

DEVELOPMENT OF EMISSION AND ENGINE TESTING PROCEDURES AND STANDARD SIDECAR DESIGN PROTOTYPE FOR TRICYCLES

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Abstract: The absence of a comprehensive policy to address the problems faced by the local three-wheelers (tricycles) became obvious when the Clean Air Act was implemented in January 2003, requiring all motor vehicles to comply with the exhaust emission standards equivalent to Euro 1. The National Center for Transportation Studies was commissioned to develop standards and baseline references for motorcycles and tricycles to facilitate compliance. The objectives are to a) establish baseline information on tricycle drivers and passengers; b) develop standard configuration in the design for the conversion of motorcycle into tricycles; c) develop emission test protocol applicable to local tricycles; and, d) determine the effects of various fuel-oil mixtures for 2-stroke and 4-stroke motorcycles. A comprehensive study of tricycles and its users across Metro Manila was produced including sidecar designs and prototype, real-road test and chassis dynamometer simulation data.

Key Words: standards, tricycle, emissions

1. INTRODUCTION

The Philippine Clean Air Act (CAA) of 1999 provides that in-use, new, rebuilt and imported

second-hand motor vehicles were required to comply with the emission standards prior to registration starting January 2003. Motor vehicles introduced in the market beginning January 2003 are required to comply with the emission standards equivalent to Euro 1.

Leaded petroleum products were phased out nationwide by the end of year 2000. In unleaded gasoline, the amount of aromatics was expected to be reduced from 45% to 35% maximum and the amount of benzene was expected to be reduced from 4% maximum to 2% maximum, in 2003. In diesel fuel, the sulfur content will be reduced from 0.2% to 0.05% in 2004. With the reformulation of fuel due to the shift to unleaded gasoline with higher octane, tricycle drivers had claimed performance problems such as overheating, greater fuel consumption and costlier maintenance. There also has been the local practice of drivers to use excessive 2T oil as lubricant and mixes the oil with gasoline in the fuel tank that results to greater HC emission levels in 2-stroke engine tricycles. There was also conflicting recommendations where the motorcycle manufacturers recommend 1:20 (1 part of 2T oil in 20 parts of gasoline) while lubricating oil manufacturers recommend a leaner 1:40.

According to the Asian Institute of Petroleum Studies, causes of heavy white smoke emissions are: poor engine condition, low octane or adulterated gasoline, improperly formulated 2T oil and the use of filtered used oil sold as 2T oil. Motorcycle makers like Kawasaki recommend to drivers not to use spark plugs that are under specification (use standard type specified by the model), not to mix 2T oil in gasoline (use auto-lube system), not to use low grade recycled 2T oil (use JASO FB or JASO FC grade) and to do regular preventive maintenance.

In the implementing rules and regulations of the Clean Air Act, the emission standards for CO at idle mode are set for 2-wheeled motorcycles/mopeds (6% for all motorcycles registered on or before December 31, 2002 and 4.5% for all motorcycles registered after December 31, 2002), which are not specific to tricycles that have sidecars with additional load of 2 passengers or more. The standard for HC was set at 7,800ppm by the Technical Committee for the Establishment of Emission Standards for Motorcycles and Tricycles of the Environmental Management Bureau (EMB-DENR).

In April 2002, The Philippine Council for Industry and Energy Research Development (PCIERD) of the Department of Science and Technology (DOST) commissioned the National Center for Transportation Studies of the University of the Philippines to conduct a study on the local tricycles entitled "Standards Development for Local Motorcycle/Tricycle Sector" in order to address the problems encountered by the sector in the implementation of the Clean Air Act.

The objectives of the research project are the following:

1. To establish baseline information on tricycle drivers and passengers;
2. To develop standard design configuration for conversion of motorcycle into tricycles;
3. To develop an emission test procedure/protocol for the local tricycles; and,
4. To determine the effects of fuel-oil mixtures for 2-stroke and 4-stroke motorcycles.

1.1 Scope of the Study

The study is divided into 4 components:

Component 1: Usage and Design Characterization Survey of Tricycle Passengers and Drivers

Component 2: Development of Tricycle Sidecar Design and Prototyping

Component 3: Tricycle Emissions Testing

Component 4: Tricycle Engine Performance Testing

Specifications on the design and conversion of the motorcycle into a tricycle are developed. These specifications and basic features are based on the concepts of ergonomics and materials of construction but the study focused on the ergonomics and safety with inputs from the technical working group, stakeholders such as passengers, drivers and sidecar manufacturers. Interview surveys of drivers and passengers and collection of design specifications, were conducted in several cities in Metro Manila to determine the existing conditions. The results were used as reference in designing the prototypes. Procedures for the testing of tricycles were developed for engine wear and tear, emission level, and noise level.

Engine deterioration of the internal parts of the engine and other maintenance indicators are qualitatively assessed after the engine performance tests to assess the effects various fuel-oil mixtures and engine types on performance. Engine and exhaust temperatures are measured to verify claims of overheating when using unleaded gasoline.

Emission testing of tricycles (2-stroke and 4-stroke engines) and the various fuel-oil mix ratios are conducted to quantify HC and CO emissions from tricycles in controlled laboratory conditions. The test included petroleum-based 2T oil and plant-based 2T lubricant called the "coco-methyl ester" or CME. Noise levels are measured from the test tricycles at various speeds and loads on the laboratory chassis dynamometer.

2. USAGE AND DESIGN CHARACTERIZATION SURVEY OF TRICYCLE PASSENGERS AND DRIVERS

Tricycle usage in the Philippines is widespread. No other transport mode can compete with the tricycle in terms of practicality, efficiency and convenience. There is not enough data on tricycle ergonomics in the country. This seminal project serves as a starting point for design standardization and provides baseline data for further research regarding tricycle design. The increase of tricycle units in the country has been attributed to various factors. Rapid urbanization has taken place in many areas along with higher incomes and vehicle acquisition. Figure 1 shows the historical trend of the number of motorcycles/tricycles registered in Metro Manila from 1980 to 2003 and it has grown almost 5 times from less than 41,606 in 1980 to 211,450 (15% of total vehicles) in 2003. Figure 2 shows the share of motorized vehicle trips based on the MMUTIS Study in 1996 where almost 27% were attributed to tricycles.

2.1 Survey Methodology

Two sets of survey questionnaires were developed and administered across Metro Manila in July 2002. It was completed in October of the same year. Fifteen (15) enumerators were trained to use the questionnaire especially designed for the average comprehension level of tricycle users. Tagalog and English were the medium of instruction. The total number of respondents totaled 330 drivers and 330 passengers from 33 Tricycle Operators and Drivers Association (TODA) areas in 11 cities and municipalities.

Socio-Economic Characteristics

53% come from the 26- 40 age bracket; 20% are aged between 18-25, 57% high school

graduates, 18% vocational, 12% college, 11% elementary, 80% have at least 1 child, 62% have been driving the tricycle from 1-5 years, 89% have professional drivers' licenses.

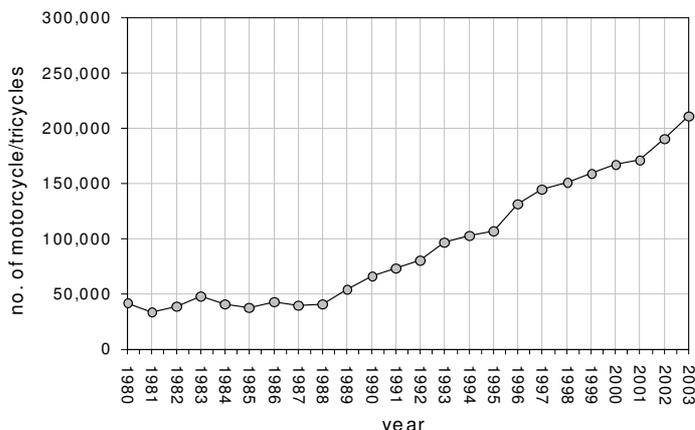


Figure 1. Registered Motorcycles/Tricycles in Metro Manila, 1980-2003

Source: Unpublished reports, Land Transportation Office

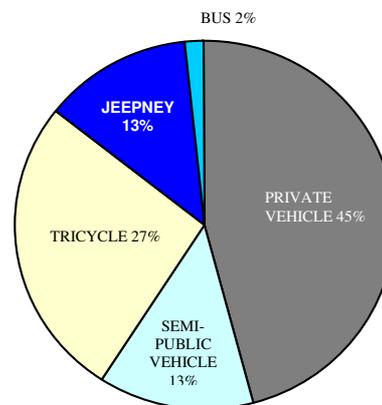


Figure 2. Motorized Vehicle Trips by Mode Per Day (3.6 million)

Source: MMUTIS, 1996

Average Daily (Weekday) Profit

About 43% earn Php300-400 while 75% pay Php100-150 as boundary. Although the daily wage for a driver is within the minimum, there is a drawback for some since many tricycle units are not exclusively driven by a single driver. In some cases, 3 to 4 drivers share 1 unit.

Average Daily Fuel Consumption and Average Daily 2T Oil Consumption in Liters

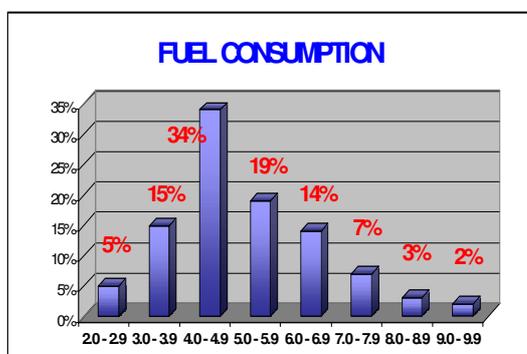


Figure 3. Daily Average Fuel Consumption of Tricycles

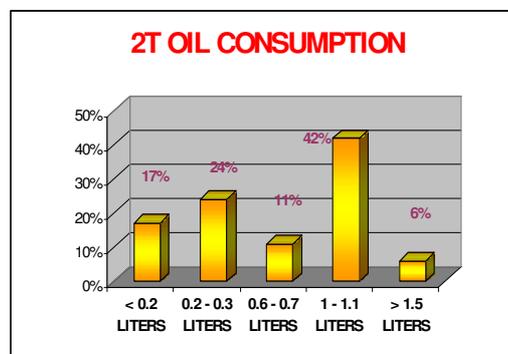


Figure 4. Daily Average 2T Oil Consumption of Tricycles

Frequent Obstacles Encountered in Operation

Most of the obstacles faced by the industry is technical in nature and can be resolved through engineering solutions. Data indicates 75% potholes, 67% humps, 47% narrow roads, 29% pedestrians, 22% manholes/canals, 7% traffic congestion, 7% flood, 3% rains, 3% slopes, 2% heat, 2% dust, 2% others and 1% parked vehicles.

Accidents

Frequency: 38% no accident; 27% once; 28% twice

Types: 33% collision with cars, 24% collision with tricycles, 16% collision with jeepneys, 9% collision with pedestrians. Bumpers are not effective impact absorbers due to low position.

Design and Safety Perceptions

77% agree that the sidecar should only accommodate 2 passengers; 90% believe motorcycle capacity limited to one passenger. About 52% agree that the tricycle is safe where 33% willing to pay P1 additional for clean technology; 17% P0.50; and 30% not willing to pay.

Passenger Characteristics

40% aged between 18-25; 25% between 26-40 years, 65% Female; 35% Male / 68% do not own any form of transport, 26% income bracket range P3 -P10 thousand; 23% income bracket P10-20 thousand, 85% right-handed, 70% with heights between 5'-5'5" while 35% weigh between 100-120 lbs; 28% between 121-130 lbs. In addition, an ergonomic study (body dimensions) for Filipinos was undertaken for this research to be able to determine the average size and related measurements for local passengers and drivers.

Reasons for Using the Tricycle

All these data were used as basis for the research components. It is also essential to note that the data gathered is, basically, for Metro Manila. So all prevailing conditions do not represent other areas especially in the provinces. On the hand, the survey was dispersed throughout the National Capital Region, while the areas chosen are good representatives of the majority of the cities and municipalities. Some areas are also not fully developed urban centers, which in some aspects, resembles rural conditions. The acquired data was used as baseline for establishing many information gaps for this tricycle study. Replication of the study is also recommendable in areas where configurations vary with socio-economic conditions as well as culture.

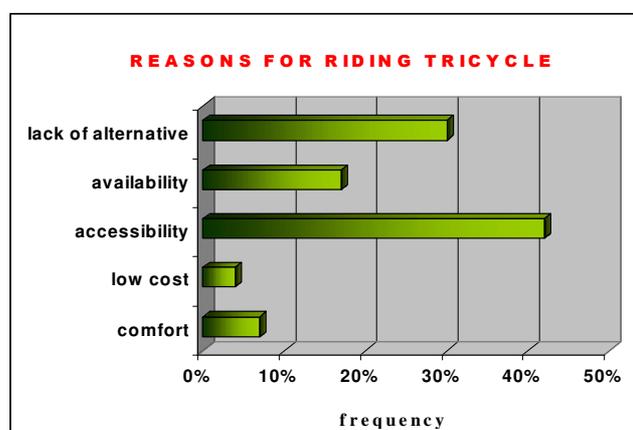


Figure 5. Reasons for Riding the Tricycle

3. DEVELOPMENT OF TRICYCLE SIDE CAR DESIGN AND PROTOTYPING

The tricycle sidecar fabrication industry is an informal small business enterprise. There is no available data as to the exact number operating across the country because those that engage in the business are essentially welding shops. The NCR survey led the group to best sidecar fabrication shops in Pasay City, Quezon City and Marikina City. The demand varies per area but the best manufacturers attract even faraway investors. Expertise as a product of experience is also passed to the next generation. The required equipment includes

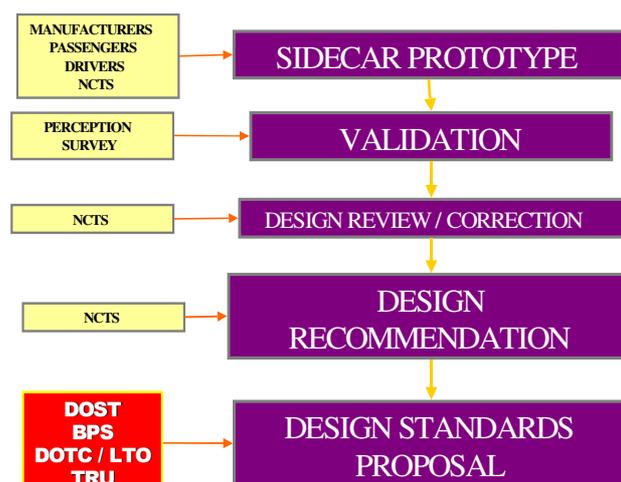


Figure 6. Tricycle Sidecar Development Flow

welding machines, cutting, drilling and bending tools and air compressors for the paint job, basic equipment found in any welding shop. Major raw materials are the common galvanized iron sheets, various sizes of steel bars and angle bars, which are cut into different shapes and sizes. The most critical part of assembly is the alignment of the sidecar with the motorcycle because it translates into good balance and better mechanical operation. Fabricators are receptive to new designs provided there will be clear details. The present situation is the result of no policy / no regulation on design and consumer welfare on tricycles. It all started when one enterprising party pioneered a motorized bicycle for public transport. The arrival of the motorcycle opened new horizons for small transport modes. Driven by market demand, it was replicated in many areas which experts call as ‘seed dispersal phenomenon’

3.1 Development Flow

Four (4) major players in this study are the passengers, drivers, sidecar manufacturers and the academe who took the lead. Inputs from all the three players were used to establish basis for design of the prototype. All design considerations were consulted with the tricycle the users (drivers and passengers as public involvement) through a perception survey in Quezon City. The results were noted to explore areas for improvement and further development.

3.2 Design Approach and Criteria

Understanding the need to redesign an existing format like the tricycle requires a macro perspective viewpoint. An industry running for almost four decades without a standard has been accustomed to the existing design. Imposing a new standard will be a dilemma if it is totally different from the current. A progressive approach to design is needed because the in-use tricycle designs cannot be simply phased-out. Figure 7 shows the phasing of this sub-project. It

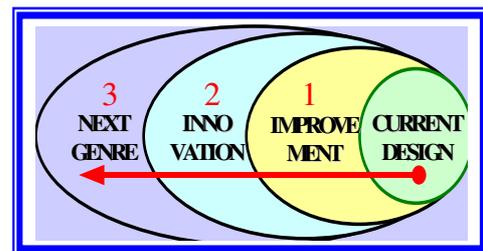


Figure 7. Design Approach

starts with the improvement of the present design format. Innovation is the next step and development of the next generation tricycles will come as the third step. This should be arranged with various stakeholders since it would involve technology upgrade, automotive expertise and intensive study with all players.

Design is based on five considerations namely, cost, safety and comfort, aesthetics, durability and environment-friendly, which are not met by many shops (Figure 8). The ideal tricycle should incorporate all the five design components. It is expected that the extent will vary on prevailing conditions particularly economic and social factors. The general specifications of the typical tricycle are shown in Table 1. For better appreciation, the current features of the tricycle were examined to focus the point of improvement and design direction. Tricycles are normally overloaded. In many instances, the load consideration is just the passenger while other factors are overlooked – motorcycle weight, sidecar weight, road friction, humps and pavement. If we examine the present format of tricycles, a prominent right angle can be viewed from Figure 9. This is due to the fact that motorcycles are primarily single unit vehicles not intended for more than two people. But since the three-wheeler concept came into practice it was converted to tricycles. This design is prone to torsion generated by the sidecar during momentum. This is a clear indication of poor engineering concepts, and an explanation this design never prospered as public transport vehicle in other places.

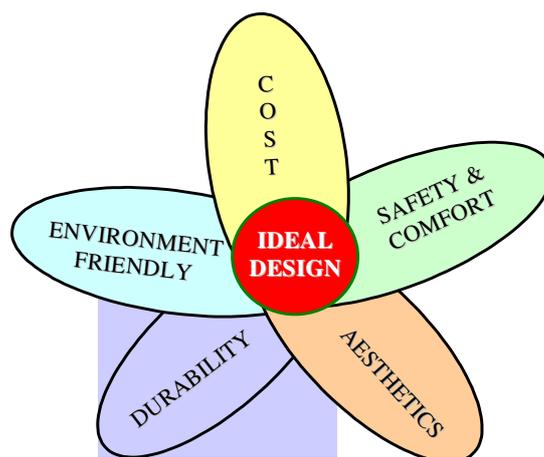


Figure 8. Design Criteria

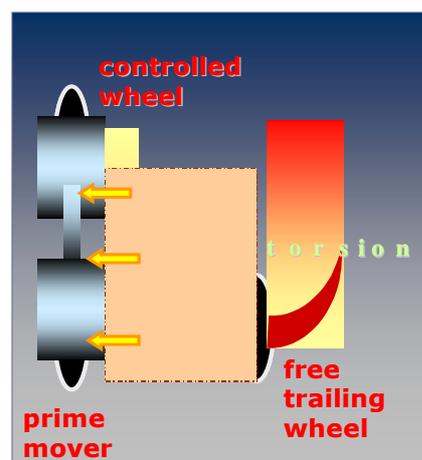


Figure 9. "Right Angle Concept" of Three-Wheelers

Table 1. Basic Specifications for the Sidecar

Item	Average Measurement	Remarks
Overall Height	1.30 m.	Not enough, should be increased
Overall Width (with 3rd wheel)	1.04 m.	Not enough, should be increased
Overall Length	1.62 m.	Not enough, should be increased
Total Weight	126-130 kg.	For consideration based on adjustments
Entrance Width (average)	0.56 m.	Should be increased
Entrance Height	1.04 m.	Should be increased
Legroom (seat to front panel)	0.46 m.	Should be increased
Headroom (seat pan to roof)	0.68 m.	Should be increased
Total Shoulder Room	0.67 m.	Should be increased
Seat Pan Width	0.82 m.	Will be based on adjustments
Seat Pan Length	0.46 m.	Will be based on adjustments
Seat Height from Floor	0.26 m.	Will be based on adjustments
Seat Back Height	0.60 m.	Will be based on adjustments
Height of Floor from Ground	0.33 m.	No bearing
Minimum Turning Radius	4.25 m.	Will be based on adjustments

Aside from increase in size for comfort and better accessibility, there are items identified that should be improved, modified or even omitted. Too much add-ons are discouraged, and since there is no standard for the design, there is also no yardstick on the quality of workmanship. At any rate, the most critical factor to follow is the "basic shell". The "basic shell" is the minimum space that could accommodate two normal adult passengers while seated inside the tricycle. Enough room is provided for the head, body width and legs. For the common two-passenger sidecar, the basic shell should be:

- not less than 400 mm in seat length
- not less than 820 mm in seat width
- not less than 1200 mm in floor-to-ceiling height
- not less than 890 mm in ceiling height from the seat cushion
- not less than 360 mm height of seat from floor

- not less than 410 mm in floor height from ground
- not less than 600 mm for leg room
- not less than 620 mm for average entry width
- full weld shall be applied on all metal joints
- no burrs or sharp protrusions shall be present on the frame and body parts
- signal lights on the front , stop lamp on the rear end and reflector on the body side panel shall installed to provide enough safe illumination
- effective comfortable suspension system (scrap must never be used)
- excessive accessories should be avoided, tricycles should not carry unnecessary load and there should be no obstruction to the driver's view.
- enough cushion should be installed all over the interior
- ample rain and sun protection should be provided



Figure 10. Prototype of Tricycle (Front)



Figure 11. Prototype of Tricycle (Rear)

In addition to the prescribed details above, anthropometric data for Filipinos was generated through the Survey and Design Characterization Study. This is a detailed graphical illustration of human body dimension representing three categories/ proportions of the typical Filipino, both male and female. This also became a basis for the internal dimension requirements of the basic shell. Driver and passenger perception surveys were conducted to validate the design improvements made on the first prototype. This includes the physical characteristics of the prototype, the safety and comfort aspects, performance and acceptability of the design. Around 78% of the drivers responded positively compared to the typical tricycle. Around 85% of the passengers responded positively to the new design.

For the next generation tricycles, an old but effective design concept is recommended. As prescribed in the survey and design characterization study, the better format is what can be called as “calesa type” where the driver is seated at the front like old horse-drawn carriages or even the tuk-tuk. Without being biased on the Thai transport, the logical concept on load distribution is seen in this format. Three points following a triangular arrangement where the middle wheel is located in front and midway between the two rear wheels. This results into a balanced load distribution, rigid structure, better aesthetics and more spacious and convenient. Unlike the tuk-tuk, the passenger seat can be designed to align with the driver seat level. With this format, a ‘unified body’ is possible for the driver and passenger. However, a new body frame should be designed to incorporate a bigger engine 4-stroke engine, a differential/

coupling and other under chassis components that may be required. It is not enough to just dwell on aesthetics, other vital considerations for the next generation tricycle are engine efficiency improvement, fuel and lubricants refinements, air pollution control devices, suspension system and new lightweight construction materials. Initially, the recommended new tricycle design will take off from pilot versions but overtime it can transform a whole manufacturing industry with highly competitive products. A potential design can be something like a streamlined three-wheeler shown in Figure 13.

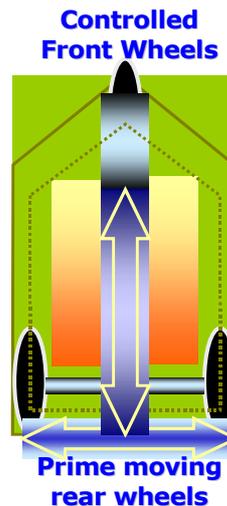


Figure 12. The Triangle Concept

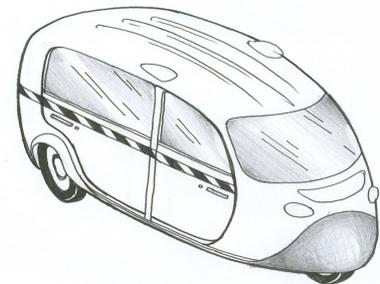


Figure 13. Proposed Next Generation

4. TRICYCLE ENGINE PERFORMANCE TESTING

4.1 Background and Objective

Issues had been raised regarding the capacity of the 2-stroke engine vis-à-vis load. In the sidecar design discussion, the average load of the 2-stroke engine is almost the equal, if not more than, the average 5-seater sedan. Overloading induces much pressure on the engine exceeding its design capacity despite claims and local practices that it can accommodate excessive load. Other factors affecting engine performance include malfunctioning auto-lube, rough roads, absence of engine maintenance, adulterated lubricants and the correctness of the fuel-oil mix. The core of this study is engine performance characteristics as well as its response to different ratios of fuel-to-oil. The expected output is the development of a procedure for tricycle engine performance testing such as bore and piston measurements and load-to-power performance. Tasks were divided namely, 1) accelerated use testing of project motorcycles, 2) monitoring of engine wear and tear (bore and piston measurements) for various fuel-oil mix ratios, and 3) monitoring of motorcycle performance (load-to-power performance) for various fuel-oil mix ratios.

4.2 Methodology

The study is limited to two fuel-to-oil ratios for the two-stroke motorcycles. The most popular 2T oil was based from the survey results. Another 2T oil (coconut-based) was also tested at 20:1 ratio. The motorcycles were tested under two loading conditions. The first one was the “full load” condition where from an empirical formula for road load power, the equivalent of 6 passengers loading (including the driver) plus sidecar was applied to the motorcycle. The second loading condition was “half load”, an equivalent of three passengers loading (including the driver) plus sidecar. Three speeds were used: 30 kph, 40 kph and 50 kph. Steady state conditions were assumed for the testing procedure because of the limitation of the dynamometer to only provide steady state loading.

4.3. Development of the Motorcycle Chassis Dynamometer

The system is composed of two subsystems, the cooling system and the chassis frame. The cooling system is used to regulate the flow and temperature of the water re-circulating through the dynamometer. The chassis frame is used as the mounting of the water-brake dynamometer and the motorcycle to be tested. The water-brake dynamometer is attached to the frame a steel block. The motorcycle is safely mounted through nylon ropes and front wheel locking mechanism (Figure 15). One end of the rope is attached to the rear upper part of the motorcycle and the other end to the frame. The adjustment on the tension of the ropes is controlled through a turnbuckle on each side. The front wheel locking mechanism holds the wheel through tapering walls and prevents the motorcycle from moving forward through the front barrier.

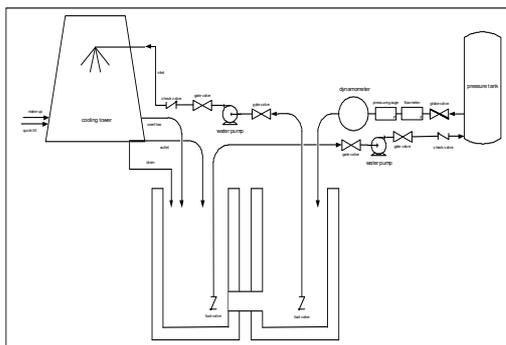


Figure 14. Schematic Diagram of the Chassis Dynamometer



Figure 15. The Chassis Dynamometer and the Mounted Test Motorcycle

A reservoir and the cooling tower is required in the test methodology. The reservoir is made up of two drums. The water used and heated by the water-brake dynamometer is brought into the drum designated for the accumulation of heated water. The accumulated water is pumped into the cooling tower. Then, it will be discharged into the other drum, which is designated for accumulation of cooled water. The heated and the cooled water in separate drums are allowed to partly mix through a pipe that connects the drums. The cooled water is then pumped up to the dynamometer. Cooled water from its designated drum is collected into a pressure tank. The pressure here is held constant. The water from the tank is then passed through two parallel valves. These valves are used to control and fine-tune the rate of flow and the pressure of water passing through the dynamometer. The rate of flow is measured through the rotameter and the pressure, on the other hand, is measured through the pressure gauge. At a maintained pressure, the braking power exerted by the dynamometer against the rollers increases as the flow of water increases. The torque in the water-brake dynamometer corresponding to the pressure reading can then be determined by using the calibration graph.

The optical tachometer used for measuring the rotational speed of the coupled roller and dynamometer was attached on the other side of the frame, opposite to that of the water-brake dynamometer. The odometer that was used to get the distance traveled by the motorcycle's rear wheel was already installed. The glass bottle containing the mixture of gasoline and 2T oil was already positioned near the frame.

4.4. Performance Results and Analysis

Figure 16 and Figure 17, respectively, show the speed-oil temperature graphs at half load and full load conditions. It can be observed from the data sheet that there was no significant difference in oil temperatures among the three 2-stroke motorcycles. The minimum temperature for the 30 kph, full load runs was observed to be at 49° C for motorcycle with 20:1 fuel-2T oil mix ratio while the maximum was 74° C for the motorcycle with 40:1 fuel-2T oil mix ratio for the 30 kph, full load runs. This small range in temperature variation is typical of this type of engine because no oil splashing occurs to effect heat transfer from the engine block to the oil. The variation may be attributable to inherent engine performance variations.

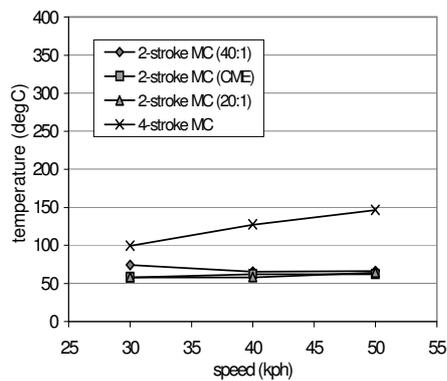


Figure 16. Speed-Oil Temperature Chart Half Load

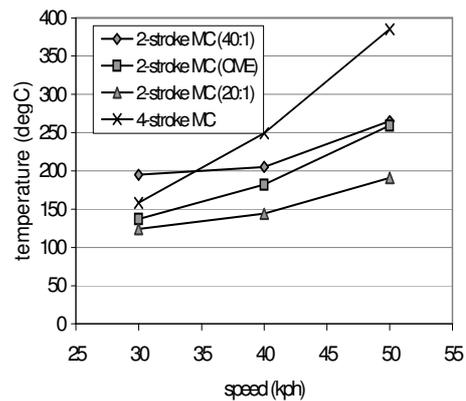


Figure 17. Speed-Oil Temperature Chart Full f Load

The 4-stroke motorcycle, on the other hand, showed expected results with higher observed temperatures. The exhaust temperature results exhibited large differences in temperatures with a minimum of 121° C for the motorcycle with 20:1 fuel-2T oil mix ratio running at full load, 30 kph. The maximum temperature was noted to be 385° C for the 4-stroke motorcycle for the 50kph, full load run.

Among the three 2-stroke motorcycles, the motorcycle with the 20:1 fuel-oil mixture using CME 2T and the motorcycle with 40:1 fuel-2T oil mix ratio yielded high temperatures. The lack of lubrication of the 40:1 fuel-oil mixture may have been the reason for the high temperature. For the fuel-oil mix using CME, at least two things can be ascribed to the high reading. First, the CME is known to be an oxygenated lubricant, therefore facilitating in the combustion process leading to higher exhaust temperatures. Another point of view is lubrication problem wherein inadequate oil is present in the cylinder walls because of oil vaporization thus giving way to more friction-related heat generation. Inherent engine variation cannot be said about this large difference because the disparity is more than 25%.

4.5 Wear and Tear

Visual inspection of the cylinders before and after testing indicates that there was wear. The presence of major scratches on the liners resulted from using petroleum-based 2T oil. This is due to the ceasing of the engines during testing. The engines overheated while they were being run at 30 and 40 kph speeds in the third gear setting. Repeated testing at the fourth gear setting showed no overheating signs. Consequently, the motorcycle running with CME 2T did not incur such scratches because it was run at the fourth gear setting for all speeds. To have a better analysis of wear and tear, longer testing periods are needed. After which an oil analysis

is made to determine wear metal content.

For the 2-stroke engine, images of the cylinder heads show that carbon build up was more prominent with 20:1 fuel-oil mix ratio using petroleum-based 2T oil while the least was seen with fuel-oil mix using CME 2T oil (Figure 18 and Figure 19). This is also evident on the photos of the spark plugs. It can be concluded that CME vaporizes easily compared to petroleum-based 2T. To have a better quantitative proof, the heating value of the fuel-oil mixture can be taken both for the petroleum-based 2T oil and CME-based 2T oil. The consequence of the CME being easier to vaporize is the loss of lubrication on the cylinder walls. This is congruent to the fact that the exhaust temperatures of the 2-stroke motorcycle with fuel-oil mix using CME 2T are significantly higher than the others.

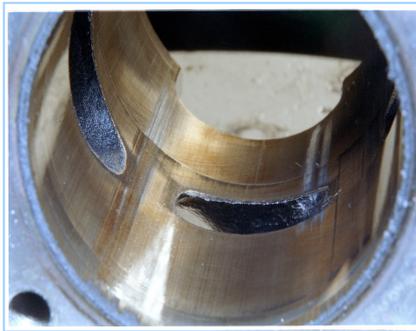


Figure 18. Test 2-Stroke Motorcycle (40:1 fuel-oil mix) Cylinder Liner, Exhaust Port Side (After Testing)



Figure 19. Test 2-Stroke Motorcycle (CME 2T) Cylinder Liner, Exhaust Port Side (After Testing)

5. EMISSIONS AND NOISE LEVEL MEASUREMENTS OF MOTORCYCLES UNDER SIMULATED TRICYCLE LOADING ON A CHASSIS DYNAMOMETER

This section discusses measurement of CO and HC emission and noise levels of new 2-stroke motorcycles with simulated tricycle loadings in a laboratory chassis dynamometer for various fuel-oil mix ratios using petroleum-based and CME-based 2T oil, and emissions from a new 4-stroke motorcycle with similar loadings using fuel only.

5.1 Emission Testing Procedure

The research project acquired 3 new 2-stroke motorcycles (125cc) and 1 unit of 4-stroke motorcycle (155cc). Premium gasoline (unleaded) and petroleum-based 2T oil (JASO FB grade) were premixed in labeled containers prior to the conduct of the tests.

A plant-based lubricant called CME (coco-methyl ester) was premixed with premium gasoline at 1:20 ratio. The components of road load power are drag, rolling resistance and load. The load consists of the vehicle mass including sidecar and accessories and the additional mass due to passengers and baggage. The load estimates for the full and the half load are shown in Table 3. Table 3 shows the 6 sets of engine performance tests which are combinations of two loading conditions and 3 steady-state speeds. All the 4 test motorcycles have undergone the 6

tests. The Horiba Portable Automotive Emission Analyzer MEXA 554JA was used to measure concentrations of CO and HC emissions at 1-second intervals for each set of test. An improvised pipe adaptor made of hard rubber was attached to the motorcycle tailpipe. The probe of the emissions analyzer was subsequently attached to this adaptor. A video8 camera was also installed to videotape the emissions and then data were encoded.

Table 2. Test Motorcycles and Fuel-Oil Mix Ratios for Tests on Laboratory

Test Motorcycle (MC)	Engine Type	Size	Fuel-Oil Ratio	Lubricant
Test MC 1	2-stroke	125cc	1:20	JASO FB 2T (petroleum)
Test MC 2	2-stroke	125cc	1:40	JASO FB 2T (petroleum)
Test MC 3	2-stroke	125cc	1:20/1:40	CME 2T
Test MC 4	4-stroke	155cc	fuel only (no premix)	

Table 3. Estimation of Load of Vehicle, Passengers and Baggage

Component of Load	Half Load	Full Load
Motorcycle	126 kg	126 kg
Sidecar + Driver's Side Roof	130 kg	130 kg
Driver (Average Weight of Person=60 kg)	60 kg	60 kg
3 Passengers (Average Weight of Person=60 kg)	120 kg	
5 Passengers (Average Weight of Person=60 kg)		300 kg
Baggage	10 kg	10 kg
Allowance	10 kg	10 kg
Total (Load)	456 kg	636kg

5.2 CO and HC Emissions Measurements

In Figure 20, under full load condition, CO concentration increases with speed for fuel-oil mixtures using petroleum-based lubricant. The CO concentration for the richer fuel-oil ratio (1:20) is 6.79%, which is 6.7 times greater than the leaner fuel-oil mix (1:40) ratio at 40 kph.

At higher speed of 50 kph, the concentration is 7.86% at the 1:20 mixture, which is 2.4 times greater than that of the 1:40 mix. The CO emissions from the fuel-CME mix is almost the same as the CO emission of the 1:20 fuel-oil mix at 40 kph and lesser at the 50 kph speed. However, the behavior was different since the CO emission increased from 30 to 40 kph and then decreased at 50 kph. It can also be said that based on the standard error, the CO emission levels are similar for the fuel-oil mixes using petroleum-based 2T and CME 2T at 30 kph. For the 4-stroke engine using pure gasoline, the CO emission is highest compared to all the other emissions from 2-stroke at 30 kph and then decreases to 4% at 40 kph which is lower than that of the 1:20 mixture ratio. Concentrations of CO from the 1:20 fuel-2T oil mixture are greater than or equal than the emissions from the 1:40 mixture, which is consistent with an earlier test. The CO emissions of the 4-stroke motorcycle are greater than the emissions from the 2-stroke motorcycles in the 30 kph speed level and greater than 1:40 fuel-oil mix of the 2-stroke motorcycles at the 40 kph speed level.

Figure 21 shows the plot of the average HC emission concentration under full load condition as a function of steady-state speed level and fuel-oil mixture and type of engine. The HC emissions from the 1:20 mix increase with speed from 30 to 40 kph and then decrease at the 50 kph. This is consistent with an earlier test. It can be seen that the emissions decrease with increase in speed from 30 to 50 kph for the richer 1:20 fuel-oil mixture. The trend is similar to the emissions of the 1:20 fuel-CME 2T mix. HC emissions of the 1:20 fuel-oil mix ratio using the CME-based 2T lubricant are higher than the 1:40 fuel-oil mixture ratio using the petroleum-based 2T. HC emissions of 4-stroke loaded motorcycles are in the magnitude of hundreds of ppm not exceeding 200ppm. These emission levels are approximately at least 1/10 of the emissions from 2-stroke motorcycles.

If the exhaust emissions are compared with the existing idle emission standards, the CO emissions of the 1:20 fuel-oil mixture for the petroleum-based and CME-based lubricants exceeded the 4.5% limit at higher speeds of 40 kph and 50 kph at full load. The emissions of the leaner 1:40 mixture are consistently lower than the limit but could have problems in lubrication manifested by the increase in temperature. The emissions of the 4-stroke motorcycle with tricycle loading had already exceeded the limit starting at the lower speed of 30 kph. Comparing the average HC emissions from 2-stroke motorcycles with simulated

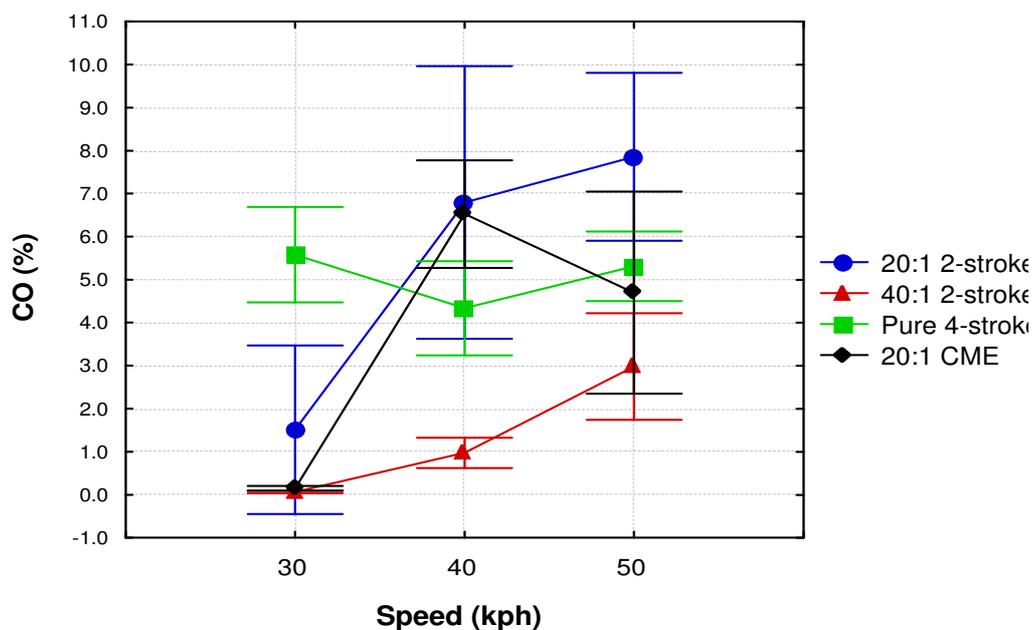


Figure 20. Mean Carbon Monoxide (CO) Emission Concentration Measurements of New Motorcycles on the Chassis Dynamometer by Fuel-Oil Mixture Ratio, Type of Engine and Speed (Full Load)

tricycle loadings with the proposed HC emission standards (7,800ppm), most of the emissions were below 4,000ppm. The average emissions from the 4-stroke motorcycles with simulated tricycle loads were much below the standards, even below 200ppm.

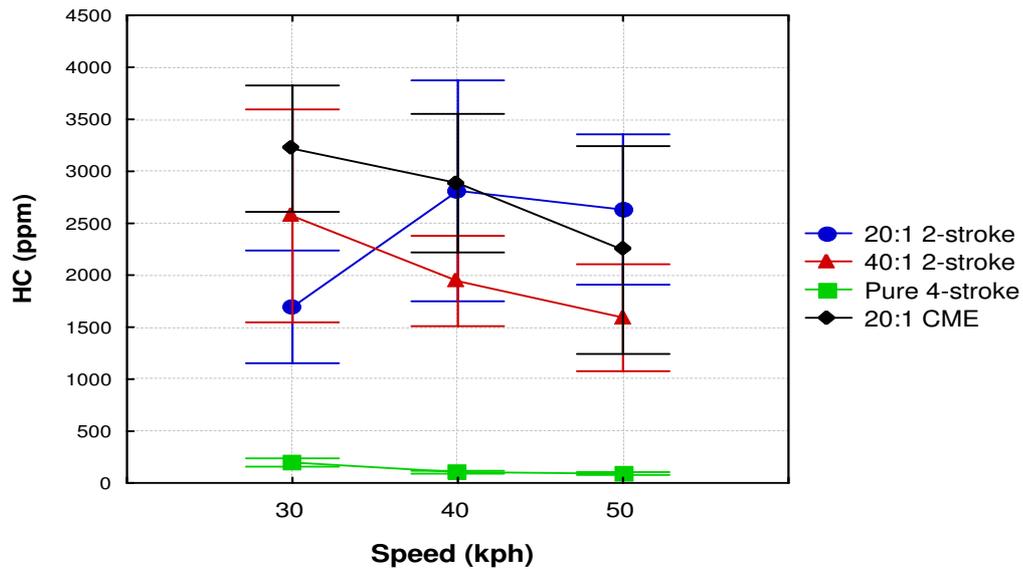


Figure 21. Mean Hydrocarbon (HC) Emission Concentration Measurements of New Motorcycles on the Chassis Dynamometer by Fuel-Oil Mixture Ratio, Type of Engine and Speed (Full Load)

5.3 Noise Level Measurements

The Integrating Sound Level Meter (Rion NL-04), was used to measure the noise levels from the loaded motorcycles. Readings of noise levels were in L_{Aeq} or the equivalent continuous sound level. L_{Aeq} is the constant noise level that, over a given time, expends the same amount of energy as the fluctuating level over the same period. The procedures for measuring the noise levels of tricycles in the laboratory were based on American standards with some modifications. The sound level meter was mounted on a tripod with its microphone placed at the same height as the center of the motorcycle tailpipe. It was positioned with its longitudinal axis parallel to the ground, 0.5 meter from the edge of the exhaust and oriented at 45° from the axis of the tailpipe. Noise measurements were taken for steady-state speed and constant loading. Measurement time was set to ten (10) seconds. It can be seen that there is an increase in the noise level for every increase in the speed of the loaded motorcycle.

6. CONCLUSIONS AND RECOMMENDATIONS

First, an educated approach to establishing a design standard for the tricycle sidecar was realized by building the baseline information on the local three-wheelers. The newly established data can be the first step to addressing long-standing problems on this mode of transportation.

The basic tricycle sidecar prototypes were designed based on baseline information and in accordance with standards on comfort and ergonomics, safety and functionality.

A basic procedure for emission and engine tests using different fuel and lubricant mix ratios was established. This can serve as a reference for further research and improvement on addressing tricycle emission issues, local fuel and lubricant quality, driver's perception of

tricycle operation and its effects on the environment.

Under controlled loading conditions on the chassis dynamometer, a rich fuel and oil mix ratio (1:20) produced higher concentrations of hydrocarbon and carbon monoxide emissions. A leaner fuel and oil mix ratio (1:40) resulted to lower emissions. There were observed significant increases in engine temperature due lesser oil acting as lubricant and coolant and thus the richer fuel-oil mix ratio is still recommended.

It is recommended that further studies be made for materials and structural frame construction for the tricycle sidecar. Prolonged testing to evaluate suitability for local conditions is also favored. Mass-based emission measurements on a chassis dynamometer will be important to more accurately quantify emissions from tricycles with varying conditions of loading and fuel-oil mix ratios.

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