 4-stroke compared to the information provided by a study in the estimation of emission and fuel consumption of sustainable transport measured in

Manila [25] (24.41 km/L for 2-stroke and 29.29 km/L for 4-stroke).

The average cost of gas for the 2-stroke and 4-stroke tricycles during data collection was PHP 55.72 and PHP 56.10, respectively. At these prices, 4-stroke tricycles spend Php 1.77 per kilometer, compared to Php 2.38 for 2-stroke tricycles. When compared to a 2-stroke tricycle, adopting a 4-stroke tricycle can save drivers PHP 0.61 per km.

According to a survey, the majority of tricycle drivers put in roughly 8 hours per day, six days per week, and cover about 100 km daily. Under these circumstances, 4-stroke tricycle drivers have a potential annual income advantage over 2-stroke tricycle drivers of about PHP 19,000.00. According to the survey, 4-stroke tricycles have lower operating and maintenance expenses than 2-stroke tricycles. This aspect adds to the advantage of 4-strokes against 2-strokes.

3.1.2 Effect of Weight

The maximum allowable number of passengers in Tuguegarao City is five. The experiment starts with only the driver as the tricycle's base load, then additional weights are added until they total 300 kg, which approximates a tricycle fully loaded with passengers.

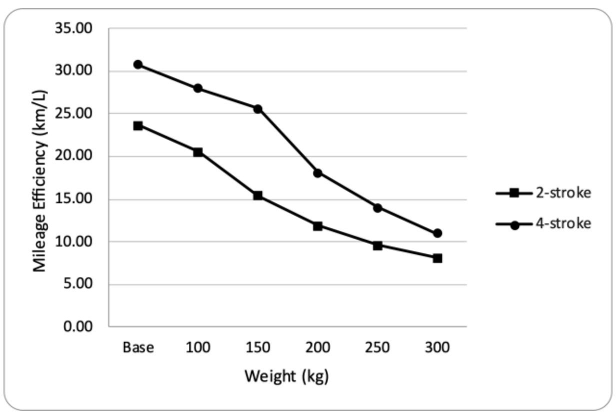


Figure 3 Mileage efficiency of the conventional tricycles at varied loads.

Figure 3 shows the result of the experiment on the tricycles with varied loads. Analysis of the data shows that an additional load of 1 kg on the tricycles decreases the mileage efficiency by an average of 0.4131% and 0.4095% on the 2-stroke and 4-stroke tricycles, respectively.

3.1.3. Effect of Road Slope

Table 3 presents the road inclination of each testing site and mileage efficiency. The driver plus load carried by the tricycles in the data shown is 300 kg. Results show that a 4-stroke tricycle is 30% more efficient, even when tested on inclines.

3.1.4 Effect of Motorcycle Age

Shown in a bar graph in Figure 4 is the mileage efficiency versus the age of the ten 2-stroke and 4-stroke tricycles that participated in the survey.

Table 3 Mileage efficiency of conventional tricycles at different road slopes

LOCATION	Road inclination (degrees)	Mileage (km/L) 2-stroke	Efficiency 4-stroke
Libag-Camela Road	8	2.64	3.41
Camasi-Camela Road	10	2.40	3.11
City hall Road	11	2.04	2.71

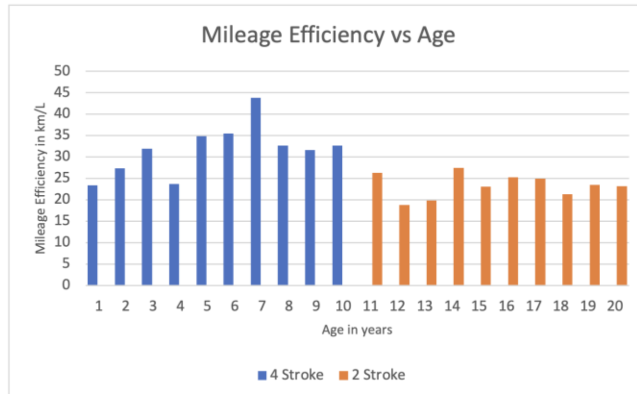


Figure 4 Mileage efficiency versus the age of 2 and 4 Stroke Tricycle

Figure 4 indicates that 4-stroke tricycles are relatively newer and exhibit higher mileage efficiency compared to 2-stroke tricycles. However, this observation does not establish a direct correlation between mileage efficiency and the age of the tricycle. Thus, it cannot be conclusively stated that newer motorcycles consistently have better mileage efficiency than older ones. Other factors, such as the maintenance practices adopted by individual owners, also play a significant role in influencing mileage efficiency.

3.2. Drive Cycle

The source for the drive cycle construction is a six-month data sample obtained from October 1, 2021, to March 31, 2022. Tuguegarao City has a total of 35 registered Tricycle Operators and Drivers' Associations (TODA). These TODAS are clustered based on their routes traveled. The average temperature in Tuguegarao City is 27 degrees Celsius. The windspeed during the data gathering averaged 3 km/h. [26]

Figure 6 shows the generated drive cycles for the 2-stroke and 4-stroke tricycles. When compared with the population data set, the absolute relative error of the 2-stroke drive cycle is 12.61%. The 4-stroke drive cycle has a calculated absolute relative error of 6.58%. Table 4 shows the parameters of each drive cycle. The high percentage of idle time and lower average velocities indicate heavy traffic in Tuguegarao City

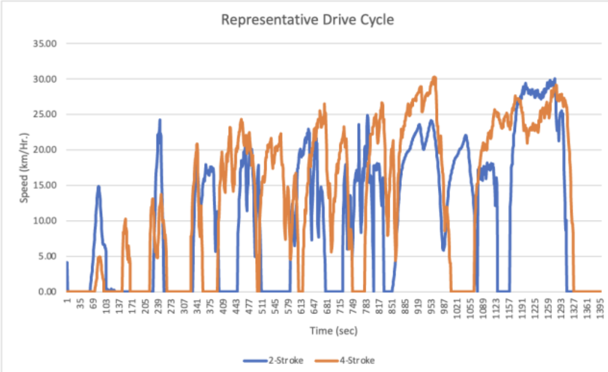


Figure 6 Representative Drive Cycle for 2 and 4-Stroke Tricycle

Table 4 Parameters of Tuguegarao City drive cycle

PARAMETER	Tuguegarao City (2-stroke)	Tuguegarao City (4-stroke)
percent idle (%)	34.86	28.84
maximum speed (kph)	30.06	30.31
minimum speed (kph)	0	0
average speed (kph)	10.76	13.28
average positive acceleration (m/s2)	0.205	0.208
average negative acceleration (m/s2)	- 0.311	- 0.248
average running speed (kph)	16.74	18.83

Two separate studies [3],[27] have been conducted to create a drive cycle for tricycles in Manila. However, the Tuguegarao City drive cycle is relatively slower compared to the other drive cycles presented in Table 5. As the drive cycle serves as the basis for designing cars and estimating mileage efficiency, range, and emissions, it becomes essential to develop a localized drive cycle. This localized drive cycle will enable the creation of more optimized designs, considering the specific conditions of the region. It highlights the fact that a "one-size-fits-all" approach is not suitable for drive cycles. Consequently, the construction of regional drive cycles for baseline data becomes significant.

Table 5 Parameters of Drive Cycle gathered at Manila Philippines

PARAMETERS	Drive Cycle by Abuzo et.al [3]	Drive Cycle by Biona et.al [27]
percent idle (%)	3.69	-
maximum speed (kph)	43	24.3
minimum speed (kph)	0	0
average speed (kph)	19.9	14.15
average positive acceleration (m/s^2)	-	0.30
average running speed (kph)	20.7	-

3.3. Load Cycle

The load cycle, represented by the instantaneous power in kW for both the 2-stroke and 4-stroke tricycles, can be calculated by multiplying the total force, as defined in equation 3, with the instantaneous speed time profile data shown in figure 6 for 2-stroke and 4-stroke. The computation of the load cycle involves other values and assumptions, which are provided in Table 6.

Table 6 Values used for the computation of power developed.

PARAMETER	Value
Gravitational acceleration *(g)* m/s^2	9.81
Rolling resistance coefficient (f_r) [28]	0.011
Coefficient of drag (c_d) [27]	1.0
Density of air (ρ), kg/m^3	1.225
Frontal area (A_f), m^2	2.20
Total driver and passenger weight (kg)	500

Figures 7 presents the load cycle generated for each type of tricycle. The tricycles' average and maximum power outputs for 2-stroke and 4-stroke engines, respectively, are 1.71 kW, 16.5 kW, and 2.45 kW, 17.8 kW. This load cycle is needed to determine whether the motorcycle power rating is sufficient, underrated, or overrated. This could also be a good input later in the design of electric tricycles on how much power is needed by the electric motor.

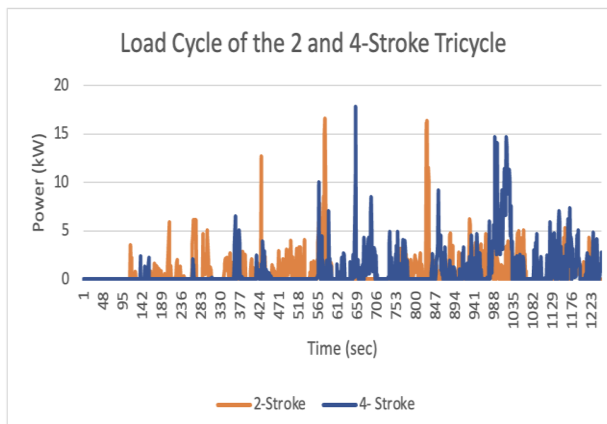


Figure 7 Load cycle using the 2-stroke drive cycle.

3.4 Emission Estimation

Based on a Department of Energy (DOE) report [29], tricycles emit 2.32 kg of CO2 per liter of gasoline. According to the survey, tricycle drivers typically travel around 8 hours daily and cover approximately 100 km. Tricycles in Tuguegarao City are allowed to carry passengers six days a week. Utilizing the emission factor of 2.32 kg per liter, the daily travel distance of 100 km, and the average mileage efficiency of 23.4 km/L and 31.77 km/L for 2-stroke and 4-stroke tricycles, respectively, the emissions can be computed using equation 8. Based on this information, Table 7 displays the daily and annual estimated emissions.

In Tuguegarao city there are 7,067 registered tricycle of which 50% are still 2-strokes. Considering the calculated emission per tricycle type, the total estimated emissions released by tricycles in Tuguegarao City are 18,980 tons of CO2 annually.

A study by Biona et al. reported that a 2-stroke tricycle on average produces 40.5 g/km of CO2. [30] Using this to estimate the emission of 2-stroke tricycles will result in 4.05 kg of CO2 per day. This figure is 60% less than the 2-stroke tricycles' daily calculated emissions in Tuguegarao City. The significant disparity can be attributed to the inclusion of idle time during heavy traffic conditions in the daily emissions calculations of this study. In Tuguegarao City, tricycles have an average idle time of 32% of their total travel time, during which they burn gasoline without covering any additional distance.

Table 7 Estimated daily and annual emission per tricycle type

TRICYCLE TYPE	Daily CO2 emission (kg)	Annual CO2 emission (kg)
2-stroke	9.91	3093.33
4-stroke	7.30	2278.38

In summary, this paper has successfully provided baseline data for the mileage efficiency of both 2-stroke and 4-stroke tricycles, considering the impact of terrain, weight, traffic conditions, and age of the tricycles. Among these factors, three directly affect mileage efficiency, while the age of the tricycle does not have a direct relationship with it. Moreover, the study has developed drive cycle and load cycle models that can be utilized as a foundation for designing and assessing transport vehicles.

The uniqueness of tricycle models and the diverse terrains across regions in the country necessitated the determination and utilization of distinct drive cycles. Lastly, the study has calculated the CO2 emissions for tricycles in Tuguegarao City. This comprehensive set of baseline data can be invaluable for future transportation-related research and can also aid in formulating policies and regulations pertaining to the transport sector.

4.0 CONCLUSION

The findings of this study confirm that 4-stroke tricycles outperform 2-stroke tricycles, with the 4-stroke showing a 35.76% better mileage efficiency. Additionally, both tricycles experience a decrease in mileage efficiency with an increase in load weight and road inclination. However, the age of the tricycle does not significantly impact its mileage efficiency. For owners of 2-stroke tricycles who decide to shift to 4-strokes, they can expect to earn an additional PHP 19,000.00 annually. These compelling results provide strong evidence for 2-stroke owners to consider switching to 4-stroke or more efficient trikes.

Candidate drive cycles for both 2-stroke and 4-stroke tricycles were determined following a 6-month deployment. The findings revealed that the 4-stroke tricycles exhibited higher recorded acceleration, average, and maximum speeds. This outcome is attributed to the 4-stroke's higher power rating in comparison to its 2-stroke counterpart. These drive cycles hold potential for future transportation-related studies, particularly in the sizing of batteries and motors for electric vehicle research.

The study demonstrates that in all the factors considered in the comparison, 4-stroke tricycles outperform 2-stroke tricycles, both technically and environmentally. Despite this evident advantage, it is noteworthy that nearly 50% of the registered tricycles in Tuguegarao City still utilize 2-stroke engines.

The findings of this study hold valuable insights for the Local Government Unit (LGU) of Tuguegarao in crafting supportive policies for transportation modernization. Transitioning to 4-stroke tricycles not only enhances drivers' income but also reduces the negative impact on the environment and public health. Furthermore, this baseline data can serve as a basis for evaluating the effectiveness of future transport modernization projects. Implementing measures to encourage the adoption of 4-stroke or more efficient trikes would lead to sustainable improvements in the city's transportation system and overall well-being.

Acknowledgement

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