Analysis on Characteristics of Passenger Car and Motorcycle Fleets and Their Driving Conditions in Developing Country: A Case Study in Ho Chi Minh City, Vietnam

Chu Tien DUNG a, Tomio MIWA b, Hitomi SATO c, Takayuki MORIKAWA d

a Section of Road and Highway Engineering, Department of Civil Engineering, University of Transport and Communications, Lang Thuong, Dong Da, Hanoi, Vietnam; E-mail: dungchu@utc.edu.vn
b Institute of Materials and Systems for Sustainability, Nagoya University, Furo-cho, Chikusa-ku, Nagoya, 464-8603, Japan; E-mail: miwa@nagoya-u.jp
c Institute of Innovation for Future Society, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan; E-mail: sato@trans.civil.nagoya-u.ac.jp
d Same as the third author; E-mail: morikawa@nagoya-u.jp

Abstract: Transportation fleets and on-road driving characteristics have known as significant factors on traffic emissions, additionally important parameters in International Vehicle Emission (IVE) model for emission inventories. Using data collected in Ho Chi Minh City, this paper analyzes characteristics of these parameters and it mainly focuses on passenger car (PC) and motorcycle (MC). It is revealed that the fleets are characterized by young PCs and MCs with medium engine volume and low usage. The video analysis shows that the on-road traffic is composed of 89% MCs, 6% PCs and 5% for other modes. Vehicle specific power (VSP) and engine stress were adopted for driving condition analysis. The VSP of positive power and engine stress at medium/high levels, indicating stable driving conditions are commonly found on highway but not on arterial and residential streets. It is found that the start-up with long engine soak usually happens during peak hours (6:00~8:00 and 16:00~18:00).

Keywords: Developing Country, Motorcycle, Fleet Characteristic, Driving Condition, Emission, International Vehicle Emission

1. INTRODUCTION

Nowadays, many cities in developing countries are suffering the same problems of traffic congestion and air pollution due to rapid growth of motorization, especially those countries have high population of motorcycle (MC) such as Vietnam, Thailand, Indonesia, Taiwan, and India. In Vietnam, Ho Chi Minh City (HCMC) is the largest city in terms of economy and population. However, the transportation infrastructure development always goes behind the growth of private transportation modes. According to HCMC department of transport (HCMCDOT, 2015), the number of MC has exploded and reached about 6.3 million and that of passenger car (PC) is nearly 0.6 million (see Figure 1). Even the growth rate of MC is decreasing in the last four years, it is still high (7.7%). And also the PCs decreased in the years of 2012 and 2013 but grew rapidly in the year of 2014, approximately 20%. These are internationally seen very high growth rates compared to others such as Europe (about 1~2%) and USA (~1%). As a result, transport situation in HCMC is worsening and traffic congestion is becoming one of six “hot” problems that the local government made priority (Nguyen et al, 2013).
Associating with traffic problems is usually air pollution problems. Numerous studies have addressed that traffic emission is the major source of air pollution in urban areas (Colvile et al., 2001; Gwilliam et al., 2004; Kawashima et al., 2006). It raises an urgency to find solutions to control the explosion of private modes, so that eliminating traffic congestion and reducing air pollution. One solution is development of public transportations that can carry huge amounts of passengers such as bus rapid transit (BRT) or mass rapid transit (MRT), currently being conducted in HCMC. Another solution is to promote HCMC’s citizens to switch from their preferred private modes to current bus system by introducing Park and Ride and Transportation Eco Point in collaboration with parking lots of commercial facilities. These policies are efforts to cut down greenhouse gas (GHG) emissions under joint crediting mechanism (JCM) that Japanese government is implementing in some South East Asian nations, e.g. Vietnam, Laos, Cambodia and Indonesia.

It is highlighted that when implementing the new policies, one important indicator is environmental co-benefit or reduction amounts of emissions. Thus, to address the benefit from the project, it is necessary to have a tool for accurately estimating emissions from on-road vehicles. Up to date, many emission estimation models have been developed with continuously updated features. In U.S. MOBILE series (U.S. EPA, 2004) and EMFAC model (CARB, 2012) are primary vehicle emission models. The base emission factors (BEFs) in these models were based on the ones taken from laboratory dynamometer tests. In the mid-1990s, it was recognized that the driving cycles in laboratory dynamometer tests were not very representative of modern driving patterns, leading to the improvement of driving cycles, e.g., CARB’s unified cycle and the supplemental federal test procedure (FTP) of the U.S. EPA (Younglove, 2005).

Traditionally, the MOBILE and EMFAC models are suitable to predict emissions for areas with a large scale than the small ones, i.e. a street or a province. Because of this reason, the U.S. EPA recognized the need of developing a new emission model that is able to estimate emissions in various scales. Recently, the U.S. EPA has developed MOVES to supersede MOBILE series. In MOVES, BEFs were obtained from a portable emissions measurement system (PEMS) test, as opposed to laboratory dynamometer ones in the previous models. The latest version MOVES2014 has included the NONROAD2008 model, allowing for modeling of both on-road and non-road emissions within the MOVES platform (U.S. EPA, 2014).

In European countries, COPERT series are the most commonly used model for official national emission inventories from road traffic (Ekström et al., 2004). COPERT has a friendly user interface and flexible application. In addition, sub-divided MC classes are more suitable...
to developing countries, where Euro standards are adopted. Nevertheless, due to low space and time resolutions, this model seems to be more appropriate to a national scale than a local urban one. Also, it is not reasonable to neglect start-up emissions from MCs. Furthermore, all PM measured in COPERT only refer to PM$_{2.5}$ and ignore PM$_{10}$. However, some studies, e.g. Cai and Xie (2008), have emphasized that PM$_{10}$ emissions could not be negligible.

In developing countries, many nations have adopted modified versions of U.S. or European emissions models as presented above. In most cases, these models can lead to significant errors in predicting emissions (Davis, et al., 2005). To solve this problem, a new tool, called the international vehicle emission (IVE) model, is specifically developed for those countries (ISSRC, 2008). The IVE model uses local vehicle technology distributions, power-based driving factors, vehicle soak distributions, and meteorological factors to tailor the model to the local situation. Moreover, MC is appropriately considered by intensively collecting the necessary MC fleet and on-road driving data in order to populate the model with critical local information. The IVE model has proved highly effective in providing an improved estimate of mobile source emissions in an urban area and allows the effective analysis of local policy options. As reported by ISSRC (2008), a lot of cities in developing countries have applied the IVE model including Mexico City (Mexico), Pune (India), Nairobi (Kenya), Shanghai and Beijing (China).

In Vietnam, Oanh et al. (2012) applied the IVE model for emission inventory of MC fleet in Hanoi. They were based on questionnaire survey in 2008 to develop database of MC fleet. However, it is not appropriate to adopt this database for MC fleet in HCMC. It is because the technology has changed significantly since then, e.g. the MCs with electronic fuel injection (FI) have recently become more popular. In addition, the habit of using MCs in HCMC may be different from Hanoi (daily usage, start-up time, etc.). Also, the database of PCs have not been available in Vietnam. In order to close this gap, our paper aims at analyzing characteristics of PC and MC fleets as well as their driving conditions in order to develop database for IVE model. This database can be applied in IVE model for emission inventory in HCMC or calculation of environmental co-benefit when implementing projects e.g. BRT, MRT or Park and Bus Ride in HCMC as previously discussed.

2. DATA COLLECTION

The survey was conducted in HCMC from 15$^{th}$ to 22$^{nd}$, December 2014 including three main surveys: questionnaire, video and GPS monitoring.

2.1 Questionnaire survey

To obtain database of fleet technologies, start-up time and engine soak distributions, a total of 3500 questionnaire sheets was randomly given to HCMC citizens and 2066 eligible questionnaire sheets were finally got. The respondents were asked to answer the questions including: brand, engine volume, odometer reading, age, and emission standard of their PC or MC if they would choose PCs or MCs as their transportation modes. They also answered the questions such as how many times they start-up engine per day and at what time they normally start/stop the engine. Furthermore, other personal information was collected to know demographic characteristics of respondents as shown in Figure 2. The figure indicates that HCMC citizens very much prefer using private modes, about 91% (in which 167 PCs samples and 1707 MCs samples) while only 8% using bus. This result is very consistent with the data from HCMCDOT (2015). As for gender and age, males occupy 12% higher than females and
most of respondents are 20~49 years old. In addition, regarding education levels, bachelor, associate and senior high school are dominant compared to others. Finally, Figure 2 (e) and (f) present the respondents’ occupation and professional field where government employee and transportation are associated with the most common ones.

Figure 2: Demographic characteristics of respondents

2.2. Video survey

Video data were recorded for the purpose of analyzing traffic compositions on different types of streets. Three typical streets, which play as highway (Dien Bien Phu), arterial (Xo Viet Nghe Tinh) and residential (D2), were selected for our study (see Figure 3). A video camera was positioned on the top of high buildings located near to the target streets to cover large observed-angles, which help to reduce errors when processing data. The video data were collected on 15th, 16th and 17th, December, 2014 at Dien Bien Phu, Xo Viet Nghe Tinh and D2.
respectively. The camera was operated 30 minutes for each hour of interest from 6:30 to 19:00 and 1170 minutes video were recorded.

2.3. GPS survey

Two GlobalSat DG-100 GPS data loggers were used to discover driving characteristics in HCMC. The GPS loggers were installed in a chosen PC and MC. The drivers were asked to run on three selected routes on 15\textsuperscript{th} December, 2014 from 6:30 to 19:00 as displayed in Figure 3. The GPS loggers were set for 1 second interval so that speeds were recorded every 1 second. It is worth mentioning that the accuracy of GPS loggers is 0.1m/s for speeds and 1-5m for the horizontal position but it is lower for altitude (GlobalSat, 2014).

3. DATA ANALYSIS AND DISCUSSIONS

3.1. Fleet technology analysis

Figure 4 and Figure 5 demonstrate general characteristics of PC and MC fleets in HCMC, respectively. They indicate that young PCs and MCs are very common in the fleets. The PCs and MCs less than 5 years old share about 66\% and 74\%, respectively. By contrast, the ones with ages of more than 10 years are very few, approximately counting for 11\% PCs and 5\% MCs. And for usage level, the PCs with low usage\textsuperscript{1} are dominant in the fleet with 68\% and the PCs with high usage are rare, about 2\%. On the other hand, the percentage of MCs with low, medium and high usages\textsuperscript{2} are quite balance. The low usage MCs have a little higher percentage compared to the other two. Regarding engine volume, the data in Figure 4 show that the PCs, which have engine size from 1.5–3 liter, account for more than half of fleet population. Meanwhile, as displayed in Figure 5, nearly 90\% of MCs have the medium engine volume (100–300cc) and the ones with engine larger than 300cc are very infrequently.

Switching to emission standard, a biggest population of both PC and MC fleets fail to comply with any euro standard, especially MCs (more than 60\%). This may result in more emission and air pollution. The common engine technologies for PCs are carbureted (Carb) and multi point fuel injection (MPFI) while it is usual to find 4-stroke-combustion cycle with carbureted engine or 4-stroke-combustion cycle with electronic fuel injection (FI). Almost three quarter of PCs use petrol and 100\% MCs use petrol as their fuel.

![Figure 4: General characteristics of PC fleet in HCMC](image)

\textsuperscript{1} According to IVE user manual: low usage car: odometer <79 thousands km, medium usage car: odometer from 80–161 thousands km, high usage car: odometer > 161 thousands km.

\textsuperscript{2} According to IVE user manual: low usage motorcycle: odometer <25 thousands km, medium usage motorcycle: odometer from 25–50 thousands km, high usage motorcycle: odometer > 50 thousands km.
Figure 5: General characteristics of MC fleet in HCMC

3.2. Average age and daily usage of PC and MC in HCMC

Average age and daily usage of vehicle are very necessary to estimate vehicle kilometer travelled (VKT) in an area, an important parameter for predicting emissions. Basically, there are two main methods to estimate VKT. The first way to estimate VKT is based on a visual observation of the number of vehicles that travel on different roadways during the day. Then, the data are multiplied with the total length of roadways in the interested area to obtain VKT. This study followed the second way discussed in an earlier study (Wang et al., 2008), which is dependent upon the relationship between accumulated vehicle usage (AVU) and vehicle age.

\[ VKT = N_T \]  
\[ T_i = AVU_{age,0.5} - AVU_{age,0.5} \]

where,

- \( VKT \) : vehicle kilometer travelled (km/year),
- \( N_p \) : population of vehicle class \( i \) in an area (vehicle),
- \( T_i \) : annual usage of vehicle class \( i \) (km/year),
- \( AVU_i \) : accumulated vehicle usage of vehicle class \( i \) (km), and
- \( age \) : average age of vehicle class \( i \) (year).

Figure 6 presents the age distributions of PCs and MCs in HCMC. As aforementioned, the PCs and MCs that have less than 5 years old are commonly observed in the fleet. The ones with higher 15 years old are seldom found in the fleet for both PCs and MCs. Average ages of PCs and MCs fleets are calculated as 4.84 and 4.15, respectively.

Since the samples of PCs and MCs with more than 15 years old are very rare and also the odometer of the very old PCs/MCs may produce large errors, those have less than 15 years old were used to determine relationship between AVU and age as displayed in Figure 7. The red points in the figures represent average vehicle usage for each age group while the grey ones show raw data. The quadratic polynomial curve was adopted to fit the relationship between odometer reading and ages. Both the curve of PCs and MCs indicate a good fitness with about 0.98 R square. The curves are shown in the following equations.

\[ AVU_{PC}(km) = -355.79 \times (Age_{PC})^2 + 16554 \times Age_{PC} - 2138.2 \]  
\[ AVU_{MC}(km) = -210.58 \times (Age_{MC})^2 + 11229 \times Age_{MC} - 3513.9 \]

where,
\[ AVU_{PC} : \text{accumulated vehicle usage of PC}, \]
\[ AVU_{MC} : \text{accumulated vehicle usage of MC}, \]
\[ Age_{PC} : \text{age of PC}, \text{and} \]
\[ Age_{MC} : \text{age of MC}. \]

Figure 6: Age distribution of PC and MC fleets in HCMC

Figure 7: Usages of PC and MC in HCMC during the last 15 years

Figure 8: Trends of PC’s usage different cities
Figure 9: Trends of MC usage in different cities

Figure 8 and Figure 9 compare usage trends\(^3\) of PCs and MCs in different cities. Notably, the available data from literature for PC fleet is copious, however, that for MC fleet is very limited. It appears that due to a low percentage of MCs in some studies; it was impossible to collect enough sample sizes. Data in Figure 8 suggest that the PC usage in HCMC is similar with Mexico City, (Mexico) higher than Pune (India) and São Paulo (Brazil) but less than the remained cities. By contrast, the trend of MC usage is much higher over Pune (India). Compared to Hanoi (Vietnam), it is similar for MCs with less than 4 years old. However, the trends of MC in Hanoi and HCMC tend to go separately when the MC ages are higher than 4 years. A possible reason for this discrepancy may come from limited sample of MC with ages more than 10 years old in Hanoi’s study (Oanh et al., 2012). It also explains why the trend seems to go down after 10 years.

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\(^3\) Other cities data from ISSRC, available online at [http://www.issrc.org/ive/](http://www.issrc.org/ive/), Hanoi data from Oanh et al. (2012)
By using equations (2), (3) and average age of PC (4.84 years), the annual usage of PC is found to be 13109.95 km/year. It is equal to 35.92 km/day. Similarly, based on equations (2), (4) and average age of MC (4.15 years), the annual usage of MC is 9481.19 km/year and it is equivalent to the daily usage of 25.98 km/day. Compared to other cities\(^4\) (see Figure 10), the average age of PC in HCMC is in the same level with Nairobi, Kenya and Pune, India. It is slightly higher than Beijing and Shanghai, China. However, it is considerably lower than Almaty, Kazakhstan and Lima, Peru. And daily usage of PC in HCMC is similar with Santiago, Chile, higher than Mexico City, Mexico and Pune, India while it is lower than other cities. Regarding average age and daily usage of MC, Figure 11 indicates that the average age of MC in HCMC is in between that of MC in Pune, India and Hanoi, Vietnam. However, the MCs in HCMC stand number one in daily usage compared to Pune and Hanoi.

### 3.3. On-road traffic composition analysis

On-road traffic composition is a necessary input in the IVE model. It accounts for a fraction of different traffic modes in different hours. The videotapes were displayed in slow motion for traffic counts. Each 30 minutes of videotapes, the traffic was counted for 15 minutes and then multiplied by 4 in order to represent traffic volume of interested hour.

![Traffic Composition](image)

Figure 12: Traffic volume of PCs and MCs by street types

Figure 12 demonstrates volumes of PCs and MCs on highway, arterial and residential streets. Inspection of Figure 12 (a) indicates that the PC volume on highway is extremely high compared to other streets. In average, it is approximately 5 times and 10 times higher than arterial and residential streets, respectively. It appears that the PCs avoid narrower streets on arterial and residential. In addition, some people may use PCs as a long trip out of the city and they head to highway. Looking at Figure 12 (b) for MC, the average volume on highway is higher but not significant, nearly 2 times and 3 times in comparison to the arterial and residential streets. Furthermore, comparing Figure 12 (a) and Figure 12 (b) shows that the MC volume on highway is about 10 times greater than PC volume. However, on arterial and residential, the ratio of MC volume per PC volume are extremely high, nearly 40 times. Figure 13 compares the traffic compositions on road in different cities worldwide. It is very clear that the MC in HCMC is dominant (89%) while it is very few in other cities except Pune, India (55%) and Shanghai, China (24%). The findings are compatible with the data of registered PCs and MCs as detailed in Figure 1.

3.4. Driving condition analysis

Driving conditions, *e.g.* speeds, acceleration or deceleration are believed to significantly affect emissions producing from on-road vehicles. In IVE model, two very important parameters, vehicle specific power (VSP) and engine stress are used to characterize the driving conditions. VSP was defined as the power per unit mass to overcome road grade, rolling and aerodynamic resistance, as well as inertial acceleration (Younglove, 2005). VSP is calculated in the following equation.

\[
VSP = v^3(3.15 + 9.81 \arctan(\sin(grade)) + 0.132) + 0.000302 \cdot v^4
\]

where,

- **VSP** : vehicle specific power (kW/ton),
- **v** : vehicle speed (km/h),
- **grade** : slope of the road, and
- **a** : vehicle acceleration (m/s²).

The IVE model divides VSP into 20 groups namely 0~19. It is worth mentioning that groups VSP of 0~10 correspond to the case of negative power. It means the vehicle is decelerating, going down or both of them. Group 11 represents the situation of zero or very low power; *e.g.* the vehicle is waiting for the red light at signalized intersections. In addition, groups of 12~19 are the situation where the vehicle is using positive power such as driving at a constant speed, accelerating, going up or some combinations of each (ISSRC, 2008).

The second parameter for driving conditions, engine stress, is shown to correlate best to vehicle power load requirements over the past 20 seconds of operation (from \( t = -5 \) sec to \( t = -25 \) sec) and implied engine revolutions per minute (RPM). Low engine stress refers to conditions in which vehicle is operating at low speeds and less accelerations during last 20 seconds of operation and a relatively low engine RPM. On the other hand, high engine stress relates to high speeds and accelerations over the last 20 seconds and a high engine RPM (ISSRC, 2008). Engine stress is calculated as follows.

\[
\text{Engine Stress} = \text{RPM}_{\text{index}} + 0.08 \cdot \text{PreaveragePower}
\]

\[
\text{PreaveragePower} = \text{Average}(VSP_{-5 \text{sec to } -25 \text{sec}})
\]

\[
\text{RPM}_{\text{index}} = \frac{\text{Speed}_{\text{avg}}}{\text{Speed Divider}}
\]

Data of other cities from ISSRC, available online at [http://www.issrc.org/ive](http://www.issrc.org/ive)
Here, speed-divider values are dependent on the speed and power cut-point. There are three stress modes including low (-1.6 ~ 3.1), medium (3.1 ~ 7.8) and high (7.8 ~ 12.6). These three stress modes are combined with 20 groups of VSP, making a total of 60 bins numbered from 0 to 59. More detailed information of VSP groups and engine stress can be found in IVE model user manual (ISSRC, 2008). To calculate VSP and engine stress, the data including altitude, latitude, longitude, time and speed were extracted from GPS logger. As mentioned earlier, the accuracy for altitude recorded from GPS logger is remarkable. In addition, considering HCMC is relatively flat, it is assumed that the grade of all roads is 0% when estimating VSP. The acceleration rate of PC and MC is estimated from time and speed data.

Figure 14: Example of second by second speeds of PC recorded by GPS logger

Figure 15: Example of second by second speeds of MC recorded by GPS logger

Figure 14 and Figure 15 give examples of PC and MC speed recorded by GPS logger, respectively. It is found that the speeds of PCs on highway are much higher than that on the arterial and residential streets. Compared to PCs, the speeds of MCs on highway are lower and more fluctuated. In addition, the MCs’ speeds are somewhat higher than that on the arterial and residential streets. It is logical since the highways have more lanes and PCs are rarely interrupted, e.g. by signalized intersections or pedestrian crosswalks. By contrast, the arterial and residential streets are relatively narrower and vehicles have to frequently accelerate or decelerate, thus, causing speed fluctuated. Their speeds sometimes become zero due to temporarily congestion or waiting at signalized intersections. These driving conditions may contribute to a factor in emissions. Interestingly, it can be seen that MCs on arterial and residential streets have higher speeds than PCs. It implies that on narrow streets, MCs are more flexible than PCs so they can maintain their speeds as high as wished. Figure 16 presents average speeds of PCs and MCs on different streets. The figure shows that PCs on highway have higher speed than MCs. On the other hand, on arterial and residential, it is concluded that MCs fairly have higher speeds than PCs. This result is consistent with above discussion.
Figure 16: Average speeds of PCs and MCs on different streets

![Average speed graph](image)

**Figure 17:** VSP distributions of PC on highway, arterial and residential

![VSP distribution graphs](image)

(a) Highway  
(b) Arterial  
(c) Residential

**Figure 18:** VSP distributions of MC on highway, arterial and residential

![VSP distribution graphs](image)

(a) Highway  
(b) Arterial  
(c) Residential

Figure 17 and Figure 18 represent VSP distributions of PCs and MCs with low, medium and high engine stress on highway, arterial and residential, respectively. It is worth mentioning that the figures only represent the groups of VSP 8−14 for comparison purpose. Other groups were excluded because they share very small percentage (less than 0.01%). Inspection of Figure 17 and Figure 18 indicates that the group 11, the situation of zero or very low power, is associated with the biggest percentage on arterial and residential for both PCs and MCs. The result confirms that on those streets, vehicles often face with temporarily congestions due to limited lanes or have to wait at signalized intersections. On the other hand, on highway, vehicles are rarely affected by signalized intersections so they commonly run with constant speeds or accelerating. Evidence for this is given in Figure 17 (a) and Figure 18 (a). Our findings are similar with driving conditions in Hanoi as shown by Oanh et al. (2012).
In addition, it can be found in Figure 17 and Figure 18 that on arterial and residential, the engine stress at medium and high level seems negligible with relatively small percentages. However, the larger percentages of medium and high engine stress are observed on highway. It is because the speeds of vehicles on arterial and residential are smaller than that on highway as discussed previously.

3.5. Start-up Patterns and Soak Distribution.

Generally, vehicles produce more emissions when they are first started than the operations when they are fully warmed up. The colder the vehicle engine when started, the typically greater emissions. It is thus important to know how often vehicles are started in an urban area and how long a vehicle is off between two starts (soak) to make an accurate estimate of start-up emissions. As recommended by ISSRC (2008), Vehicle Occupancy Characteristics Enumerator (VOCE) is used to measure start-up pattern and soak distribution. Basically, it provides information such as the times that vehicles are started and how often. In addition, it also gives information on how long vehicles are typically operated at different hours of the day. However, in this study, we use the less accurate method, questionnaire survey, to discover start pattern and soak distribution. It is restated that in our questionnaire, respondents were asked how many times they start per day and what time they start/stop. Based on their answer, the start pattern and engine soak distributions are analyzed as follows.

3.5.1. Start-up Patterns

![Figure 19: Number of start of PC and MC/day](image)

The daily number of starts of PC and MC is displayed in Figure 19. It is concluded that both
PC and MC share the same tendency with 3~5 starts/day. 167 PCs make total 718 starts and 1707 MCs make 8017 starts and they are equivalent to average daily starts of 4.30 and 4.75 for PCs and MCs, respectively. In addition, Figure 20 shows that the starts frequently occur during 6:00~8:00 and 16:00~18:00 for not only PCs but also MCs. The tendency is understandable since during these times, people leave home for working and they come back home after work. Another peak of starts happens around 12:00~13:00 when people may go out to have lunch.

3.5.2. Engine Soak Distribution

Figure 21 indicates the overall engine soak length distribution. It is obvious that the long duration between stop-start (longer than 6 hours) occupies the biggest percentage over the others. This is logical since people start engine to leave home for working around 6:00~8:00 and after they come back home (16:00~18:00), they stop engine until the next morning.

![Engine soak length distributions](image)

Figure 21: Engine soak length distributions

Figure 22 presents engine soak distributions by different time of the day. The time category was divided based on the start frequency as showed in Figure 20. It is concluded that the cold starts (soak time > 12h), resulting in the most emission, frequently happen from 6:00~8:00 and from 16:00~18:00. It means the engines were turned off during the night time and noon time. On the other hand, the short engine soaks (<2h) are commonly observed during periods of 8:00~16:00 and 18:00~22:00. During these periods, people are going out for business, lunch, dinner, etc. Therefore, the duration between stop ant start engines is short.

![Engine soak length distributions by different times of day](image)

Figure 22: Engine soak length distributions by different times of day
4. CONCLUSIONS

Using data obtained from questionnaire, video and GPS surveys in HCMC, this research figured out the characteristics of PC and MC fleets as well as their driving conditions to build necessary input data for IVE model. It is found that the fleets are characterized by young populations (less than 5 year-age), medium engine volume (PC: 1.5~3liter, MC: 100~300cc) and low usage (less than 79 thousands km for PC and 25 thousands km for MC). Average ages of PCs and MCs are 4.84 and 4.15 years old, respectively. In addition, their daily usages are 35.92 km/day (PCs) and 25.98 km/day (MCs). Moreover, it is found that most of PCs and MCs fail to comply with any Euro standard, especially MCs. This may be associated with greater emissions from the fleets.

The video analysis showed that volume of PCs on highway is about 5 times higher than the volume on arterial. Additionally, it is approximately 10 times bigger compared to residential. Turning to MCs, it is concluded that their volume on highway is larger than other streets, but not significant, nearly 2 times compared to arterial and almost 3 times compared to residential. Furthermore, the comparison between two modes show that on highway, the volume of MCs is 10 times greater than the volume of PCs. Meanwhile, on arterial and residential, it is extremely higher than the volume of PCs, almost 40 times. The results suggest that MCs should be carefully considered when promoting HCMC’s citizens to switch their private modes to public transportation or when estimating traffic emissions in HCMC.

Regarding driving conditions, our results indicate the stable conditions in term of acceleration/deceleration on highway, in addition to the higher speeds. On the other hand, the driving conditions on arterial and residential are not stable due to frequent acceleration/deceleration and the speeds are lower. The average speeds of PCs are 42.80km/h (highway); 19.75km/h (arterial) and 16.83km/h (residential). Meanwhile, that of MCs are 37.32km/h (highway); 20.39km/h (arterial) and 17.39km/h (residential). These findings are also confirmed by VSP analysis, where the group of VSP 11, indicating zero or very low power, is common on arterial and residential for both PCs and MCs. In addition, the engine stress at medium and high levels is hardly ever observed on those streets. By contrast, the groups of VSP that represent positive power as well as the medium and high engine stress levels are normally seen on highway. It indicates the driving conditions of constant speeds and less acceleration/deceleration on highway.

Switching to start-up pattern and soak distribution, it is concluded that in average, the PCs have 4.30 times start-up per day and MCs have a little bit higher start-up frequency with 4.75 times/day. The start-up with long engine soak commonly occur during morning and afternoon peak hours (6:00~8:00 and 16:00~18:00) when citizens leave home to work or back home after work.

To sum up, our research contributes to reveal the characteristics of PC/MC fleets and their driving conditions in HCMC, a typical city of developing countries where MCs share a major composition. This research will be further extended to investigate emission inventory from transportation sectors using database presented in this paper and IVE model. In addition, future work is needed to predict the environmental co-benefit before implementing any policy, e.g. Park and Bus Ride or MRT.

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