Information note

Proposed stepwise approach for determining baseline and project emissions for vehicle retrofit projects

I. Background

1) The transportation sector is considered by the Executive Board (hereinafter referred to as the Board) of the clean development mechanism (CDM) to be a priority sector for further work on methodological issues.[1] It is also an under-represented sector in terms of the number of registered projects.

2) CMP 6 requested the Board to develop standardized baselines, as appropriate, in consultation with relevant designated national authorities (DNAs), prioritizing methodologies that are applicable to least developed countries (LDCs), small island developing states (SIDS), Parties with 10 or fewer registered CDM project activities as of 31 December 2010, and underrepresented project activity types or regions, inter alia, for energy generation in isolated systems, transport and agriculture.

3) In addition, the Board has included the top-down development of small scale methodologies using standardized approaches for transport in its Management Plan (MAP) as one of its products for 2012.[2].

4) Therefore, the purpose of this document is to provide a step-wise approach to determine the fuel consumption and emissions of common on-road vehicle types, with the aim to streamline project development in this sector. While the approach described herein may have wide applicability, the initial focus of this work has been on two and three wheeled motorized vehicles and the specific geographical region of South East Asia (SEA).

5) Project activities for which the approach may initially be applicable would be those that involve the retrofit of existing two and/or three wheelers applying AMS-III.S and AMS-III.AA. Project proponents would have the option of using this approach as an alternative to the approach prescribed in the existing approved methodologies. This approach would therefore not be mandatory.

6) The main contents of this document are:

- Step-wise approach for determining vehicle fuel consumption;
- Example of application of the approach;
- Annex 1: Determination of traffic coefficients;
- Annex 2: Determination of vehicle Cd and Crr from Roll-down tests;
- Annex 3: Determination of frontal area;
- Annex 4: Additional information on the proposed country-specific traffic pattern;

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[1] <http://cdm.unfccc.int/EB/051/eb51_repan11.pdf>

[2] <http://cdm.unfccc.int/Reference/Notes/gov/info_note32.pdf>

II. Methodological approach for determining vehicle fuel consumption

2.1 Step wise approach for determining vehicle fuel consumption

1) Define vehicle type
The first step is to define the type of baseline vehicle that will be retrofitted. This includes the vehicle type, engine type, fuel, fuel delivery system, passenger load and usage information.

2) Determine relevant vehicular parameters
For the selected vehicle type, measure the following parameters:

Vehicle Mass
Payload Mass (Driver + Passenger)
Frontal Area
Drag Coefficient (Cd)
Rolling Resistance Coefficient (Crr)

Procedures for measurement of the Cd, Crr, and the frontal area are provided in the annexes 2 and 3.

3) Determine appropriate test points
The test points consist of various speeds, weighting factors and an acceleration factor. These numbers are determined from the baseline vehicles or typical drive cycles of similar vehicles in the geographical area of interest. A suggested method of determining these factors is given in Annex 1.

In addition, the following traffic patterns for two and three wheelers are proposed for two groups of courtiers in the SEA. Please refer to annex 4 for more information.

Low Speed, Low Acceleration countries in SEA:
Laos, Cambodia, Nepal, Bhutan, Myanmar, Vietnam, Papua New Guinea and the Philippians

Speed	% of time
Idle	20
15kph	25
30kph	35
50kph	20

Acceleration 0.1 m/s^2

Moderate Speed, High Acceleration countries in SEA[3]:
Malaysia, Singapore, Thailand, Indonesia, Brunei[4]

[3] For analysis purpose only. Only the countries belong to LDCs, SIDs and countries with less than 10 registered projects by December 2010 are covered under the current mandate.

Speed	% of time
Idle	21
15kph	13
30kph	26
50kph	40

Acceleration 0.13 m/s^2

4) Measure baseline vehicle fuel consumption at standard test points

Once the vehicle and test points have been defined, a number of representative baseline vehicles should be tested at the given test points on a calibrated chassis dynamometer. The power of each test point (except idle, which has no measurable dynamometer power) is determined from the following formula:

$$\mathbf{Pv = (M \times A + Crr \times M \times g + \tfrac{1}{2}\, \rho a \times Cd \times Af \times V^2) \times V} \qquad \textbf{(1)}$$

Where:

Pv	Power required to move the vehicle at speed V and accel. A [W]
M	Mass of the vehicle and payload [kg]
A	Acceleration of the vehicle (positive in the forward direction) [m/s^2]
Crr	Coefficient of Rolling Resistance
g	Gravitational constant 9.81 m/s^2
ρa	Atmospheric air density 1.2 kg/m^3
Cd	Coefficient of Aerodynamic Drag
Af	Frontal area of the vehicle [m^2]
V	Speed of the vehicle [m/s]

Prior to measuring fuel consumption, the vehicle should be warmed up to the expected operating temperature, and operated at steady state at each test point. The fuel consumption should be measured for a minimum of one minute. The test average fuel consumption is the weighted average of the measured fuel consumptions:

$$FC_{ave} = \sum_{1}^{i} (FC_i \times Weight_i) \qquad \textbf{(2)}$$

Where:
FC_{ave} is the test average fuel consumption of the vehicle [gm/sec]
FC_i is the fuel consumption of the i^{th} test point [gm/sec]
$Weight_i$ is the weighting factor of the i^{th} point

Fuel consumption in grams per kilometer can be derived by dividing the weighted average vehicle speed in kilometers per hour for each test point by the tested average fuel consumption:

$$\mathbf{FC_{mass} = FC_{ave} \times 3600 \,/\, (\sum_{1}^{i} (Speed_i \times Weight_i))} \qquad \textbf{(3)}$$

Where:
FC_{mass} is the test average fuel consumption of the vehicle [gm/km]
FC_{ave} is the test average fuel consumption of the vehicle [gm/sec]

$Speed_i$ is the speed of the test point [km/h]
$Weight_i$ is the weighting factor of the i^{th} point
3600 is the number of seconds per hour

A large enough sample of vehicles should be measured to establish a reasonable measurement error.

5) Measure project vehicle fuel consumption at standard test points
The project vehicle is measured at the same test points as the baseline vehicles. The speeds will be the same as the test points used in the step 4). The power associated with each test point will be the same if there is no significant change between the relevant parameters of the baseline vehicle and the project vehicle (i.e. they have similar weights, payloads, frontal areas, Cd and Crr).

In the event that there are larger differences (more than 10%) between the baseline vehicles and the project vehicles in any one factor, the power for each test point needs to be separately calculated for the project vehicle as per equation 1, using the appropriate values for the project vehicle.

6) Calculation to account for uncertainties
Once the fuel consumption of the baseline vehicle and project vehicle have been calculated, an uncertainty factor of 80% needs to be applied to ensure a conservative estimate of the fuel consumption reduction for the proposed project.

$$\mathbf{FC_{savings} = [FC_{mass}(Baseline) - FC_{mass}(Project)] \times 80\%} \quad (4)$$

Where:
$FC_{savings}$ is the amount of fuel savings (per kilometer) of the project [gm/km]
FC_{mass}(Baseline) is the fuel consumption of the baseline vehicle [gm/km]
FC_{mass}(Project) is the fuel consumption of the project vehicle [gm/km]
80% is the proposed uncertainty factor

2.2 Example of applying the stepwise approach

1) Vehicle type definition
The following example assesses the case of retrofitting the gasoline powered Yamaha RS100 2-stroke taxi motorcycle with a retrofit technology, namely the Liquid Petroleum Gas (LPG) Transfer Port Injection (GXI) in Myanmar.

Thus, the baseline vehicle definition is:
Yamaha RS100, 100cc, 2-stroke Carbureted Gasoline Motorcycle Taxi, with one driver and one passenger, used for short urban or rural trips in Myanmar**.**

2) Determine relevant vehicular parameters
For this vehicle the vehicle parameters are determined as follows:

Vehicle Mass:	***130kg***
Driver + Passenger Mass:	***65 + 65kg***
Frontal Area:	***0.6 m^2***

Drag Coefficient, Cd: ***0.7***
Rolling Resistance Coefficient, Crr: ***0.018***

Vehicle, driver and passenger masses can be directly measured using any appropriate weight scale. For this example, a single passenger is used as the load, though the average passenger load will be around 1 to 2. The frontal area is computed according to procedure in annex 3. Rolling resistance and aerodynamic resistance can either be taken from published numbers for this class of vehicles, or be measured from the actual target vehicle via the "roll down" technique according to Annex 2.

3) Determine appropriate test points

The appropriate test points need to be determined on a project-by-project basis, and there may be different test points for urban and rural settings (please refer to Annex 1 for detailed procedures). In the case of Myanmar, the following traffic pattern is proposed to determine the appropriate test points (refer to section 2.1 above):

Speed	*% of time*
Idle	*20*
15kph	*25*
30kph	*35*
50kph	*20*

Acceleration ***0.1 m/s^2***

The vehicle power at each test point can be determined by applying equation 1 and using the parameters established for the target baseline vehicle:

Parameter		**Source**
A	0.1 m/s	Geographic Traffic Study
V	0, 15, 30, 50 kph	Geographic Traffic Study
Crr	0.018	Roll-Down Measurement
M	130 + 65 + 65 kg	Measurements of vehicle, passengers
g	9.81 m/s^2	Constant
ρa	1.2 kg/m^3	Constant
Cd	0.7	Roll-Down Measurement
Af	0.6 m^2	Photographic Measurement

The resulting values for power as calculated from equation 1 are:

Test Point	*Speed (km/h)*	*Power (W)*	*Weight (%)*
1	*Idle*	*0*	*20*
2	*15*	*312*	*25*
3	*30*	*661*	*35*
4	*50*	*1590*	*20*

4) Measure baseline vehicle fuel consumption

Once the appropriate test points have been defined, the task of measuring the fuel consumption is straightforward. The vehicle is mounted on a chassis dynamometer, instrumented with the roller's linear speed and power (including frictional compensation). The vehicle must be provided with sufficient cooling air to keep the engine at normal operating temperatures. Fuel is provided to the engine from a weighed tank, taking care to eliminate any air bubbles in the fuel path. Prior to taking data the vehicle should be operated, rolling the dynamometer for several minutes to ensure that everything is functioning properly, and the engine and dynamometer are warmed up to normal operating temperature. Before taking the fuel consumption data, the ambient air temperature, barometric pressure and relative humidity should be noted for application of the SAE[5] power correction factor.

The vehicle should be operated at each speed and load, being placed in the gear that is most appropriate for that particular operating condition based on actual driver preference. The dynamometer should be placed in speed control mode at the desired test speed. The vehicle operator should smoothly accelerate to the designated speed, changing gears as necessary, and the throttle opened until the target power is achieved. Throughout the test, the power and speed should be maintained to within 5% of the target value. Once the speed and power are stable the fuel consumption measurement can begin. The initial fuel weight should be noted as FW1 and a timer started. When the timer reaches 60 seconds the weight should be noted again as FW2. The fuel consumption is thus FW1 – FW2 and should be divided by 60 to give fuel consumption in grams per second. Ideally, during the test the actual speed and power should be continuously measured and averaged, and reported as the average speed and power for that test point. This process is repeated for each test point. The idle test point is measured at zero linear speed and power with the engine fully warmed up and transmission in neutral.

Data measured for the Yamaha RS100 Carbureted Gasoline Motorcycle are as follows:

Date: 15-12-2011 ***Air Temp: 28C*** ***Baro: 754 mmHg*** ***%RH: 65%***

Test Point	***Target Speed***	***Power***	***Gear***	***FW1***	***FW2***	***FC (gm/sec)***
1	***Idle***	***0***	***0***	***106.5***	***97.3***	***0.15***
2	***15***	***312***	***2***	***37.5***	***27.3***	***0.17***
3	***30***	***661***	***3***	***87.2***	***74***	***0.22***
4	***50***	***1590***	***4***	***121.5***	***94***	***0.46***

During testing, slight variations from the desired power may occur. These can be compensated for by correcting the FC data as follows.

$FC_{corrected} = FC_{measured} \times Power_{target} / Power_{measured}$

Where:
$FC_{corrected}$ is the corrected fuel consumption [gm/sec]
$FC_{measured}$ is the measured fuel consumption [gm/sec]
$Power_{target}$ is the target power for the test point [W]
$Power_{measured}$ is the actual measured power for the test point [W]

Finally the test average fuel consumption can be calculated via equation 2 above. For the data presented here the test average fuel consumption is:

[5] Society of Automotive Engineers

FC_{ave} = 0.15 x 20% + 0.17 x 25% + 0.22 x 35% + 0.46 x 20% = 0.24 gm/sec

For our chosen test points the test average fuel consumption from equation 3 is then:

FC_{mass} = 0.24 x 3600 / (15 x 25% + 30 x 35% + 50 x 20%) = 35.9 gm/km

5) Measure project vehicle fuel consumption
The same procedure is repeated for the project vehicle. In this case the project is to apply a retrofit technology to reduce the emissions and fuel consumption of the vehicle, thus the same test points and weighting factors must be used, and the same gears should be used for the various test points.

Data measured as above for the gaseous fuel injection system are as follows:

Date: 15-12-2011 Air Temp: 29C Baro: 754 mmHg %RH: 65%

Test Point	*Target Speed*	*Power*	*Gear*	*FW1*	*FW2*	*FC (gm/sec)*
1	*Idle*	*0*	*0*	*12.3*	*10.2*	*0.04*
2	*15*	*312*	*2*	*101.3*	*95.9*	*0.09*
3	*30*	*661*	*3*	*29*	*23*	*0.10*
4	*50*	*1590*	*4*	*90.1*	*71.3*	*0.31*

Using the appropriate weighting factors the test average fuel consumption is then:

FC_{ave} = 0.04 x 20% + 0.09 x 25% + 0.10 x 35% + 0.31 x 20% = 0.13 gm/sec

Converting into fuel consumed per kilometer we get:

FC_{mass} = 0.13 x 3600 / (15 x 25% + 30 x 35% + 50 x 20%) = 18.88 gm/km

6) Calculation to account for uncertainties
The original carbureted system gave a fuel consumption of 35.9 gm/km, and the LPG fuel injection retrofit kit gave a fuel consumption of 18.88 gm/km on the same test. The fuel consumption reduction per kilometer is the difference. To be conservative a default factor of 80% is applied to determine the discounted fuel consumption savings for the project. According to equation 4, the fuel injection system should thus result in a reduced fuel consumption of:

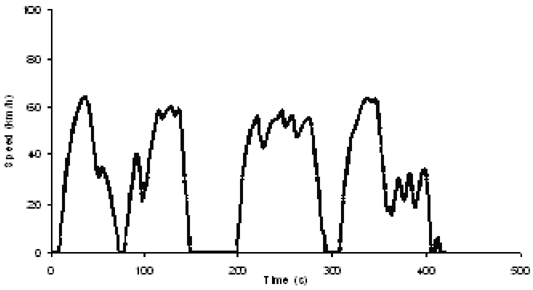
FC_{saving} = (35.9 – 18.88) x 80% = 13.62 gm/km

The emission reductions will be calculated by multiplying fuel savings by the corresponding fuel emission factor. If the project vehicle uses a different fuel, then the two different emission factors shall be applied.

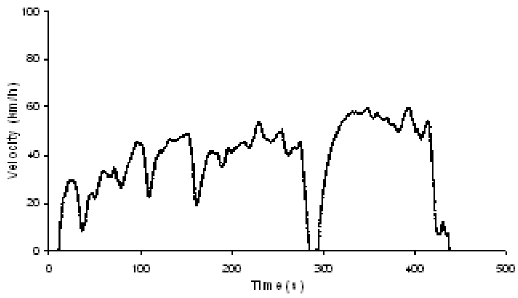
Annex 1

DETERMINATION OF TRAFFIC COEFFICIENTS (TRAFFIC PATTERN)

The appropriate traffic coefficients can be directly determined from drive cycle measurements of the target vehicles of a specific project or in the country/region of interest. The speed of the representative vehicle needs to be measured during typical usage in the baseline scenario or the specific geographical area of interest. Many different drive cycles need to be measured to give good usage statistics. In general there are several different drive cycles for a given region, typically including urban, inter-urban (also called suburban), rural, highway and delivery drive cycles. However, for a specific project, some of these drive cycles may not be relevant.
From analysis of drive cycles in SEA it has been noticed that a mixed urban-rural drive cycle covers the vast majority number of trips. The following are examples of typical drive cycles for Malaysian traffic.



Urban drive cycle



Suburban drive cycle

The individual drive cycles are then statistically analyzed for several factors including the following:

Travel Distance [m]	Total distance traveled
Travel Time [s]	Total duration
Average Speed, Vavg [km/h]	Average speed in a cycle including idle periods
Acceleration [m/s^2]	Average rate of change of speed above 0.25 m/s^2
Maximum Accel. [m/s^2]	Maximum Acceleration over the drive cycle.
Deceleration [m/s^2]	Average rate of change of speed below -0.25 m/s^2
%Acceleration	Fraction of time spent accelerating above 0.25m/s^2
%Deceleration	Fraction of time spent decelerating below -0.25 m/s^2
Maximum Velocity [m/s^2]	Maximum Velocity over the drive cycle.
Cruise Speed, Vavgc [km/h]	Average speed above 5km/h (accel. < +/- 0.25 m/s^2)
%Cruising	Fraction of time spent in cruising mode (accel. < +/- 0.25 m/s^2)
Idling Time [s]	Time spent at speed below 5km/h
%Idling	Fraction of time spent in idling condition

These basic drive cycle statistics are calculated for a statistically valid number of drive cycles and then averaged together. The table below shows the analysis of urban, suburban and rural drive cycles for Malaysia, which are averaged together to get the bottom line average statistics.

Drive cycle	Accmax (m/s^2)	Accavg (m/s^2)	% Cruise	% Idle	% Dec	% Acc	Vmax (km/h)	Vavgc (km/h)
Urban	2.73	0.68	20.2	23.7	27	31.7	64.1	50.9
Suburban	2.69	0.5	53.4	6	17	24.4	59.3	44.9
Rural	1.47	0.44	65.1	3.9	16.7	15.9	33.2	22.1
Average	**2.3**	**0.5**	**46.2**	**11.2**	**20.2**	**24.0**	**52.2**	**39.3**

The averaged statistics are then analyzed to determine the appropriate test points as follows:

Test Acceleration is the average acceleration multiplied by the percent [%] of time spent in acceleration.

Acceleration = 0.5 m/s^2 x 24% = 0.13 m/s^2

The average of the maximum drive cycle velocities is then calculated and rounded to the nearest 5km/h to get the maximum test velocity, thus 52.2 km/h yields the maximum test velocity of 50km/h. The other test velocities are taken to be 60% and 30% of this maximum speed, and again rounded to the nearest 5 km/h:

Vtestmax = 50 km/h
V60% = 50 x 60% = 31 km/h rounds to 30 km/h
V35% = 50 x 30% = 16 km/h rounds to 15 km/h

Weighting factors are determined as follows. The idle weighting factor is the average of the percentage of time spent (%time) at idle plus half of the %time spent decelerating rounded to the nearest 1%. The reason for dividing the deceleration %time by 2 is that much of this time the engine may actually be providing some significant input power to the vehicle, and not be at idle.

Idle Weighting = 11.2 + 20.2 / 2 = 21.3% rounds to 21%

The weighting of the various test speeds is then taken to be proportional to the speed of the test point, and the total of weighting factors, including idle, sums to 100%. As the idle weighting is 21% the weighting factors for the speeds must sum to 79%:

Weight(Vtestmax) = 50 x 79% / (50 + 30 + 15) = 40%
Weight(V60%) = 30 x 79% / (50 + 30 + 15) = 26%
Weight(V30%) = 15 x 79% / (50 + 30 + 15) = 13%

Thus for Malaysia (and countries with similar traffic patterns) we have the following test points:

Speed	% of time
Idle	21
15kph	13
30kph	26
50kph	40

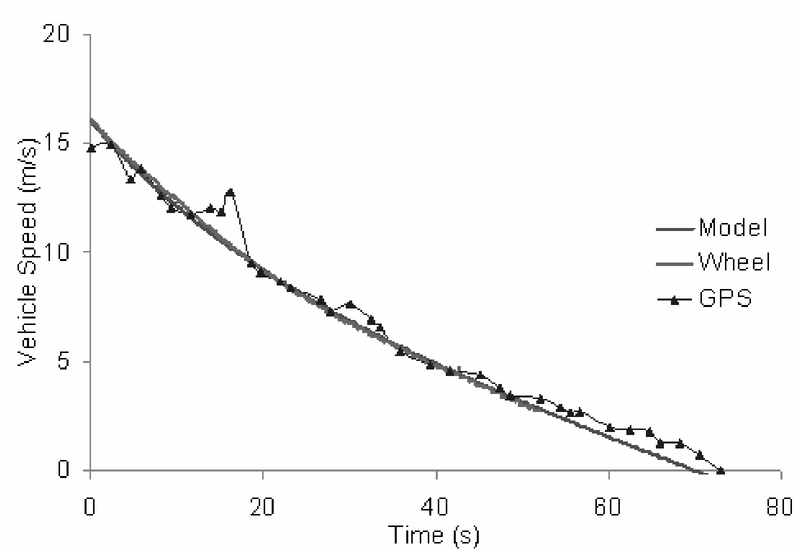
Acceleration 0.13 m/s

Annex 2

DETERMINATION OF VEHICLE CD AND CRR FROM ROLL-DOWN TESTS

For measurement of the rolling resistance and aerodynamic resistance the test vehicle should be operated on a flat windless road at 70km/h. The clutch disengages the engine, and the vehicle is allowed to roll to stop. A speed pickup placed on a wheel and a data logger record the speed of the wheel throughout the test. With the roll down speed, a graph of speed versus time can be plotted for the test. Another plot of modeled speed against time is also plotted on the same graph. This modeled curve depends only on the measured mass, and frontal area, the gravitational constant and air density and the Cd and Crr of the vehicle. Since the force slowing the vehicle down is the aerodynamic force (Fa) plus the rolling resistance (Fr), we can calculate the theoretical velocity as a function of time by simply estimating the Cd and Crr of the vehicle. Cd and Crr are then chosen to minimize the difference between the modeled velocity profile and the measured velocity profile.

This procedure is repeated in opposite directions several times and the average value of the best fit Cd and Crr are used as estimates of the vehicles coefficient of aerodynamic resistance and coefficient of rolling resistance.



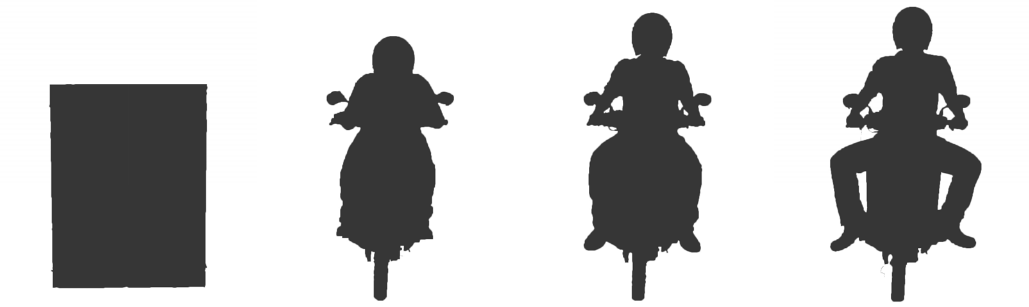
Measured velocity and modeled velocity profile during a “roll down” test.
Note: uncompensated GPS data is generally not accurate enough to capture the rolling resistance of the vehicle.

Annex 3

FRONTAL AREA DETERMINATION

Most motorcycles in Asia are of the "Honda Cub" style with a plastic handle bar nacelle, and splash guard front faring. Taking this as the standard motorcycle body format, any slight differences in individual models are relatively insignificant at the low speeds prevalent in SEA.

For vehicle frontal area three different rider postures (crouched, normal, and open) are photographed from a large distance with a telephoto lens. A 1 m^2 board with exact measurements was similarly photographed as a reference. The images were then enhanced and analyzed for the number of pixels contained within the darkened area of each image. Dividing the vehicle image's dark pixel counts by the number of dark pixels in the 1 m^2 reference image we have a measure of the vehicles frontal area in square meters.



Datum	Minimum	Normal	Maximum
1 m^2	0.62 m^2	0.73 m^2	0.82 m^2

Frontal images of motorcyclist with different postures and a datum area.

Annex 4

PROPOSED COUNTRY SPECIFIC TRAFFIC PATTERN VALUES

For regions of similar demographics, economic development, geography, climate and transportation infrastructure and patterns it may be possible to generalize the traffic pattern in a country or a region encompassing more than one country. For example, motorcycles in most parts of SEA are very similar as they are all imported from the same manufacturers, and of similar specifications. In less developed countries with high fuel costs and poor roads, drivers tend to accelerate slowly and drive at lower speeds, thus it may be possible to use the same values for baseline parameters for countries that fall in this category. More developed countries with modern transportation infrastructure will tend to have higher accelerations and speeds..

Based on surveys of relevant parameters (geography, population and population density, land transportation infrastructure, per-capita income and etc.) the following countries can be treated as a single region: Laos, Cambodia and Myanmar. Aside from being located adjacent to one another, they are all significantly less developed than their neighboring countries, have similar geography and climate, and similarly underdeveloped transportation infrastructure, generally consisting of a paved main highway, and unimproved (dirt) roads leading to the dispersed villages. Despite some differences in road transport patterns, it is likely that Laos, Cambodia, Nepal, Bhutan, Myanmar, Vietnam, Papua New Guinea and the Philippines have similar enough traffic patterns to be treated as a single region.

A second region consisting of Malaysia, Singapore, Brunei, Thailand and Indonesia will generally have traffic with higher accelerations and speeds when compared to the less developed countries.

The following traffic patterns for two and three wheelers are proposed for the above two groups of countries,

Low Speed, Low Acceleration countries in SEA:

Laos, Cambodia, Nepal, Bhutan, Myanmar, Vietnam, Papua New Guinea and the Philippians

Speed	% of time
Idle	20
15kph	25
30kph	35
50kph	20

Acceleration 0.1 m/s

Moderate Speed, High Acceleration countries in SEA:
Malaysia, Singapore, Thailand, Indonesia, Brunei

Speed	% of time
Idle	21
15kph	13
30kph	26
50kph	40
Acceleration	0.13 m/s