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ATRANS RESEARCH
Journal of Asian Transportation Research Society

Asian Transportation Research Society (ATRANS)

Asian Transportation Research Society or **ATRANS** in short is a total non-profitable research institution which was initiated on 4 May 2007 and was licensed on 1st April 2008. ATRANS was established for encouragement of academics / researchers to conduct an empirical and pragmatic research regardless of transportation-related problems, traffic safety, energy and environment in multidisciplinary manner. ATRANS is expected to play an important role in increasing communication between experts in fields related to transportation, not only in Thailand, but across Asia. ATRANS is also expected to encourage the launch of many new collaborative research endeavors, and to propose significant policies based on such research from a fair and unbiased standpoint.

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ATRANS RESEARCH

Journal of

Asian Transportation Research Society

Chairperson's message

The Asian Transportation Research Society (ATRANS) is pleased to present the second volume of ATRANS Research: Journal of Asian Transportation Research Society.

Transportation plays a significant role in supporting economic growth and better quality of life in society, but it is a two-edged sword. While transportation provides great benefits it also generates adverse effects. Since its foundation in May 2007, ATRANS has tackled transportation and traffic safety issues regarding Thailand and other Asian nations by promoting research projects, symposia, and other related activities.

Last year we successfully launched the first volume of our journal, ATRANS Research, bringing together papers that describe the results of ATRANS research projects in addition to contributions from overseas. This second volume also contains many interesting research findings and outcomes including a special issue section for student version. This special issue (student version) is launched so as to provide an opportunity to students to submit their quality papers for peer-review and publication in ATRANS Research.

Publishing our own journal is a challenging endeavor but is an effective way to disseminate the results of ATRANS research projects worldwide. More importantly, we believe it could make an important social contribution by providing a platform for active academic discussion in the range of transportation-related issues that face most Asian nations in today's mobile society.

We hope readers / viewers will make active use of this platform, and by doing so make it part of the solution to tackling transportation-related issues throughout Asia and beyond.

Finally, as chairperson I would like to express my deepest appreciation to everyone who made publication of this second volume possible, and to ask for your continued support and attention.

With best regards,

Rapin Charutula, Mr.
Chairperson
Asian Transportation Research Society (ATRANS)
Bangkok, December 2010

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JOURNAL OF

ASIAN TRANSPORTATION RESEARCH SOCIETY

Editor-in-Chief's message

Asian Transportation Research Society (ATRANS) is a total non-profitable research institution with the sustenance of the International Association of Traffic and Safety Sciences (IATSS), Japan. ATRANS's principal mission is to promote research activities and provide research funds for Asian academics and young researchers to conduct empirical and pragmatic researches in transportation related field, traffic safety, energy and environment in multidisciplinary manner.

To achieve the mission, one of the important tasks is to issue a yearly international level publication: ATRANS Research: Journal of Asian Transportation Research Society. Thanks to the telecommunication technology, ATRANS Journal is able to receive generous cooperation from friends and colleagues worldwide, participating in the paper review and publication processes. All submitted papers are peer reviewed by at least two reviewers and the editorial board, formed by Thai and renowned foreign transport research experts.

This second volume of the ATRANS Journal has six interesting papers: three from the ATRANS research projects funded during 2008-2009 and other three selected students' papers from the ATRANS Symposium Student Chapter session held in Bangkok in August 2009 and 2010.

I hope this ATRANS Journal has brought the up-to-date scientific knowledge in transport research and practice. I also hope that the journal will become an important means of promotion and transferring the transport achievements and experiences in Asia.

Wiroj Rujopakarn, Prof. Dr. Ing.
Vice Chairperson and Editor in Chief
Asian Transportation Research Society (ATRANS)

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EVALUATION OF STATIC-EQUIVALENT STIFFNESS BY A SIMPLE FALLING WEIGHT DEFLECTOMETER

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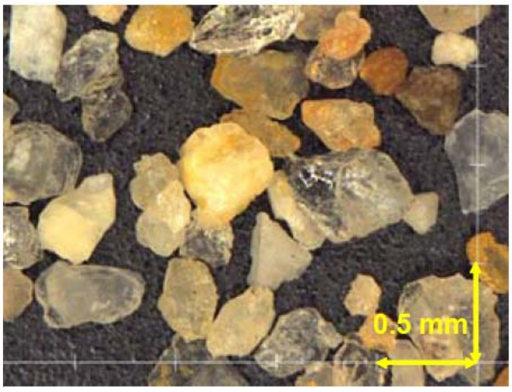
Two series of falling weight deflectometer (FWD) tests and plate load tests (PLT) were performed in a laboratory to evaluate the surface stiffness values of different pavement structures and to compare the results from these FWD tests with the corresponding PLT results. In this study, it was found that the stiffness values originally obtained from the FWD tests were substantially higher than the values from the PLTs. The differences in the results between FWD test and PLT are, at least, attributed to: a) dynamic property; and b) viscous property of test materials. Adjustments on the FWD test results were performed by taking the two above-mentioned factors into consideration. Then, it was shown that the stress-strain relations by FWD tests became similar to the ones of PLTs. However, it was inconvenient to employ the above-mentioned adjustments on FWD test result prior to determining the stiffness values. Therefore, in this study, an analytical method by undamped harmonic motion (UHM) was introduced to determine the static-equivalent stiffness by FWD tests. It was found that, after having been analysed by UHM method, the stiffness values by FWD and PLT were similar. Therefore, based on UHM method, FWD test can be used in place of PLT to accurately obtain the stiffness values of different pavement structures.

Keywords: Stiffness, Modulus of subgrade reaction, Falling weight deflectometer, Plate load test, Pavement

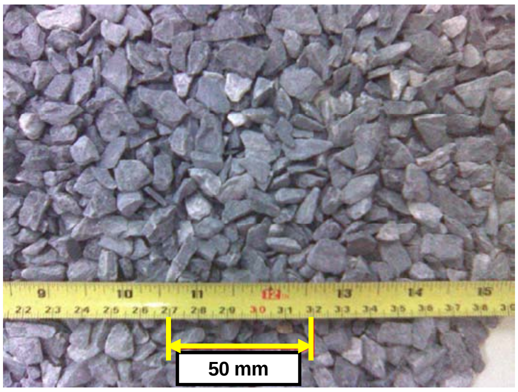
1 INTRODUCTION

Road maintenance is important to keep the safety so that road can serve for transportation. It is therefore necessary to evaluate the pavement structure physical condition to select the location for repair work. This evaluation is usually based on the pavement deflection and/or stiffness. In general, when the pavement structure physical condition was deteriorated, the deflection and stiffness respectively increased and decreased to values that are significantly higher and lower than the ones before deterioration. In conventional practice in the field, the deflection is measured by non-destructive devices (NDT), for example, Benkelman Beam, La Croix Deflectograph, by which tests are performed by applying static or slowly moving loads (Shahin, 1994). On the other hand, Plate Load Test (PLT) is usually employed to determine the stiffness of pavement structure. These conventional tests, which are categorised as static tests, to determine deflection and stiffness are time-consumed and therefore it is very difficult to employ them on sufficient number of locations during maintenance.

To this end, a number of dynamic test devices for stiffness evaluation were introduced, for example, Falling Weight Deflectometer (FWD) aiming on reducing operation time on a test location. Stiffness by FWD test is determined by applying load dynamically on the pavement surface and then measuring the settlement. However, despite that tests were performed on the same test conditions, stiffness values



a)



b)

c)

Figure 1 Constituting Materials to Prepare for Different Pavement Sstructures in This Study: a) KMUTT Sand; b) Uniform Gravel; and c) Asphaltic Concrete

determined by dynamic test devices were higher than the values determined by conventional tests (e.g., Bush and Baladi, 1989; AASHTO, 1993; Ping et al., 2002; George, 2003; Loizos et al., 2003; Hirakawa et al., 2008).

In view of the above, a simple small-size FWD was newly developed in this study. Experiments were performed on three different pavement structures to account for different stiffness values. Also, PLTs were performed in parallel with FWD tests for respective pavement structures to compare the test results. Reasons for difference between FWD and PLT results were unveiled. Then, the static-equivalent stiffness by FWD was determined. All the experiments presented in this study were performed in a temperature- and humidity-controlled laboratory.

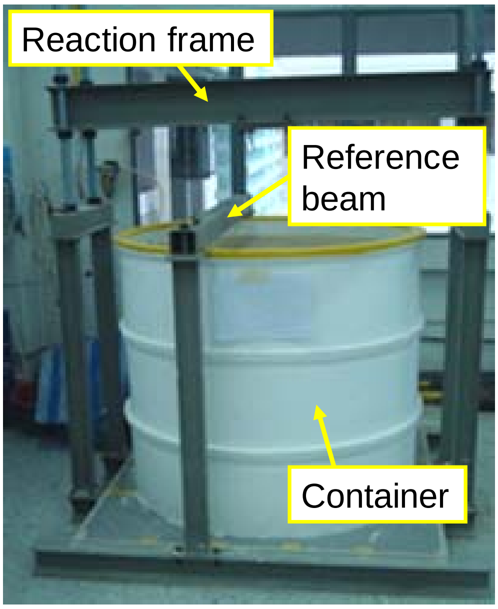


Figure 2 Cylindrical concrete container for scaled-down modelling of different pavement structures

2 TEST METHODS

2.1 Test Materials

Cleaned uniform sand named "KMUTT sand" (Figure 1a) was used to prepare subgrade layer in this study. It is originally sediment river bed sand from Ratchaburi province, Thailand. It was firstly prepared by sieving the original sand to pass through sieve No. 40 (0.425 mm) and to retain on sieve No. 100 (0.150 mm). Then, it was cleaned by tap water to remove dust and undesired materials and then dried by an oven at a temperature of 140 °C for 24 hours to make dried and eliminate any organic matter. This sand is a sub-angular uniform fine sand, classified as SP following the Unified Soil Classification System with D_{50} = 0.285 mm; the maximum and minimum void ratios equal to 1.06 and 0.71; and a specific gravity equal to 2.64.

Uniform gravel (Figure 1b) to model for the top surface of gravel road (explained later) was modified from coarse aggregates. It was prepared by sieving the coarse aggregates to pass through sieve opening 3/8 in. (9.50 mm) and to retain on sieve No. 4 (4.75 mm). Then, it was cleaned by tap water and dried by an oven, similar to KMUTT sand.

A layer of hot-mixed asphaltic concrete was prepare to model for the asphaltic pavement (explained later). In this study, aggregate for preparing asphaltic concrete consisted of both coarse and fine aggregates. The particle size distribution of aggregate was based on standard test No. DRR 209-2545 of the Department of Rural Roads, Thailand. On the other hand, asphaltic cement of AC 60/70 grade was used to prepare the asphaltic concrete (DRR 230-2545). Then, both aggregates and asphaltic cement were heated in an oven for about two hours at temperature of 145±5 °C before bringing them for mixing. Then, they were mixed on tray placed on a stove. The amount of asphaltic cement used was at the optimum asphaltic content of 5 % by weight of aggregate (Thaisri et al., 2008). Then, a layer of asphaltic concrete having 95 cm in diameter and 5 cm in thickness (Figure 1c) was prepared by compacting hot-mixture of aggregate and asphaltic cement into a mould. Compaction was performed by dividing the thickness into two equivalent layers and controlling the density to be equal to 2.13 g/cm^3. Subsequently, the temperature of specimen is allowed to decrease until lower than 60 °C. Then, the specimen was removed from the mould and each specimen was cured for 16 hours before being used (ASTM D 6927-06).

2.2 Test Ppreparations

A container was used for scaled-down modelling of the pavement structures for testing in laboratory (Figure 2). It was made from a cylindrical concrete-tube having 100 cm in inner-diameter, 90 cm in height and 5 cm in thickness. All materials for modelling different pavement structures were filled-in this container.

When preparing layers of KMUTT sand by compaction method, not only it is difficult to control the homogeneity of sand layer but also it is possible that sand particles are broken, resulting in variation of particle-size distribution. In place of compaction, a multiple-sieving apparatus was used to prepare subgrade layer by pluviating air-dried KMUTT sand through air into the container. This apparatus was made based on a typical pluviation method for preparing triaxial sand specimen (Miura and Toki, 1982). By means of this technique, the sand sample thus obtained was significantly similar to the one prepared by well-compacted dry-compaction in that the average densities were similar; however, the air-pluviated sand sample was more uniform than the compacted one.

Three different pavement structures including unpaved and paved structures were modelled in the container. They are: 1) unpaved subgrade structure; 2) gravel surface subgrade structure; and 3) asphaltic-paved structure. The unpaved subgrade structure was prepared by pluviating air-dried KMUTT sand (Figure 1a) into the container until the height of 90 cm (Figure 3a). On the other hand, for gravel surface subgrade structure, air-dried KMUTT sand was pluviated into the container until the height of 65 cm and then the gravel (Figure 1b) was pluviated by passing through the sieve opening 1/2 in. (12.5 mm) to model the gravel surface of 25 cm in thickness (Figure 3b). Similarly, for asphaltic-paved structure, air-dried KMUTT sand was pluviated into the container until the height became 85 cm and then the 5-cm thick asphaltic concrete layer was placed on the top surface (Figure 3c).

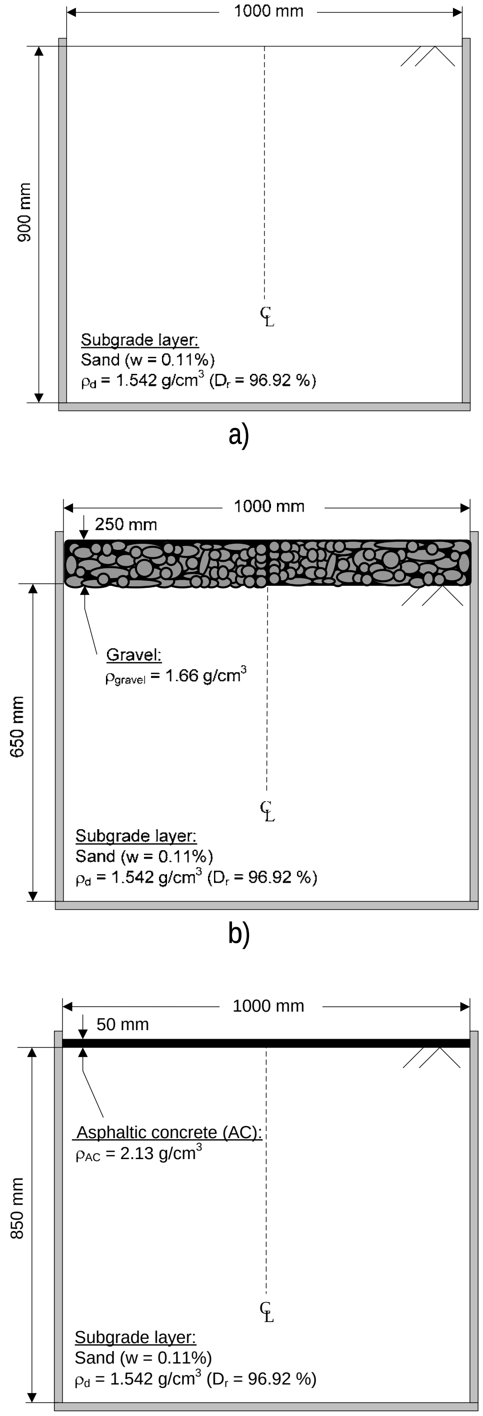


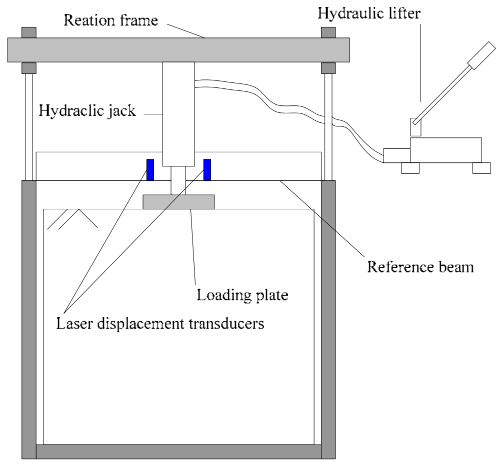
Figure 3 Configurations of: a) Unpaved Subgrade Structure; b) Gravel Surface Subgrade Structure; and c)

2.3 Test Devices and Measurement

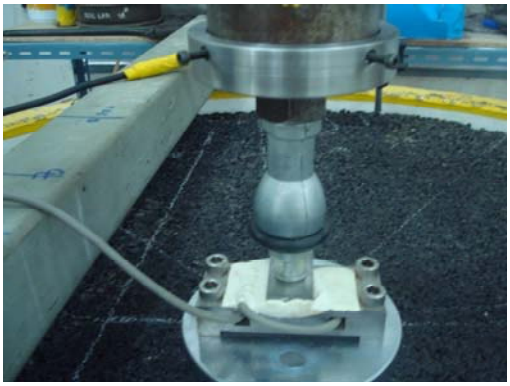
Plate Load Tests

Plate Load Tests (PLTs) were performed to determine the modulus of subgrade reaction on the three above-mentioned different pavement structures. All PLTs were performed by using a circular loading plate having 15 cm in diameter. The influence factors determined following the Boussinesq's formula for the vertical boundary at the side and the horizontal boundary at the bottom of the container were less than 5 %. Therefore, any boundary effects were obviously insignificant. Test procedures were in accordance with ASTM D 1195-93. A hydraulic lifter was installed between the loading plate and the reaction frame of the container to apply compression on the plate at a constant rate of settlement of ±0.3 mm/min (Figure 4a). A universal joint was installed on the plate to eliminate any bending moment (Figure 4b). The settlement of loading plate was measured by laser displacement transducers installed on the reference beam (Figure 2) that is independent of compression of the loading plate. The load generated by the hydraulic lifter was measured by a load cell installed on the loading plate (Figure

4b). These measurements were recorded by a dynamic data



a)



b)

Figure 4 Configurations of Plate Load Test: a) Global Detail of Set Up; and b) Connection Detail for Eliminating any Bending Moment

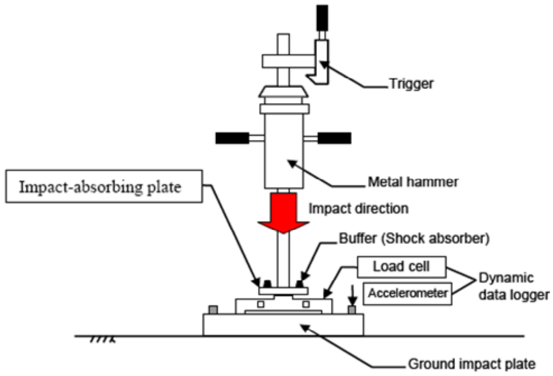
logger at a sampling frequency of 1 Hz. PLTs were

performed by applying steps of loading and unloading as global (repetitive) for about seven cycles until the maximum value of plate pressure exhibited.

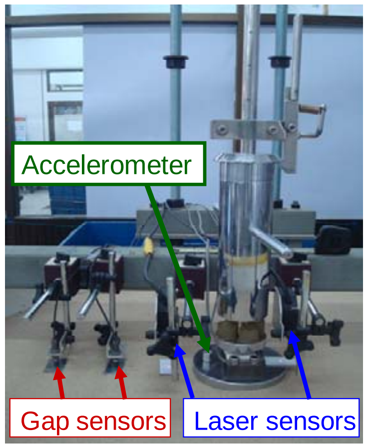
Falling Weight Deflectometer

A Falling Weight Deflectometer (FWD) was newly developed in this study, modifying from a prototype (i.e., Hirakawa et al., 2008). It consisted of a ground impact plate, a load cell, an accelerometer, a set of dampers, a guiding rod with handle, a hammer and a trigger (Figure 5a). Impact loads and consequent deflections were measured by a load cell and accelerometers (Figure 5b), respectively. The hammer can be manually lifted and hold with the trigger and used to generate the impulse load. The generated impact load could reach 20 kN when the falling height is 500 mm. Tests were performed by increasing the falling heights in series as: 10, 25, 50, 100, 200, 300, 400 and 500 mm for all different pavement structures. All data were recorded by a dynamic data logger at sampling frequency of 5 kHz. Detail of the FWD was listed in Table 1.

Accelerometers were used to measure the surface settlement and transient deformations inside the backfill by double-integration time histories of acceleration. In this study, three



a)



b)

Figure 5 Configurations of Falling Weight Deflectometer Used in This Study: a) Global Detail; b) Detail of Settlement Measurement

accelerometers having different measuring capacities of

100g, 50g and 20g; where g is the gravitational acceleration were used. Commonly, for the three different pavement structures, the 100g-accelerometer was installed on the ground impact plate to measure the plate settlement while the 50g- and 20g-accelerometers were placed inside the subgrade at the depths of 15 cm and 30 cm measured from the top surface of subgrade, respectively. In addition, when performing tests on unpaved subgrade structure, tests were re-performed at the same conditions by changing the locations of these three accelerometers to adequately measure the transient deformations and their distributions inside the subgrade (explained later).

Furthermore, two laser displacement sensors and two gap sensors (Figure 5b) were installed on the reference beam installed across the concrete container to measure the plate settlement and the surface settlements at 0.75D, 1.25D and 2D from the plate centre; where D is the diameter of ground impact plate (150 mm). However, these measurements were prepared for further analyses which are out of scope of this study.

3 ANALYTICAL METHODS BY UNDAMPED HARMONIC MOTION

A method for evaluating modulus of subgrade reaction from a FWD test was introduced. This method can be described by the Newton's law of motion or undamped harmonic motion (UHM) (Das, 1992).

Table 1 Detail of Falling Weight Deflectometer Used in This Study

Items	Values/Details
Weight of metal hammer	10 kg
Maximum falling height	500 mm
Maximum impulse load	20 kN
Loading plate diameter	150 mm
Impact load measurement	Load cell
Displacement measurement	Accelerometer
Measurement sampling frequency	~ 5 kHz
Total weight	19.23 kg

Figure 6 shows a resting loading plate on a spring. Let the spring having a spring constant of k_{ground} represents the elastic properties of the ground. If the loading plate is disturbed from its static equilibrium position, the system will vibrate for a single-action dropped hammer. The equation of motion of the loading plate when it has been disturbed through a vertical displacement (u) can be written from UHM (e.g., Hirakawa et al., 2008; Das, 1992) as:

$$\ddot{u} \cdot m_p + k_{ground} \cdot u = 0 \tag{1}$$

where u is the vertical displacement; $\ddot{u}$ is the vertical acceleration; and m_p is the summation of mass of loading plate, load cell, damper, guiding rod and trigger (= 9.23 kg; Figure 6). From Equation 1, let u is:

$$u = A_1 \cdot \cos \omega_n t + A_2 \sin \omega_n t \tag{2}$$

where A_1 and A_2 are constants; ω_n is natural frequency; and t is the elapsed time. From Equations 1 and 2, we obtain:

$$\omega_n = \sqrt{\frac{k_{ground}}{m_p}} \tag{3}$$

Substituting Equation 3 into Equation 2, we obtain:

$$u = A_1 \cdot \cos\left(\sqrt{\frac{k_{ground}}{m_p}} \cdot t\right) + A_2 \sin\left(\sqrt{\frac{k_{ground}}{m_p}} \cdot t\right) \tag{4}$$

At time t = 0, the vertical displacement $u = u_o$. Therefore, from Equation 4, we obtain:

$$u_o = A_1 \tag{5}$$

Differentiate Equation 4 and then substitute that the vertical velocity $du/dt = \dot{u} = v_o$, we obtain:

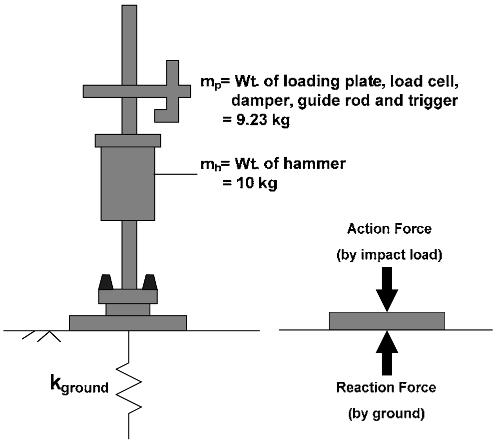


Figure 6 Illustration of Action Force and Reaction Force from a FWD Test on Ground

$$\dot{u} = v_o = A_2 \cdot \sqrt{\frac{k_{ground}}{m_p}} \tag{6}$$

At t = 0, the vertical displacement rate at the moment of impaction can be defined by the conservation of energy law (e.g., Walker, 2004) as:

$$v_o = \sqrt{\frac{m_h}{m_p} \cdot \left(v_b^2 - v_a^2\right)} \tag{7}$$

where m_h is the mass of hammer (= 10 kg; Figure 6); v_o is the velocity of the loading plate; and v_a and v_b are the velocities of the hammer after and before the impact. Here, it is assumed that v_a = 0. The velocity of the hammer immediately at the moment before impaction to damper by the weight freely dropped from the height h is:

$$v_b = \sqrt{2 \cdot g \cdot h} \tag{8}$$

Combining Equations 6, 7 and 8, we obtain:

$$A_2 = \sqrt{\frac{2 \cdot g \cdot h \cdot m_h}{k_{ground}}} \tag{9}$$

From the boundary conditions of $u = 0$ when $t = 0$ we obtain: $u_o = 0$ and therefore:

$$u = \sqrt{\frac{2 \cdot g \cdot h \cdot m_h}{k_{ground}}} \cdot \sin \omega_n t \qquad (10)$$

Table 2 Comparison of Modulus of Subgrade Reaction between k_{PLT} Directly Obtained Following AASHTO and FDOT Methods and k_{UHM}

Pavement structure	Modulus of subgrade reaction (kPa/mm)		
	PLT (k_{PLT})		FWD† (k_{UHM})
	AASHTO*	FDOT§	
Unpaved subgrade structure	98.15	85.96	61.82
Gravel surface subgrade structure	78.55	73.30	60.28
Asphaltic-paved structure	281.45	203.08	143.70

Note: * = Eq. 13; § = Eq. 14; and † = Eqs. 11 &12

Then, the peak vertical load acting on the ground is:

$$F_{peak} = \sqrt{\frac{2 \cdot g \cdot h \cdot k_{ground} \cdot m_h}{1000}} \qquad (11)$$

where F_{peak} is the peak vertical load on the plate (kN); g is the gravitational acceleration (m/s^2); h is falling height (mm); k_{ground} is ground spring constant (kN/mm); and m_h is the hammer weight (kg). Then, by following undamped harmonic motion, we can determine the modulus of subgrade reaction from FWD test as:

$$k_{UHM} = k_{ground} / A_p \qquad (12)$$

where A_p is the area of the plate (m^2)

4 TEST RESULTS AND DISCUSSIONS

4.1 PLT Results

Figures 7a, b and c show relationships between the plate pressure (p) and the plate settlement (s) obtained from PLTs on unpaved subgrade structure, gravel surface subgrade structure and asphaltic-paved structure, respectively. Respective fourth-degree polynomial functions were best fitted to the post-yielding regimes of repetitive $p-s$ relations to obtain the non-repetitive ones. Then, the following methods to determine the modulus of subgrade reaction (k_{PLT}) were applied to these $p-s$ relations:

AASHTO method: AASHTO (1993) defines k_{PLT} from a $p-s$ relation as:

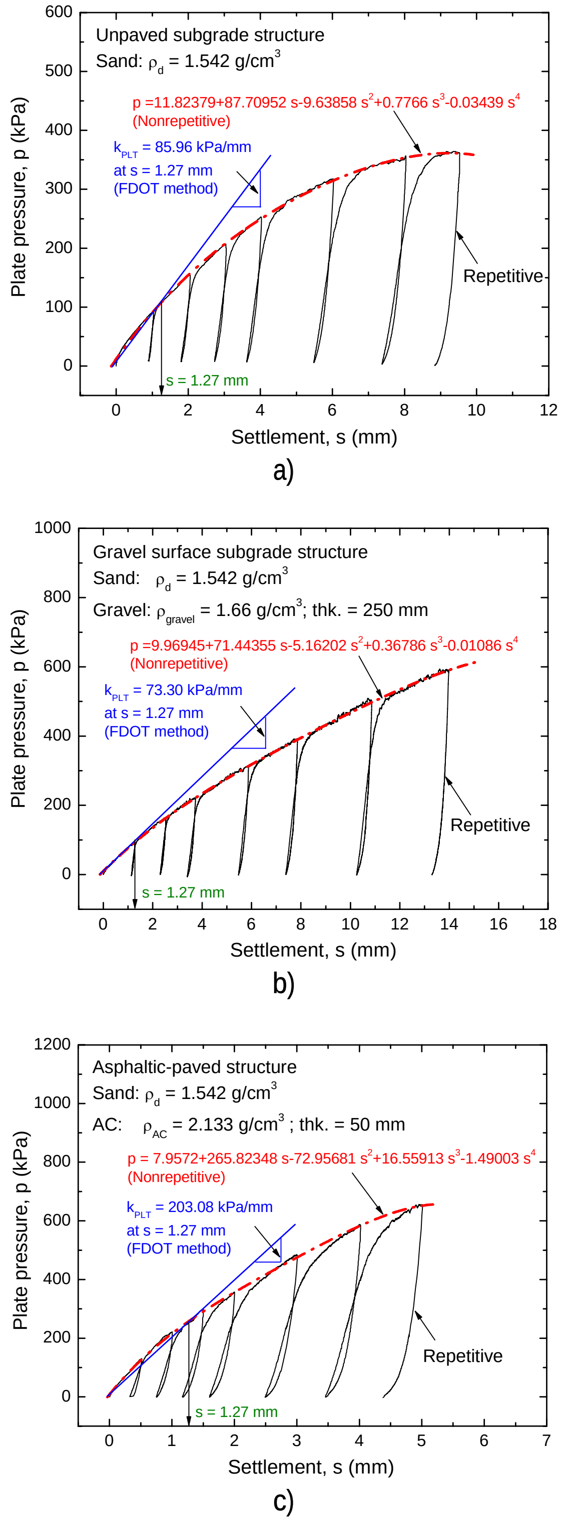


Figure 7 Relationships between Plate Pressure and Settlement from PLT and Modulus of Subgrade Reaction (FDOT method) Obtained on: a) Unpaved Subgrade Structure; b) Gravel Surface Subgrade Structure; and c)

$$k_{PLT} = \frac{68.9\,kPa\,(10\;psi)}{s\;at\;p = 68.9\,kPa\,(10\;psi)} \qquad (13)$$

FDOT method: FDOT (1988) defines k_{PLT} from a $p-s$ relation as:

Table 3 Modulus of Subgrade Reaction Originally Obtained by FWD Tests on Different Pavement Structures

Falling height (mm)	Modulus of subgrade reaction, k_{FWD} (kPa/mm)§		
	Unpaved subgrade structure	Gravel surface subgrade structure	Asphaltic-paved structure
10	169.21	128.51	629.93
25	115.64	116.25	558.47
50	88.51	98.59	480.09
100	75.21	90.94	422.00
200	68.60	72.31	373.58
300	49.51	58.06	339.00
400	47.10	48.73	280.78
500	41.63	43.49	237.60

Note: § = Eq. 15

$$k_{PLT} = \frac{p\;at\;s = 1.27\,mm\,(0.05\,in.)}{1.27\,mm\,(0.05\,in.)} \qquad (14)$$

The modulus of subgrade reaction (k_{PLT}) were obtained following AASHTO and FDOT methods as listed in Table 2. The following trends of behaviour may be seen from Figure 7 and Table 2:

1) Similar k_{PLT} values were obtained when based on different definitions by AASHTO and FDOT methods.

2) Asphaltic-paved structure provided a higher k_{PLT} value than the values of unpaved subgrade structure and gravel surface subgrade structure due to that the stiffness of asphaltic concrete layer was higher than the ones of sand and gravel.

3) Modulus of subgrade reaction obtained from gravel surface subgrade structure was lower than the value of unpaved subgrade structure. This is likely due to that the gravel surface was at a loose stage. When comparing the density of gravel surface (1.66 g/cm^3) to values for different conditions of gravel (e.g., Hausmann, 1990), it was found that the gravel surface was in a loose stage.

4.2 FWD Results

FWD tests were performed to obtain $p-s$ relation for each falling height. Settlements measured for subsequent falling heights were accumulated to the precedent values. The modulus of subgrade reaction (k_{FWD}) can be determined from the product of the maximum value of p divided by the maximum value of s for respective falling height as:

$$k_{FWD} = p_{\max}/s_{\max} \qquad (15)$$

Figures 8a, b and c show the $p-s$ relations obtained by FWD tests on unpaved subgrade structure, gravel surface subgrade structure and asphaltic-paved structure,

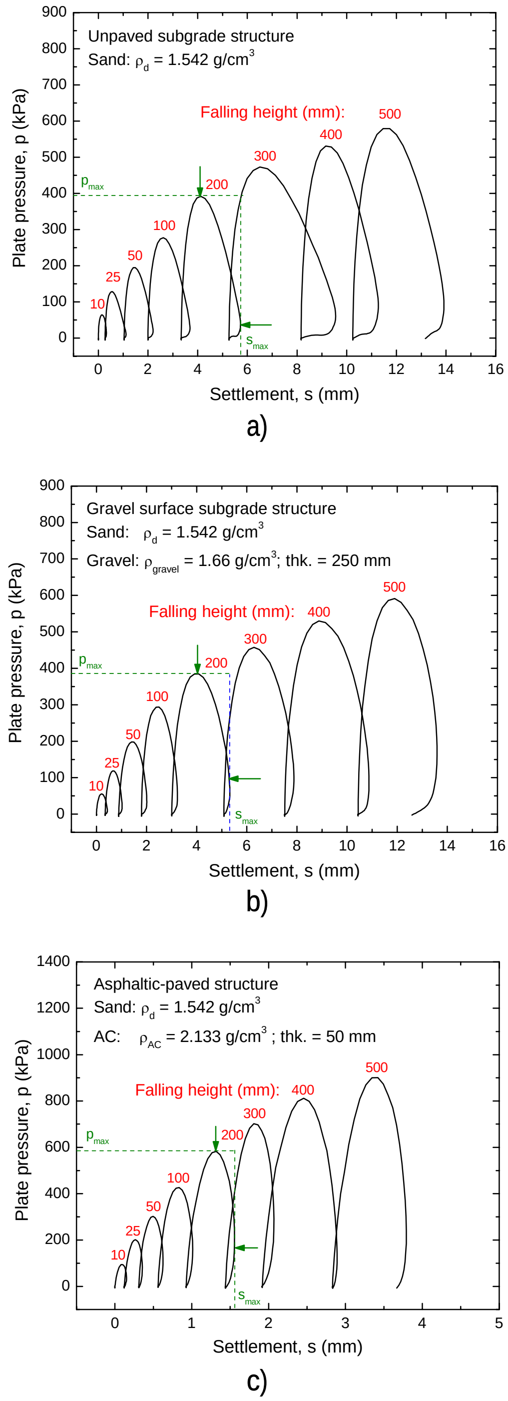


Figure 8 Relationships between Plate Pressure and Settlement from FWD Tests Performed on: a) Unpaved Subgrade Structure; b) Gravel Surface Subgrade Structure; and c) Asphaltic-Paved Structure

respectively. Table 3 lists k_{FWD} values for respective pavement structures. It may be seen that the obtained k_{FWD} substantially decreased with the increasing falling height. Therefore, it becomes difficult to select the suitable k_{FWD} values to represent stiffness of test pavement structures and

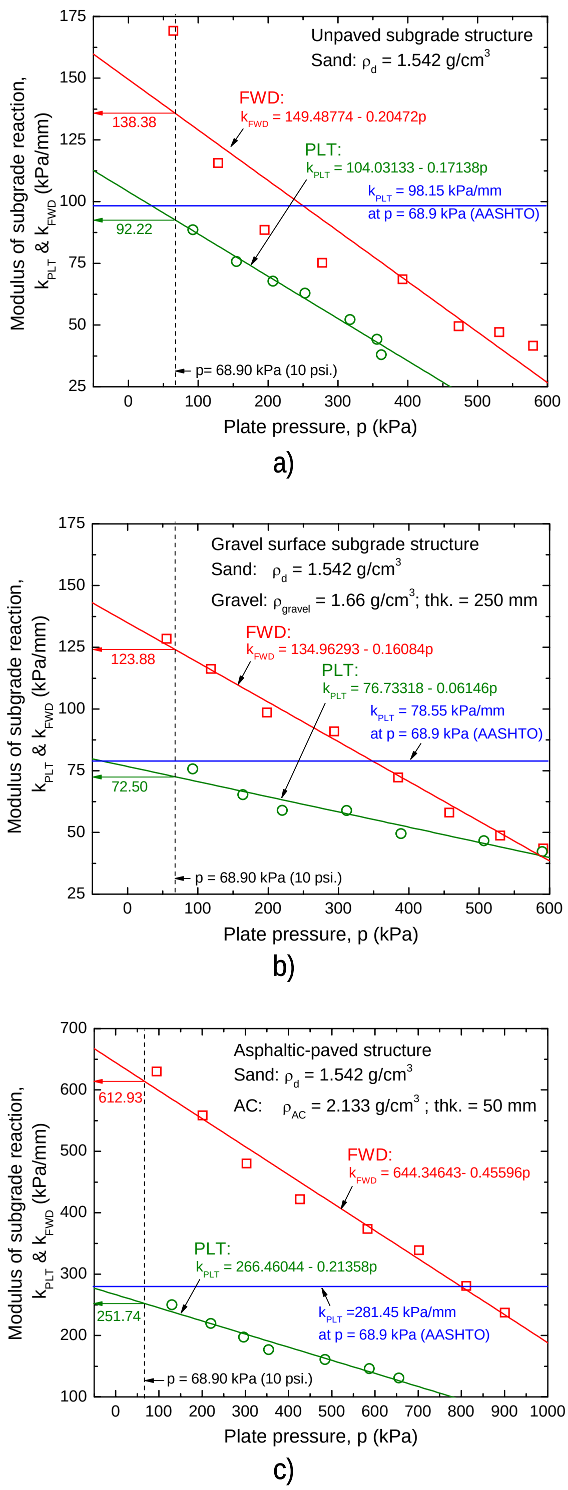


Figure 9 Relationships between Modulus of Subgrade Reaction and Plate Pressure from PLT and FWD Tests Performed on: a) Unpaved Subgrade Structure; b) Gravel Surface Subgrade Structure; and c) Asphaltic-Paved Structure

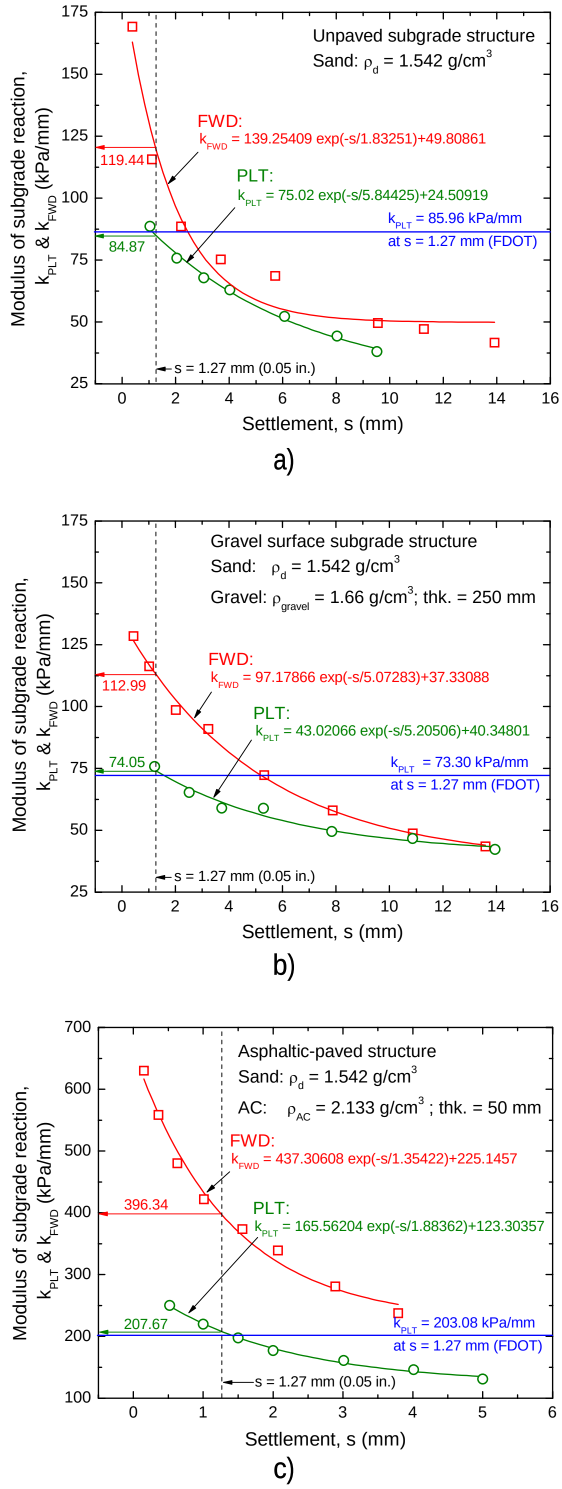


Figure 10 Relationships between Modulus of Subgrade Reaction and Plate Settlement from PLT and FWD Tests Performed on: a) Unpaved Subgrade Structure; b) Gravel Surface Subgrade Structure; and c) Asphaltic-Paved Structure

to compare with k_{PLT} in a systematic manner.

To this end, k_{FWD} values (Table 3) were plotted with the respective values of p for all the falling heights as shown in Figures 9a, b and c respectively for unpaved subgrade structure, gravel surface subgrade structure and asphaltic-paved structure. Furthermore, from the repetitive $p-s$ relations obtained by PLTs, the k_{PLT} values were re-determined for each loop of loading and then unloading. That is, k_{PLT} was determined at the state (s, p) at which the unloading of each loop started. Then, different k_{PLT} values obtained from different loops of loading and unloading were plotted with the respective p values at which the unloading started as also shown in Figures 9a, b and c respectively for unpaved subgrade structure, gravel surface subgrade structure and asphaltic-paved structure. Then, lines were best fitted on $k_{FWD}-p$ and $k_{PLT}-p$ relations for FWD and PLT results, respectively.

Table 4 Comparison of Modulus of Subgrade Reaction between PLT and FWD Tests Based on AASHTO and FDOT Methods

Pavement structure	Modulus of subgrade reaction (kPa/mm)			
	AASHTO		FDOT	
	k_{PLT}	k_{FWD}	k_{PLT}	k_{FWD}
Unpaved subgrade structure	99.22	138.38	84.87	119.44
Gravel surface subgrade structure	72.50	123.88	74.05	112.99
Asphaltic-paved structure	251.74	612.93	207.67	396.34

Similarly, k_{FWD} values were also plotted against the respective s values from different falling heights as shown in Figures 10a, b and c for unpaved subgrade structure, gravel surface subgrade structure and asphaltic-paved structure, respectively. In addition, k_{PLT} values were plotted with respective s values at which the unloading started as also shown in Figure 10. Two 1st-degree exponential decay functions were best fitted to $k_{FWD}-s$ and $k_{PLT}-s$ relations for FWD and PLT results, respectively.

Then, by following the AASHTO method to determine the modulus of subgrade reaction at p = 68.9 kPa (10 psi.), both k_{FWD} and k_{PLT} can be obtained in a consistent way by reading the k_{FWD} and k_{PLT} values from the fitted $k_{FWD}-p$ and $k_{PLT}-p$ relations at p = 68.9 kPa (Figure 9). Similarly, both k_{FWD} and k_{PLT} can be obtained in a consistent way following FDOT method by reading the k_{FWD} and k_{PLT} values from the $k_{FWD}-s$ and $k_{PLT}-s$ relations at s = 1.27 mm (0.05 in.) (Figure 10). These k_{FWD} and k_{PLT} values which were obtained as shown in Figures 9 and 10 are listed in Table 4. The following trends of behaviour may be observed:

1) Different definitions to determine the modulus of subgrade reaction by AASHTO and FDOT methods provided similar k_{PLT} and k_{FWD} values for respective different pavement structures.

2) The values of k_{PLT} directly obtained from non-repetitive $p-s$ relations as listed in Table 2 are similar to respective values listed in Table 4. This confirmed that evaluations of the modulus of subgrade reaction based on the $k_{PLT}-p$ and $k_{PLT}-s$ relations are relevant.

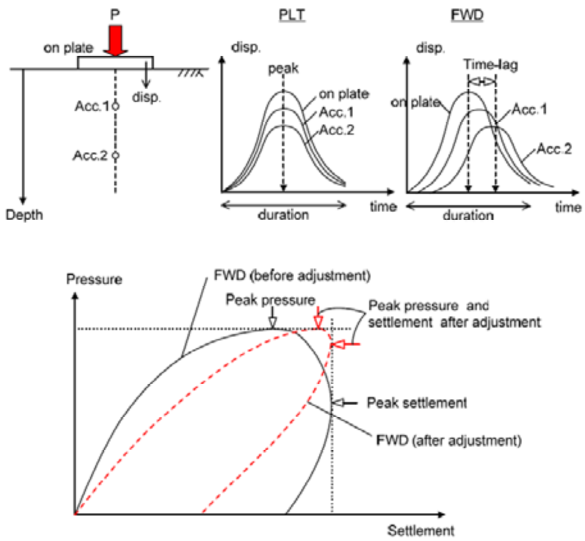


Figure 11 Time-Lag due to Wave Propagation in FWD Test (after Hirakawa et al., 2008)

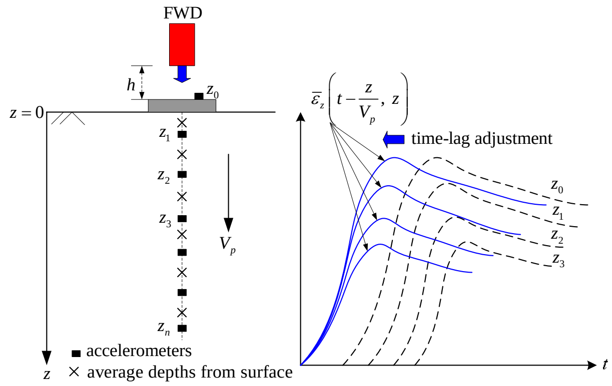


Figure 12 Time Histories of Average Vertical Strains at Different Depths before and after Adjustment for Time-Lag (after Hirakawa et al., 2008)

3) Most importantly, when tested on the same pavement structure, the obtained k_{FWD} values were substantially higher than the respective k_{PLT} values.

4.3 Effects of Dynamic and Viscous Properties

From the above, it seems that the difference in the modulus of subgrade reaction by PLT and FWD are due to, at least, the following two effects (Hirakawa et al., 2008; Masuda, 2007):

1) Dynamic behaviour of tested material; and

2) Viscous behaviour of tested material.

Here, the two above-mentioned effects were explained as follows (Hirakawa et al., 2008):

Dynamic effect

When the falling weight drops onto a surface of material, an impulse enters the material beneath and creates body wave. This results in the different occurrences of peak acceleration when measured at different depths beneath the centre of the loading plate along the vertical direction. The elapsed time measured when the peak acceleration at a location exhibited to the peak acceleration at the next location exhibited is called "time-lag" (Figure 11). Time-lag usually comprises of two components: a) time-lag due to the propagation of the waves from the applied load; and b) time-lag due to material damping of the wave (Lytton and Michalak, 1979). Effects of damping of material may be assumed negligible. Then, the influence of time-lag can be seen by that the settlement under the loading plate by FWD test at the same plate pressure is less than the one by PLT.

Accelerometers were arranged inside the subgrade to measure the accelerations at different specified depths from the surface. The settlement inside the ground u_z can be calculated by double-integration the time histories of acceleration. Then, different settlements measured from accelerations at different depths in the ground were obtained. And, the average strain at each depth can be determined (Hirakawa et al., 2008) as:

$$\overline{\varepsilon}_z = \frac{u_{(z,t)} - u_{(z+\Delta z,t)}}{\Delta z} \tag{16}$$

where $\overline{\varepsilon}_z$ is the average vertical strain; and $u_{(z,t)}$ and $u_{(z+\Delta z,t)}$ are settlements at time t and depths z and $z+\Delta z$. To adjust for dynamic effect, the velocity of wave propagation (V_p) must be investigated and the time histories of average strains at different depths can be adjusted for time-lag as (Figure 12):

$$\overline{\varepsilon}_z(t,z) = \overline{\varepsilon}_z\left(t - \frac{z}{V_p}, z\right) \tag{17}$$

Then, the settlement of loading plate at time = t_1 can be accurately obtained by correcting for the time-lag (Hirakawa et al., 2008) as:

$$[s]_{(t_1)} = \int_{z=0}^{\infty}\left[\int_{t=0}^{t_1} \overline{\varepsilon}_z\left(t - \frac{z}{V_p}\right)\cdot dt\right]\cdot dz \tag{18}$$

where $[s]_{(t_1)}$ is the settlement of loading plate at time = t_1.

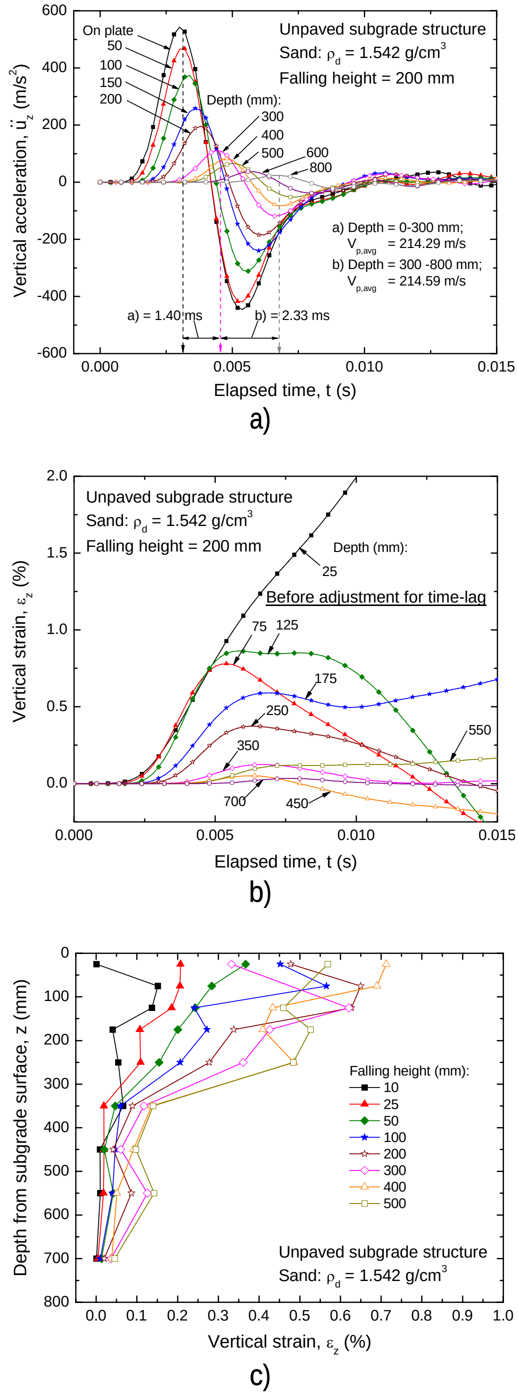


Figure 13 Measurements by Accelerometers Installed at Different Depths inside The Subgrade: a) Time Histories of Local Acceleration; b) Time Histories of Local Vertical Strain; and c) Distributions of Local Vertical Strains at Different Depths Observed at Different Falling Heights

Viscous effect

Loading rate is defined as a time-dependent stress-strain response of a given type of geomaterial due to its viscous property. Basic structure of viscous property of geomaterials is described by a non-linear three-component model (e.g., Di Benedetto et al., 2002; Tatsuoka et al., 2002; Tatsuoka et al., 2008; Kongkitkul et al., 2008). Following this model, the total stress (σ) is composed of the inviscid stress component (σ^f) and the viscous component (σ^v). The σ^v component is a function of the instantaneous irreversible (or viscoplastic) strain rate ($\dot{\varepsilon}^{ir}$ or $\dot{\varepsilon}^{vp}$) and other relevant parameters, not by time. Therefore, the higher $\dot{\varepsilon}^{ir}$ results in

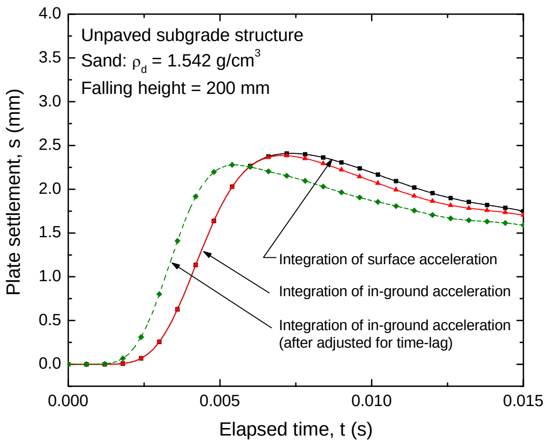


Figure 14 Time Histories of Settlement of Loading Plate Obtained from Acceleration at The Loading Plate Alone and Accelerations Inside The Subgrade with and without Correction for Time-Lags

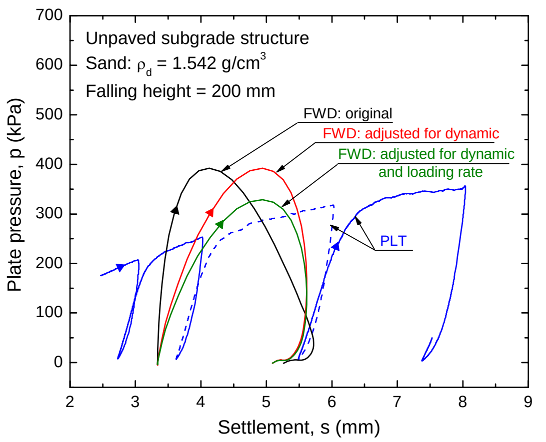


Figure 15 Comparisons of Relationship between Plate Pressure and Settlement before and after Adjustments for Dynamic and Viscous Effects by FWD Test and The Respective Relation by PLT

the higher σ^v. This explains why the plate pressure by a FWD test, at the same value of plate settlement, was higher than the one by PLT, as the value of $\dot{\varepsilon}^{ir}$ encountered in FWD test was substantially higher than the one encountered in PLT.

It is first necessary to know how much the difference in the settlement rates between FWD and PLT was. Then, the consequent amount of plate pressure difference between FWD test and PLT at a given settlement value can be determined. Then, FWD test result can be adjusted for this rate difference and compared with PLT results. The plate pressure differences between FWD test and PLT due to differences in the plate settlement rates can be determined as:

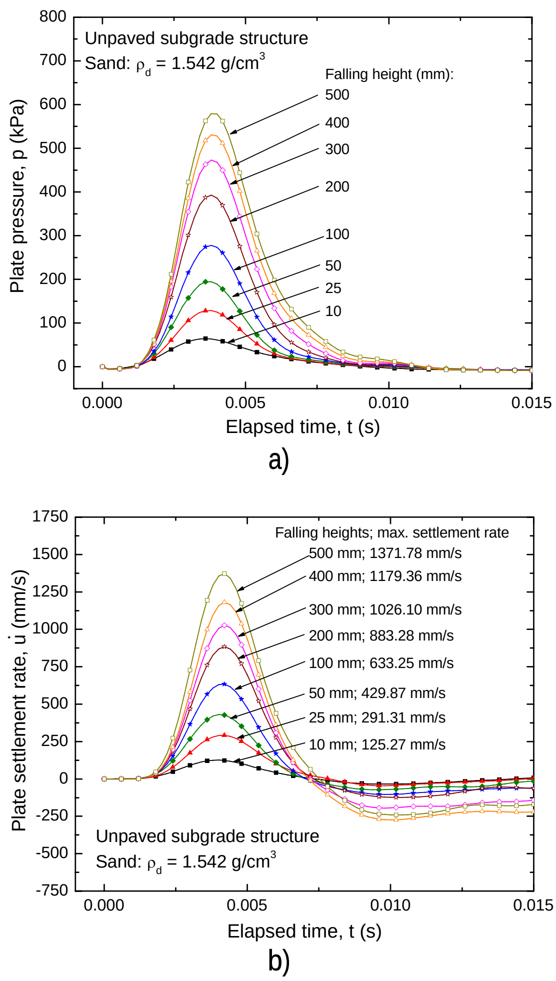


Figure 16 Time Histories of: a) Plate Pressure; and b) Plate Settlement Rate by Different Falling Heights in a Series of FWD Tests

$$\frac{\Delta p}{p} = \beta_{PLT} \cdot \log_{10}\left(\frac{\dot{s}_{FWD}}{\dot{s}_{PLT}}\right) \tag{19}$$

where Δp is the plate pressure difference; p is the instantaneous plate pressure; $\dot{s}_{FWD}$ and $\dot{s}_{PLT}$ are plate settlement rates observed in FWD and PLT tests; and β_{PLT} is the rate-sensitivity coefficient of test material under PLT configurations. Equation 19 was modified from the viscous property quantification for geomaterials tested in triaxial modes (Di Benedetto et al., 2002; Tatsuoka et al., 2002; Tatsuoka et al., 2008). In this study, β_{PLT} for KMUTT sand of 0.0361 was found relevant based on results of consolidated drained triaxial compression test (Moryadee et al., 2009).

Adjustments for Dynamic and Viscous Effects

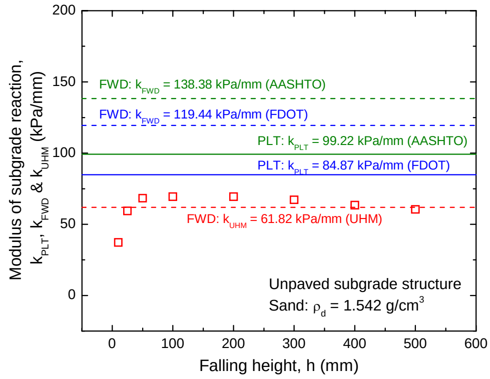
Here, the FWD test result on unpaved subgrade structure was adjusted for dynamic and viscous effects and then compared with respective PLT result. Figure 13a shows time histories of acceleration measured at the loading plate and inside the subgrade when the hammer was dropped from the falling height of 200 mm. It is clearly seen that there were time-lags when wave vertically propagated into the subgrade. Then, the time history of vertical displacement at each depth can be determined by double-integration the respective time history of acceleration. Then, the vertical strains at different average depths were determined following Equation 16 as shown in Figure 13b. Figure 13c shows the distributions of the vertical strains at different depths for all the falling heights. By correcting for time-lags following Equation 17, the corrected time histories of vertical strain were obtained. Then, the settlement of loading plate was obtained following Equation 18 as shown in Figure 14. Figure 15 compares the $p - s$ relations between FWD test with falling height of 200 mm before and after adjustment for time-lag and the respective PLT. It is obvious that, at the same p, the settlements after time-lag adjustment increased when compared with the original one. Importantly, the $p - s$ relation from FWD test became close to the one from PLT after this adjustment.

Figures 16a and b respectively show the time histories of pressure and settlement rate of the loading plate by different falling heights in a series of FWD test. On the other hand, the nominal plate settlement rate for PLT was 0.3 mm/min. The average measured plate settlement rate was 0.237 mm/min (0.00395 mm/s). Then, the $p - s$ relation by FWD test that had been adjusted for dynamic effect (Figure 15) was adjusted again for the loading rate effect based on different ratios of the plate settlement rates by FWD test to the average value by PLT. As seen in Figure 16b, for the falling height of 200 mm, this ratio was about 2.24 x 10^5 when the plate settlement rate by FWD test exhibited the maximum value. Due to this difference in the plate settlement rates, the plate pressure by FWD test was higher than the one by PLT for about 19.31 % (Figure 15) based on Equation 19. Considering for all the falling heights, these ratios were about 10^4 – 10^5. Therefore, the plate pressure by FWD was higher than the one of PLT for about 18.68 % in average.

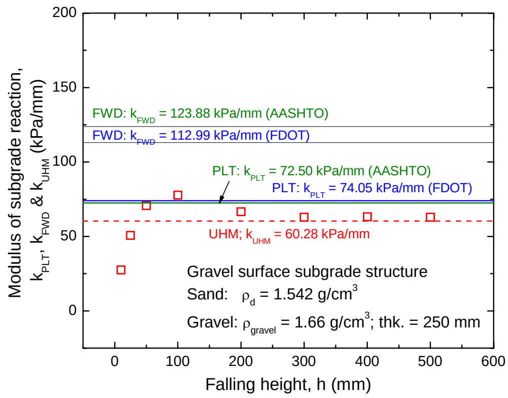
It is therefore necessary to adjust the FWD test results, at least, to account for dynamic and viscous effects to reliably determine the modulus of subgrade reaction of test material. However, it may become very difficult, if not impossible, to measure the vertical strain distributions underneath the loading plate and the viscous property of test material in the field. Therefore, in this study, a simple analytical method by undamped harmonic motion was proposed to determine the modulus of subgrade reaction from FWD test result.

4.4 Modulus of Subgrade Reaction Determined by Undamped Harmonic Motion

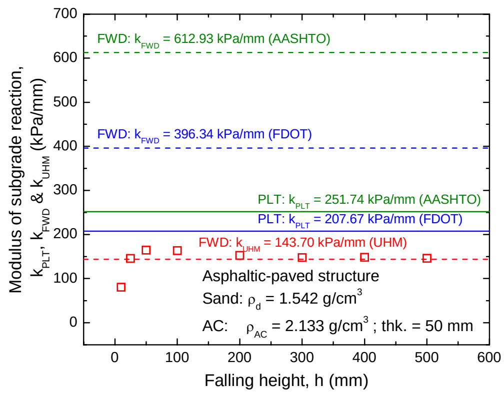
For respective falling heights in FWD test, the maximum force acting on the loading plate (F_{peak}) can be determined. Then, by following Equations 11 and 12, k_{UHM} can be determined. Figures 17a, b and c show the relationships between k_{UHM} and falling height obtained from FWD tests on unpaved subgrade structure, gravel surface subgrade structure and asphaltic-paved structure, respectively. Data points in these figures show respective k_{UHM} values determined by undamped harmonic motion for respective



a)



b)



c)

Figure 17 Comparison between Modulus of Subgrade Reaction Determined by FWD Test and The Respective Value by PLT on: a) Unpaved Subgrade Structure; b) Gravel Surface Subgrade Structure; and c) Asphaltic-Paved Structure falling heights. The horizontal dash line is located at respective average values of k_{UHM} for all falling heights. In addition, k_{UHM} values from FWD tests were also compared with respective k_{PLT} values from PLTs in Figure 17. Table 2 also compares these values of modulus of subgrade reaction. It may be seen from Figure 17 and Table 2 that, for different conditions of pavement structures, k_{UHM} values were similar to respective k_{PLT} values. Therefore, it may be seen that the FWD newly developed in this study is effective. And, the analytical method by undamped harmonic motion to obtain the modulus of subgrade reaction from FWD test is relevant at this moment. It is to be noted, however, that field test results, which are undergoing, are necessary to confirm this relevancy. These will be reported in the near future by authors.

5 CONCLUSIONS

The following conclusions may be derived from test results, discussions and analyses in this study:

1) A simple small-size falling weight deflectometer was successfully developed to reliably determine the modulus of subgrade reaction on various pavement structure conditions.

2) For the same pavement structure condition, the originally obtained modulus of subgrade reaction values by falling weight deflectometer (FWD) tests were always higher than the respective ones by plate load tests (PLTs).

3) Differences in the modulus of subgrade reaction between FWD test and PLT were due to, at least, the time-lag caused by dynamic property (dynamic effect) and the different viscous stress caused by different loading rates between FWD test and PLT (viscous effect).

4) After being adjusted for dynamic and viscous effects, relationships between the plate pressure and the plate settlement obtained by FWD test became close to the ones by PLT. Therefore, if these adjustments were performed, FWD test can be used in place of PLT to accurately obtain the modulus of subgrade reaction for various pavement structures.

5) Analytical method to obtain the modulus of subgrade reaction by undamped harmonic motion (UHM) was relevant for all pavement structures presented in this study.

ACKNOWLEDGEMENTS

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IMPACT OF TRANSPORT ON APARTMENT RENT IN BANGKOK: COMPARATIVE HEDONIC STUDY ALONG RAIL AND ROAD CORRIDORS

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That transportation brings large benefit to the surrounding area is well recognized; however, to what extent it has influence over space is still questionable. This paper examines the effects of transportation on apartment rent by a comparative analysis of rail and road corridorsin Bangkok. Three types of regression model are constructed: ordinary least square regression, spatial autoregressive model, and geographically weighted regression. The global model reveals the degree of explanation of the independent variables such as age of the apartment, proximity to the city center, access to railway station, and local environment. Two types of spatial effect are examined. The spatial dependence is found significant in both cases informing that neighborhood has strong influence in rent setting. On the contrary, the spatial nonstationarity of some variables is present differently. This empirical finding implies that railway has stronger impact to diminish the dissimilarity in the area in terms of property valuation.

Keywords: Hedonic, Spatial Effect, Spatial Dependence, Nonstationarity

1 INTRODUCTION

Since 1960, Bangkok Metropolitan Region of Thailand has undergone rapid urbanization. The total population in 2005 takes 16.8% of the country and produces 44.2% of GDP. Presently the city is extremely busy with almost all kinds of activities. Physically, resident and employment locations are largely concentrated in the inner core. Such urban structure unavoidably generates huge amount of travel demand, which are mostly made by long distance trips by private vehicles. The transportation in Bangkok is presently based on road. Private modal share was 53% while the public modal share 44% in 2005. The reason is that travel on private car is far superior to travel on crowded bus running in heavily congested traffic. The present bus routes are still not enough to accommodate the travel demand, especially from/to suburban areas. Recently, four lines of railway service are available: BTS Sukhumvit line, BTS Silom line, MRT blue line, and SRT airport line. Previous studies showed that the impact of railway to the property development is large (Vichiensan et al. 2007), (Vichiensan and Miyamoto 2010). A similar study stated that the premium of transit accessibility adding to the property value is approximately $10 for every meter closer to the station (Chalermpong 2007). This confirms the impact of transportation to urban development, which is also apparent in other cities. In Hong Kong, there were positive price expectation effects well before the completion of the tunnel (Yiu and Wong 2005). The expectation effects allow the government to finance infrastructure projects by selling land in the affected districts in advance.

Although the previous studies have insisted that railway has large influence on urban development, it is still not very clear how the impact is different than that provided by highway or urban arterial. The objective of this study is to examine how transport has influence on residential property. Although the theoretical contribution of this paper is moderate, it employs the spatial econometric models to empirically evaluate the impact of transportation having on urban development with a comparative case study of railway and road corridors in Bangkok. Due attention has been paid to examining whether spatial effects are present in order to learn the local behavior that make rail and road corridors different. The rest of paper is organized as follows. The next section describes the model framework, followed by case study description. The result of model estimation is presented in the section that follows. Finally, the last section concludes the paper.

2 PRESENT STATUS

The term hedonic is often used in economics, especially in real estate (property) economics, to estimate demand or prices as a combination of separate components, each of which may be treated as if it had its own market or price. In the context of regression, these separate components are often treated as independent variables in the modeling process. Classical hedonic approach has long been employed. For example, The model for Bogota advised that walk access to BRT has great impact on property value (Raskin 2007). Some studies have taken into account the neighborhood effects. The neighborhood composition have great influence on land value in California (Cervero and Duncan 2004).

In terms of model specification, different forms of hedonic price models are constructed. It ranges from classical regression model to complicated spatial regression models. A simple hedonic model is employed in Seoul and indicated that distance to Line-5 subway station has less impact than other factors such as quality of school district, proximity to high-status sub-center, and accessibility to recreational resource (Bae et al. 2003). Likewise, San Diego study showed with simple regression that access to highway is significant effect to office rent while access to LRT is not (Ryan 2005). A similarly simple hedonic regression in Shanghai showed the land value premium of proximity to train station (Pan and Zhang 2008).

Taking into account the spatial effects, models with spatial lag variable were proposed. In Chicago, a spatial autoregressive model examines the impacts of vehicle traffic having on the property values along selected arterial corridors (Kawamura and Mahajan 2005). In Seoul, the impact of transportation accessibility on residential property value in Seoul is examined through a model with similar form (Shin et al. 2007). In Bangkok, a spatial autoregressive regression model was proposed to examine the impact of BTS urban railway on property price (Chalermpong 2007). In Buffalo, NY, the impact of the LRT in New York on station-area property value was determined with an individual regression model for each among 14 LRT stations (Hess and Almeida 2007). Moreover, the effects are not felt evenly throughout the system. The proximity effect is positive in high-income station areas but negative in low-income station areas. In Lisbon, a spatial lag model informs that the proximity to one or two metro lines leads to significant property value changes (Martínez and Viegas 2009).

Literatures in urban studies have shed light to the local variation of the impact by incorporating nonstationarity; a situation when parameter estimates vary with different spatial entity used. For example, geographically weighted regression has been employed to examine the impact of transportation on land use change by looking at local effect (Paez and Suzuki 2001). Similarly, a study in Tyne and Wear Region, UK also employed GWR and found that nonstationarity existing in the relationship between transport accessibility and land value (Du and Mulley 2006). It also showed that transport accessibility may have a positive effect on land value in some areas but in others a negative or no effect. The important conclusion was that a uniform land value capture would be inappropriate. Moreover, based on GWR framework, a nonstationary spatial interpolation method was proposed, in which spatial autocorrelation and nonstationarity were accommodated (Vichiensan et al. 2006).

In this paper, the spatial effect is explicitly considered and represented in the model to determine the factors that influence rent setting along with the variation of the influence over the study area. Three types of models are presented. A classical regression model is a reference model. The rest two models are employed to examineif the spatial effect is present: the spatial autoregressive model and the geographically weighted regression model.

2.1 Ordinary Least Square Regression

Regression analysis is used to model the relationship between one (or more) dependent or response variablesand a number of independent or predictor variables. The general regression model can be specified as follows.

$$y = \boldsymbol{X}\boldsymbol{\beta} + \varepsilon \tag{1}$$

$$E[\varepsilon] = \mathbf{0} \tag{2}$$

$$\mathbf{\Omega} = E[\varepsilon\varepsilon'] = \sigma^2\mathbf{C} \tag{3}$$

where $\boldsymbol{y}$ is a vector (n×1) of observations corresponding to a dependent variable, $\mathbf{X}$ is a matrix (n×k) of observationsof k independent variables, $\boldsymbol{\beta}$ is a vector (k×1) of regressionparameters, $\boldsymbol{\varepsilon}$ is a vector (n×1)of errors, and $\mathbf{C}$ is a positive definite covariance matrix. The errors are often assumed to be normally distributed with an expected value of 0 anda variance-covariance matrix $\mathbf{\Omega}$ of size n×n. Classical ordinary least squares (OLS) is obtained by defining $\mathbf{\Omega}= \sigma^2\mathbf{I}$and the solution for the coefficients is obtained as Equation(4).

$$\hat{\boldsymbol{\beta}} = (\mathbf{X}'\mathbf{X})^{-1}\mathbf{X}'\boldsymbol{y} \tag{4}$$

2.2 Spatial Autoregressive Model

A spatial autoregressive model,or abbreviated by SAR, consists of a spatially lagged term of the dependent variable **y** adding with the explanatory terms and the error as follows.

$$\mathbf{y} = \rho\mathbf{W}\mathbf{y} + \mathbf{X}\boldsymbol{\beta} + \boldsymbol{\varepsilon} \tag{5}$$

This model is similar to a standard linear regression model with the addition of the autoregressive component, which is constructed from a predefined n by n spatial weighting matrix, **W**, applied to the observed variable, **y**, together with a spatial autoregression parameter, ρ, which can be estimated from the data. The model communicates that the value of a variable at a given location is related to the values of the same variable measured at nearby locations, representing the spatial autocorrelation, with the influence of other aspatial predictor variables. The solution to the model in Equation (5) can be obtained in the closed form, i.e., the model coefficients in Equation (6)and the variance in Equation(7) can be estimated by maximizing the log likelihood function in Equation(8) in a straightforward manner.

$$\boldsymbol{\beta} = (\mathbf{X'X})^{-1}\mathbf{X'}(\mathbf{I} - \rho\mathbf{W})\mathbf{y} \tag{6}$$

$$\sigma^2 = \frac{1}{n}\mathbf{y'}[1 - \mathbf{X}\left(\mathbf{X'X}\right)^{-1}\mathbf{X'}]\mathbf{y} \tag{7}$$

$$\ln(L) = -\left(\frac{N}{2}\right)\ln(2\pi) - \left(\frac{N}{2}\right)\ln(2\sigma^2) \tag{8}$$

$$+\ln\left|\mathbf{I} - \rho\mathbf{W}\right| - \frac{1}{2\sigma^2}\left(\mathbf{y} - \rho\mathbf{W} - \mathbf{X}\boldsymbol{\beta}\right)'\left(\mathbf{y} - \rho\mathbf{W} - \mathbf{X}\boldsymbol{\beta}\right)$$

2.3 Geographically Weighted Regression

Geographically Weighted Regression,or abbreviated by GWR, (Fotheringham et al. 2002) is the term used to describe a family of regression models in which the coefficients, **β**, are allowed to vary spatially. The regression model in Equation (1) may be rewritten for each local model at observation location *o* as follows.

$$y_o = \boldsymbol{X}_o\beta_o + \varepsilon_o \tag{9}$$

wherethe sub-index *o* indicates anobservation point where the model is estimated. The coefficients $\boldsymbol{\beta}_o$ are determined by examining the set of points within a well-defined neighborhood of each of the sample points. This neighborhood is essentially a circle, radius *r*, around each data point. However, if *r* is treated as a fixed value in which all points are regarded as of equal importance, it could include every point (for r large) or alternatively no other points (for r very small). Instead of using a fixed value for r it is replaced by a distance-decay function, *f(d)*. Various functional forms of *f(d)* are available. A simple function may be defined such as $f(d) = \exp(-d^2/h)$, where *d* is the distance between the focus point *o* and other data points, and *h* is a parameter (is also called bandwidth). A small bandwidth results in very rapid distance decay, whereas a larger value will result in a smoother weighting scheme. This parameter may be defined manually or alternatively by some forms of adaptive method such as cross-validation minimization or minimization of Akaike Information Criterion (AIC). The variance-covariance matrix for the GWR model may be defined as follows.

$$\boldsymbol{\Omega}_o = E[\varepsilon_o\varepsilon_o] = \sigma_o^2\mathbf{C}_o \tag{10}$$

The diagonal elements of matrix $\mathbf{C}_o$ are given by

$$g_{oi}(\gamma_o, d_{oi}) = \exp(\gamma_o d_{oi}^2) \tag{11}$$

whereas the off-diagonal elements are all equal to 0.

The variance is defined as a function of two parameters, namely σ_o^2 and γ_o, and d_{oi} is the distance between focal point *o* and observation *i* (=1,…, n). The advantage of using an exponential function such as (11) is that the *i*-thdiagonal element of the covariance matrix $\omega_{oi}> 0$ as long as $\sigma_o^2> 0$, thus ensuring positive definiteness. Assuming normally distributed errors with a variance-covariance matrix as in (10)and(11), the local parameter estimates can be obtained:

$$\hat{\beta}_o = (\mathbf{X'C}_o^{-1}\mathbf{X})^{-1}\mathbf{X'C}_o^{-1}\boldsymbol{y} \tag{12}$$

$$\hat{\sigma}_o^2 = \frac{1}{n}(\boldsymbol{y} - \mathbf{X}\hat{\beta}_o)'\mathbf{C}_o^{-1}(\boldsymbol{y} - \mathbf{X}\hat{\beta}_o) \tag{13}$$

These areconditional upon a structure of matrix $\mathbf{C}_o$. These estimators, when substituted and introduced into the corresponding log-likelihood function, result in a concentrated function that depends on a single parameter, namely γ_o:

$$-\frac{n}{2}\ln\left[\frac{1}{n}(\boldsymbol{y} - \mathbf{X}\hat{\beta}_o)'\mathbf{C}_o^{-1}(\boldsymbol{y} - \mathbf{X}\hat{\beta}_o)\right] - \frac{1}{2}\sum_{i=1}^{n}\gamma_o d_{oi}^2$$

The above function can be numerically maximized with respect to γ_o to obtain a parameter that can be substituted in (8) to obtain the maximum likelihood estimates for $\hat{\beta}_o$ .This paper considers the nonstationarity in the hedonic price model parameters and presents a hedonic price model within theGWR framework. The model is estimated in reference tothe OLS and SAR models.

3 COMPARATIVE STUDY

This paper presents a comparative hedonic study of road and railway corridors. The case of railway corridor is the area along Sukhumvit road, which is coinciding with the alignment of BTS Sukhumvit line. The road corridor case is the area along Ladphrao road. Field data collection of residential properties along Sukhumvit and Ladphrao Roads were conducted.

3.1 Sukhumvit Rail Corridor

BTS Sukhumvit line is the first urban rail transit in Bangkok, having been in service for over 10 years.The elevated track of BTS is constructed on the median of Sukhumvit Road. The area has undergone rapid development as a result of BTS and MRT railway services. To illustrate such rapid development along Sukhumvit corridor, the change in land value is observed by considering the officially appraised land value at representative locations along Sukhumvit Road. It is found that land value has appreciated substantially.

In this study, 238 apartments for rent along Sukhumvit Road were investigated for the offering rent and their attributes. Locations of the sampled apartments are shown in Figure 1.The stations of the two urban railway lines, i.e.,MRT blue line and BTS green line, are also shown.

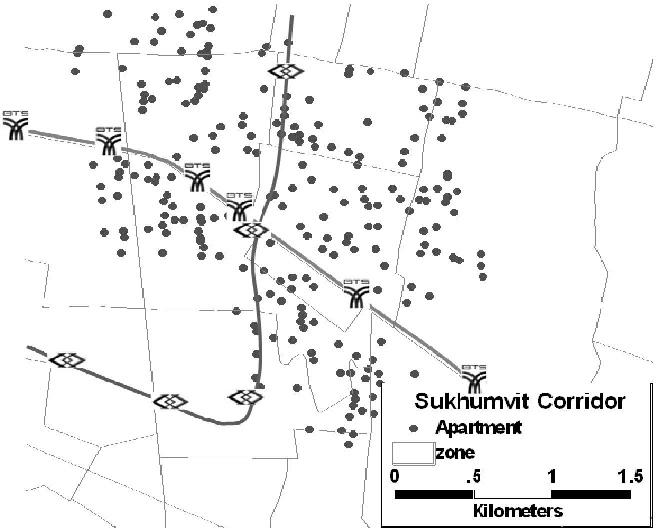


Figure 1 Sukhumvit Study Area

3.2 Ladphrao Road Corridor

Ladphrao road is a radial 8-lane main road connecting the outer residential area to the inner Bangkok area. The traffic congestion in the morning and evening peak is extremely severe since it receives huge amount of travel demand of car and bus traffic. The only alternative public transport is Sansaeb canal boat; however its capacity is limited due to the size of the boat and the physical width of Sansaeb canal. Nevertheless, it accommodates certain number of passenger in and out the city.Figure 2 shows the area along Ladphrao road where the canal boat service is available from many piers in the southern part of the area. These piers can be easily accessed by local transport such as motorcycle taxi. This greatly makes the canal boat popular for middle-income commuters. Although the northern part of Ladphrao Road is not attached to piers, the canal boat is still popular for people living in the eastern area where local transport can bring them to The Mall Pier at low cost. In this study, 452 mid-level apartments for rent surrounding Ladphrao road were investigated; their locations are also shown in Figure 2.

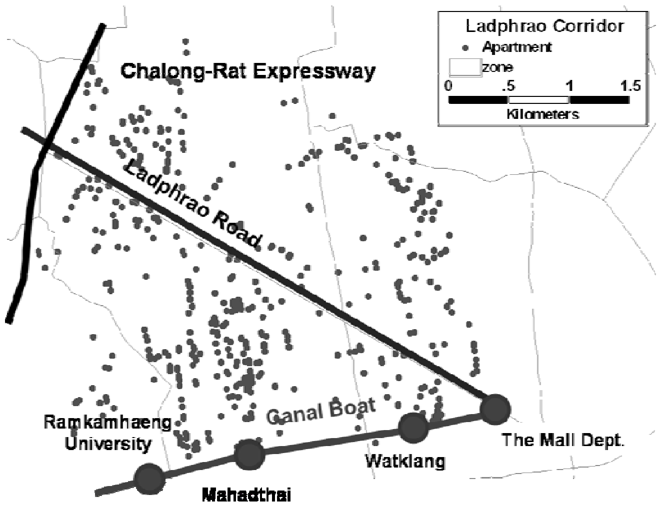


Figure 2 Ladphrao Study Area

3.3 Variables

In the field investigation, threetypes of information areof interest, i.e.,self-attribute of the building such as age; characteristics of the unit being advertised for rent such asoffering rent, floor location, optional service; accessibility to major facilities such as railway station, hospital, or educational institutions.The dependent variable, i.e., rent and the explanatory variables are summarized in Table 1 where the descriptive statistics are shown in Table 2.

Table 1 Variable Description

Variable	*Description (Unit)*
RENT	*Montly rent* of an apartment unit (Baht/sq.m.)
AGE	*Age* of the building (year)
DIST_RAIL	*Distance to urban railway station*, i.e., BTS or MRT station (km); used in Sukhumvit model
DIST_BOAT	*Distance to canal boat pier* (km); used in Ladphrao model
JOB_ ACCESSIBILITY	*Employment accessibility* calculated based on negative exponential expression of job opportunity and travel time; used as proxy of the closeness to the city center in Sukhumvit model
TIME_ LADPHRAO	*Travel time to Ladphrao MRTstation by car*, which has park-and-ride facility; used as proxy of the closeness to the city center in Ladphrao model (minutes)
WALK_ ENVIRONMENT	*Dummy variable*: the value is 1 if the surrounding is walk-friendly; and 0 otherwise.
SHORTCUT_ ROAD	*Dummy variable*: the value is 1 if an apartment is facing to shortcut road that links to the other main roads; and 0 otherwise

Age of the building represents the physical condition of the whole property. It is considered as the time since the last renovation for those refurnished. Station proximity is represented as the reasonable walking distance, which might not be the shortest one but with preferable environment such as width and cleanliness of the walkway, security, shopping attraction, etc. Employment accessibility is calculated from the output of the travel demand model of Bangkok running on CUBE platform where there are 505 internal zones covering Bangkok Metropolitan Region of approximately 7,700 sq.km. The travel timeoutput in year 2005 in the model is used in calculating the employment accessibility based on the negative exponential expression: $A_i = \sum_j Emp_j \exp(-0.1 t_{ij})$ where A_i is the employment accessibility of zone *i*, Emp_j is the number employment in zone *j*, and t_{ij} is the travel time by car from zone *i* to *j* obtained from the travel demand model.The employment accessibility is a proxy variable to represent the urban structure of Bangkok that may beconsidered as a relatively monocentric city where the BTS railway serves as radial line bringing workers in and out the city from the southwestern area.

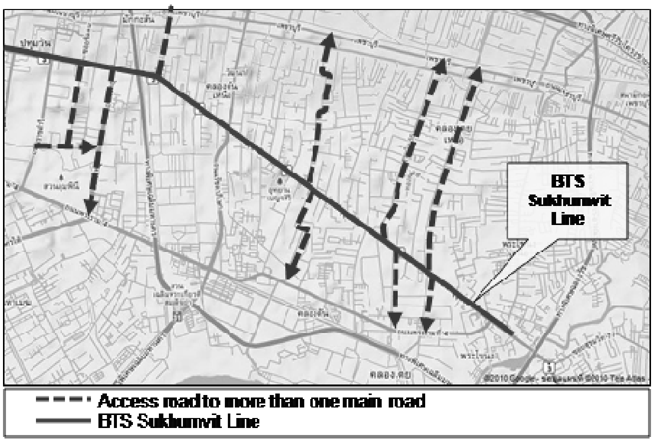


Figure 3 Shortcut Roads

a) Encouraging Walk-Environment

b) Discouraging Walk-Environment

Figure 4 Walk Friendliness

Table 2 Descriptive Statistics

	Sukhumvit Corridor				***LadPhrao Corridor***			
	min	*max*	*mean*	*s.d.*	*min*	*max*	*mean*	*s.d.*
Rent *(Baht/sq.m.)*	120	1,600	388	186	75	389	163	53
Self-attribute								
Age of the building (year)	0.50	39.00	12.41	7.52				
Alternative public transport								
Distance to the MRT station (km)	0.04	2.75	0.75	0.48				
Distance to the canal boat pier (km)					0.13	4.72	2.13	1.12
Proximity to urban center								
Employment accessibility	0.44	6.87	2.41	1.43				
Time to MRT Ladphrao Station (min)					22.92	32.94	29.12	3.30
Local Surrounding								
Walk environment (dummy)	0.00	1.00	0.67	0.47	0.00	1.00	0.83	0.38
Shortcut road (dummy)	0.00	1.00	0.65	0.48	0.00	1.00	0.69	0.46
Number of sample	238				452			

Table 3 Ordinary Least Square Regression

	Sukhumvit Corridor			**Ladphrao Corridor**		
	Coeff.	*t-Stat*	*Std.Coeff.*	*Coeff.*	*t-Stat*	*Std.Coeff.*
Self-attribute						
Age of the building	-12.745	-12.190	-0.515			
Alternative public transport						
Distance to MRT station	-48.763	-2.603	-0.126			
Distance to canal boat pier				-22.993	-11.375	-0.491
Proximity to urban center						
Employment accessibility	35.549	6.233	0.273			
Time to MRT Ladphrao Station				-6.475	-8.926	-0.406
Local Surrounding						
Walk environment (dummy)	68.251	3.873	0.175	20.476	3.573	0.147
Shortcut road (dummy)	43.861	2.494	0.111	9.856	1.984	0.087
Constant	422.236	13.429		377.202	16.614	
Goodness of Fit						
R2	0.441			0.278		
AIC	4,308.7			4,728.8		
Error Sum of Squares	6.53×10^{6}			8.99×10^{5}		

Most of the apartments are located on small roads,called Soi in Thai language. Many of these Soi connect to main roads, i.e., Petchburi road in the north and RamaIV road in the south. These road may be are in fact shortcut roads. Figure 3 shows the shortcut roads along Sukhumvit road, represented in the model by a dummy variable. Walk-friendly environment is also represented by a dummy variable, i.e., the value is 1 if the surrounding attracts people to walk. Example of good and poor walk-environment is shown in Figure 4.

4 RESULTS

The three models, i.e., OLS, SAR, and GWR, were coded in MATLAB in order to estimate the model coefficients. The GWR model results were cross-checked by the software GWR 3.0.

4.1 Hedonic Price

The based models; i.e., the ordinary least square model, has been estimated for the two corridors. The results are shown in

Table 3. It is found that the sign of each coefficient is intuitive. Note that the coefficients obtained are global, i.e., the coefficientsare constant over the study area. Age of the apartment is significant in Ladphrao case; but not in Sukhumvit case. Proximity to alternative public transport, i.e., rail in Sukhumvit and canal boat in Ladphrao, is substantially significant. An apartment closer to railway station or canal boat pier will be more expensive due to convenience to commute and travel. The positive coefficient of employment accessibility indicates that an apartment locating close to job is expensive in Sukhumvit. Likewise, the negative coefficient of travel time to MRT Ladphrao station indicates that an apartment locating farther away on Ladphrao road will be cheaper. The two dummy variables also have positive coefficients indicating positive impacts, i.e., shortcut road and walk-friendly environment raise up the rent setting.

The results reveals that transportation has large influence on the apartment rent in both study areas, either rail or road corridors. The standardized regression coefficient allows understanding the relative influence of the explanatory variables to the dependent variable. In both cases, proximity to the city center has large influence relative to the other effects. In addition, it is interesting that the walk environment variable is statistically significant in both cases. That is, walking is an easy mode to transport people to and from railway station, so it is exceptionally important to pay attention to improving the walk mode in the rail corridor, as revealed from the result of the hedonic analysis. Likewise, walking is equally important along Ladphrao road. Most of the apartments are of the middle-income class where access to bus stop on the main street is important. This again calls for attention to walk environment development. Notice that the OLS model has moderate level of the goodness-of-fit based on the three evaluation indicators: the coefficient of determination (R^2); Akaike Information Criterion (AIC), which is based on the value of the likelihood function and weighs in the trade-off of how much information is obtained and the number of variables used; and the Residual Sum of Square (RSS).

4.2 Spatial Dependence

The spatial autoregressive model (SAR) described in Section 2.2 is estimated for the two corridors. The results are shown in Table 4. The coefficients of the explanatory variables are similar to those obtained by OLS regression. The spatial lag variable (ρ) appears to be statistically significant, indicating that spatial dependency is present in both dataset. Adding the spatial effects, i.e., the lagged autogressive term, has improved the goodness-of-fit in both cases comparing with the OLS models, however at different degree of improvement; considering the three indicators. That is, the goodness-of-fit of Ladphrao has substantially improved when the spatial lag structure is specified. It is then confirmed that the apartment rent in both cases significantly depends on the rent of nearby apartments.

4.3 Spatial Nonstationarity

The variability of the coefficients, i.e., effect of certain factors, over the study area is tested based on the GWR model, described in Section 2.3. Since GWR estimates a model at each data point, the number of estimated parameters is equal to the number of data points available. For ease of presentation, the results of GWR model are summarized by the three representative statistics: the minimum, maximum, and mean of the coefficients. The coefficients of the GWR models are summarized in Table 5. The coefficients estimated by the GWR model have the same trend as that of the OLS and SAR models. The goodness-of-fit based on the three indicators show that the GWR model is superior to the other two reference models, implying that accounting for nonstationarity has played significant role in improving the model fit. Moreover, the significance of the spatial variability in the local parameter estimates more formally by conducting a Monte Carlo test. The results of a Monte Carlo test on the local estimates indicate that there is significant spatial variation in the local parameter estimatesfor some variables, at certain degree of confident.

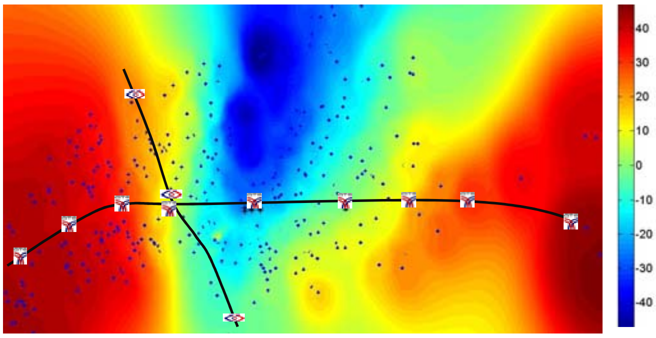
Table 4 Spatial Autoregressive Model

	Sukhumvit Corridor		**Ladphrao Corridor**	
	Coeff.	*t-Stat*	*Coeff.*	*t-Stat*
Self-attribute				
Age of the building	-10.671	-8.5552		
Alternative public transport				
Distance to the MRT station	-52.5863	-2.5796		
Distance to the canal boat pier			-22.599	-9.994
Proximity to urban center				
Employment accessibility	36.0451	5.465		
Time to MRT Ladphrao Station			-6.465	-8.152
Local Surrounding				
Walk environment (dummy)	66.1117	3.5551	20.094	3.104
Shortcut road (dummy)	49.7099	2.6503	10.287	2.021
Constant	399.0625	10.8505	375.86	13.873
Rho	0.266	4.3062	0.107	6.014
Goodness of Fit				
R2	0.535		0.433	
AIC	4299.9		4723.1	
Error Sum of Squares	6.49×10^6		8.96×10^5	

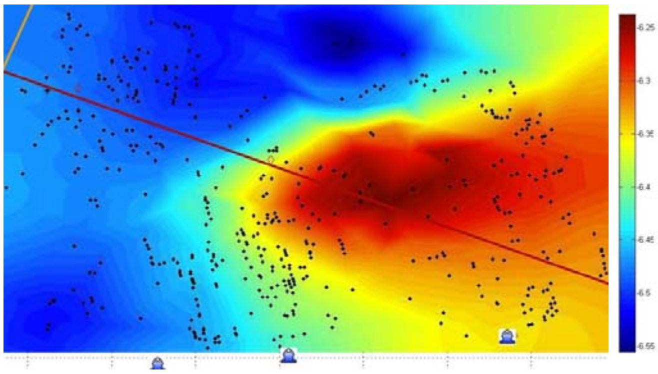
Table 5 Geographically Weighted Regression

	Sukhumvit Corridor				**Ladphrao Corridor**			
`	*Min*	*Max*	*Mean*	*Variability, p-value*	*Min*	*Max*	*Mean*	*Variability, p-value*
Self-attribute								
Age of the building	-14.2154	-10.8565	-12.4701	n/s, 0.21				
Alternative public transport								
Distance to MRT	-129.571	-26.924	-73.2215	n/s, 0.12				
Distance to canal boat					-23.354	-20.108	-21.895	0.1% sig, 0.00
Proximity to urban center								
Job accessibility	-48.3606	47.8376	6.3801	0.1% sig,0.00				
Time to MRT Ladphrao station					-6.556	-6.207	-6.402	0.1% sig,0.00
Local Surrounding								
Walk environment (dummy)	20.2834	92.2476	59.3485	n/s, 0.31	17.93	22.734	20.002	5% sig 0.03
Shortcut road (dummy)	-21.8949	75.7464	30.7124	n/s, 0.21	7.74	13.891	10.361	0.1% sig,0.00
Constant	392.9846	596.2121	495.5263	0.1% sig,0.00	360.586	382.239	372.517	0.1% sig,0.00
Goodness of Fit								
R2	0.694				0.492			
AIC	4300.204				4716.744			
Error Sum of Squares	6.04 x106				6.86 x105			

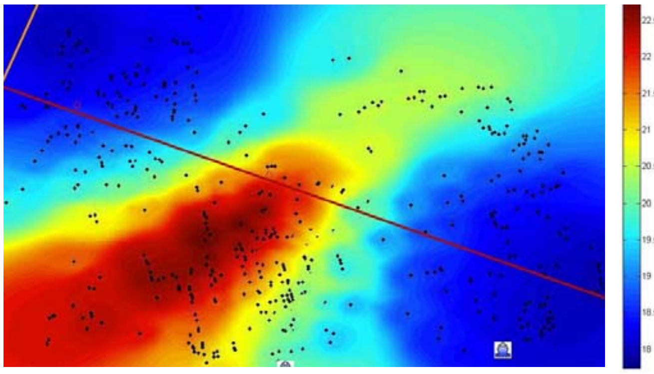
In Sukhumvit case, variation of the coefficient of job accessibility variable and the constant is significant; while in Ladphrao case, the coefficients of the distance to canal boat, travel time to MRT Ladphrao station, the two local surrounding variables, and the constant term vary significantly over the study area. The spatial variation in the remaining variables is not significant and in each case there is a reasonably high probability that the variation occurred by chance. In the other words, the extent of the effect of each explanatory variable to the apartment rent varies substantially in both study areas. To illustrate this, the coefficients are interpolated by the inverse distance weighting method. The colored contours of some variables that its spatial variability is significant are shown in Figure 5. The only effect that varies significantly is the employment accessibility, as proxy of closeness to the city center. Figure 5a shows the positive coefficient in the red areas, where there are many office and commercial buildings, centered to many workplace and job opportunities. The closeness to the city center is represented as travel time to MRT Ladphrao station, of which the coefficient varies significantly over the study area, shown in Figure 5b. The effect is symmetry to Ladphrao road. The effect of the local surrounding, having on the apartment rent is also found to vary over the study area, walk environment, e.g., the walk environment effect is shown in Figure 5c. That is, the effect of walk-friendly environment is pronounced in the red area where there are local activities such as street vendors, local supermarket, etc.



a) Employment accessibility (Sukhumvit Case)



b) Travel time to MRT Ladphrao Station (Ladphrao Case)



c) Walk Environment (Ladphrao Case)

Figure 5 Nonstationarity of the Coefficients

5 CONCLUDING REMARKS

The hedonic analysis has shown that the influence of transportation on apartment rent is significant. The global model shows that transportation has large effect on the apartment rent at different degree. Local circumstance such as walk-friendly environment or shortcut road also has positive impact on the apartment rent. This reveals that access to main road and railway station either by vehicle or by walk is more or less equally important. This paper has also shown that the spatial effects are present in both case studies: spatial dependence and nonstationarity. The significance of a spatial lag variable, i.e., spatial dependence confirms that neighborhood atmosphere is important, e.g., an apartment in the expensive area tends to be equally expensive. The significance of the variation of some coefficients, i.e., nonstationarity, implies that the study area is not homogenous but comprises of different local behavior. It is found, based on the empirical results, that good accessibility provided by railway has disseminated the dissimilarity of the inner and outer areas in Sukhumvit so that nonstationarity in the transportation effect is not present.

Meanwhile, the poor accessibility provided by Ladphrao road made the area more heterogeneous; indicated by the nonstationarity of the coefficients in GWR model. In the modeling aspect, accounting for spatial dependence and spatial nonstationarity has improved the goodness-of-fit. However the coefficients of determination (R^2) are not very high in all models, this may be due to large unexplained constant term. Improving the model fit may need more sophisticated model specification to account for the other form of spatial effects such as spatial error autocorrelation or heteroscedasticity. This is left for further study.

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TRANSPORT DEMAND ELASTICITY OF BANGKOK AND NAKHON RATCHASIMA: EFFECTS OF OIL PRICE ON GASOLINE CONSUMPTION AND TRAVEL BEHAVIOR

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Due to the recent gasoline price crisis in 2007-2008, we observed changes on travel behavior of citizens and businesses in a noticeable manner. The purpose of this study is to explore how fuel consumption and transport demand in Thailand had changed at a macroscopic level with respect to the gasoline price using the concept of the demand elasticity. The study analyzed the historical data of gasoline price along with economics, demographics, and characteristics of transport system on the demand of various fuels as well as the activities on various transport modes over the study period of 10 years. In this study, the fuels are classified into 3 groups: unleaded gasoline/gasohol, liquid petroleum gas/compressed natural gas, and diesel, while the transport demands are represented by the four indicators, traffic volumes on expressway, BMTA bus ridership, BTS skytrian ridership and MRTA subway ridership. It was found that the energy and the transport demand elasticity of Thailand was inelastic (< 1.0), similar to previous studies all over the world; however, the estimated numbers of Thailand tend to be more inelastic than those derived in the developed countries.

Keywords: Fuel Consumption, Transport Demand, Demand Elasticity

1 INTRODUCTION

Transport is one of the crucial sectors that facilitate the economic and social development in any country. It involves all movements of people and goods on roads, on rails, on waterways and in the sky. In Thailand, the transport sector consumes as much as 37 percent of overall energy consumption each year. From 1981 – 2001, the energy consumption in the transport sector has grown with an average growth rate of 16.6 percent per year, and the growth does not seem to lose its pace in the near-term future. Thus, the energy planning and policy from the government cannot overlook the energy consumption in the transport sector.

The historical gasoline price crisis in the past few years has affected the transport sector in many ways. People as well as transport operators have somehow adjusted their behavior in response to the huge price increase, for example, driving less, carpooling, switching modes to public transit or non-motorized transport, using alternative fuel, or making fewer number of trips after all. We all have witnessed demonstrations from transport operators as well as protests from public all over the world, requesting their government to issue some measures to relieve the problems on them. This is a worldwide crisis. Many European and North American researchers have taken the opportunities to investigate the impacts of oil crisis on travel behavior and consumer behavior in a variety of aspects, to understand the way public reacts to the change. However, such studies are rare in Thailand. Understanding the local transport behavior and its sensitivity to the oil price is greatly useful for engineers and policy makers to understand the public and transport operator’s behavior in response to the gasoline price increase, which will be useful to forecast the effectiveness of various proposed gasoline price-related policies in the future.

This study aims to analyze the effects of the gasoline price increase on the transport sector in the Bangkok Metropolitan Area and Nakhon Ratchasima at an aggregate level. In particular, the researchers aim to investigate: the changes in gasoline consumption and travel behavior as a result of the recent fuel price increases using the concept of demand elasticity,whether the demand elasticity is different between Bangkok and Nakhon Ratchasima, and whether the demand elasticity vary across cities in other countries.

The demand elasticity analyzed in this study can be broadly categorized into two groups. The first group is the fuel demand elasticity: how people/industries change their consumptions of various fuel types in response to the fuel price change. Due to a variety of fuels available, the study will focus on major fuels, as listed below:

- Unleaded gasoline 95 (ULG95),
- Unleaded gasoline 91 (ULG91),
- Gasohol 95,
- Gasohol 91,
- Liquid petroleum gas (LPG),
- Compressed natural gas (CNG) or CNG,
- Diesel.

The second group is the transport demand elasticity: how people adjust their travel behavior in response to the gasoline price change. This study will cover the following aspects of travel demand:

- Traffic on expressways,
- BMTA bus ridership,
- MRTA subway ridership
- Number of registered vehicles.

Information revealed from this study will be the sensitivity of local people in Bangkok and Nakhon Ratchasima to the gasoline price, which will be useful for transport engineers and policy makers to better formulate effective priced-related transport measures in the future. Simultaneously, they can anticipate how much reduction or increase of the fuel import from overseas. Furthermore, since this study also investigated the fuel price effects on various aspects of travel demand; the information revealed here could explain how the tax scheme would effect the toll collections from vehicles using expressways and how much ridership on buses and subways would be changed, so that the authorized offices can plan/adjust their operations to accommodate the new level of usage/ ridership appropriately. Furthermore, it would infer the impacts to the automobile industry on how much the car sales be altered from the normal situation. This case simply shows an example of benefits from this study; in fact, these benefits can be applied to any situations when the gasoline price has changed.

2 LITERATURE REVIEW

2.1 Concept of Demand Elasticity

This study investigates the sensitivity of people and transport operators in Bangkok and Nakhon Ratchsima, in response to the price increase, primarily using the concept of the elasticity. The demand elasticity is regularly used to gauge the responsiveness of demand when the price has changed (Oum *et al.*, 1992). More specifically, the elasticity represents the percentage change in consuming of a goods from the one-percent change in price, commonly used in the field of economics. According to Balcombe *et al.* (2004), the demand elasticity is defined as follows:

$$e_{x_i} = \frac{\text{The proportional change in demand}}{\text{The proportional change in the explanatory variable}} \quad (1)$$

$$\text{or} \quad = \frac{\Delta y / y}{\Delta x_i / x_i} \quad (2)$$

where Δy denotes the change in demand, and

Δx_i denotes the change in the explanatory variable x_i

When the change in the explanatory variable Δx_i is very small (or approaches zero), then the elasticity could be rewritten as:

$$e_{X_i} = \left(\frac{\text{Limit}}{\Delta x_i \to 0}\right)\left(\frac{\Delta y / y}{\Delta x_i / x_i}\right) \quad (3)$$

$$e_{X_i} = \frac{\left(\frac{dy}{y}\right)}{\left(\frac{dx_i}{x_i}\right)} \quad (4)$$

$$e_{X_i} = \frac{d\,(\ln y)}{d\,(\ln x)} \quad (5)$$

Thus, the demand elasticity can simply be estimated by the derivative of the logarithm of the demand (ln *y*) with respect to the independent variable (ln x_i). If the demand function takes a form of the logarithm, the coefficient of the independent variable x_i (or ln x_i) will then become the demand elasticity measure.

In theory, the value of the elasticity can have either positive or negative sign. The positive value shows that the change in demand and price go in the same direction. That is, when the price increases, the demand will also increase, or if the price decreases, the demand will decrease as well. The negative value represents the case where the changes go into the opposite direction, i.e., when the price increases, the demand will decrease, or vice versa. This is sometimes called 'cross-elasticity. The demand elasticity in transport can have either negative or positive sign, depending on the issue of interest.

2.2 Review of Demand Elasticity Estimates

The elasticity measures of road traffic and fuel consumption with respect to gasoline price had been intensively studied in North America and Europe for a few decades. Oum *et al.* (1992) reviewed empirical elasticity estimates for both passenger and freight demand studied during the period of 1970's and 1980's. It was found that the demand elasticity of automobile usage calculated by the previous studies ranged from -0.09 to -0.52. The study also found that the elasticity estimates for the long-run is generally higher than those for the short-run; nevertheless, they are not statistically different. Table 1 below shows the summary of the demand elasticity of automobile usage as summarized by Oum *et al.* (1992).

Table 1 Demand Elasticity of Automobile Usage (all values are negative)

	Short Run	Long Run	Unspecified*
United States	0.23	0.28	0.31-0.26, 0.15-0.45
Australia	0.09-0.24	0.22-0.31	0.22-0.52, 0.25-0.34
United Kingdom	n.a.	n.a.	0.14-0.36

Source: Oum *et al.* (1992)
*The literature does not specify whether it is a short-run or a long-run analysis.

Table 2 summarized the demand elasticity estimates of urban transit as collected by Oum *et al.* (1992). As shown, the elasticity estimates ranged between -0.01 to -0.78, as they were estimated by various data types.

Table 2 Demand Elasticity of Urban Transit (all values are negative)

Data types	Elasticity Estimates
Time series*	0.01-0.62, 0.17-0.59, 0.18-0.22, 0.23-0.25, 0.23-0.27, 0.27-0.78, 0.29-0.34, 0.36-1.32
Cross-section	0.05-0.34
Pooled data	0.06-0.44
Before/after data	0.10-0.60, 0.70

Source: Oum *et al.* (1992)
*Review of the elasticity estimates from earlier studies by Oum *et al.* (1992)

Goodwin (1992) also reviewed the demand elasticity from the previous studies, and developed a summary table of the elasticity of petrol consumption and traffic level with respect to gasoline price, on Tables 3 and Table 4, respectively. It was found that the short-term elasticities of gasoline consumptions vary from -0.27 to -0.28, while the long-term ones are 3 times as higher (see Table 3), ranging from -0.71 to -0.84. These elasticity estimates seem to be higher than the elasticity of traffic demand with respect to the gasoline price (Table 4), which was -0.16 for the short-term period, and in between -0.29 to -0.33 for the long-term period.

Table 3 Summary of evidence from studies of elasticity of Petrol consumption with respect to price

	Explicit*		Ambiguous
	Short-term	Long-term	
Time-series	-0.27	-0.71	-0.53
Cross-section	-0.28	-0.84	-0.18

Source: Goodwin (1992)

Table 4 Summary of Evidence from Studies of Elasticity of Traffic Levels with Respect to Petrol Price

	Explicit		Ambiguous
	Short-term	Long-term	
Time-series	-0.16	-0.33	-0.46
Cross-section	-	0.29	-0.5

Source: Goodwin (1992)

A recent study by Goodwin *et al.* (2004) had summarized the 69 demand elasticity studies/reports issued after his previous work in 1992, and reached the following interesting findings as summarized in Table 5.

Table 5 Short-term and Long-term Impacts from 10% Increase in Fuel Price

	Impact	
	Short-term	Long-term
Traffic volume	decreases around 1%	decreases about 3%
Fuel Consumption	decreases by 2.5%	decreases by 6.0%
Fuel use efficiency	improves by 1.5%	improves by 2.5%
No. of vehicle ownership	Decreases by 1%	decreased by 2.5%

3 METHODOLOGY

The researchers attempt to investigate the public reactions on gasoline consumption as well as on travel demand due to the change in gasoline price in the past 10 years. Section 3.1 shows key graphical presentation of the historical data of gasoline consumption, gasoline price and travel demand in the past 10 years. In addition, it will first propose appropriate demand functions to be used to explain the demand of gasoline price and travel demand of particular interest. Section 3.2 explains the list of variables needed for the analysis, and the source of such data.

3.1 Proposed Demand Functions

The proposed demand functions of fuel consumption as well as travel demand are listed below. It should be noted that these demand functions was developed based on the literature review, critical thinking and personal familiarity with the area

<u>Fuel demand function</u>

3.1.1 Consumption of ULG95:

Figure 1 below shows the historical trends of the ULG95 price, and the ULG95 consumptions for the whole country, for Bangkok and for Nakhon Ratchasima (Korat) from 1998 to 2008. As shown, the ULG95 price was relatively stable around 15 to 16 baht per liter during 2000 to 2004, and had been increasingly since 2004 to reach 35 baht per liter in 2008. In 1998, the consumptions of ULG95 were over 1 billion liters per quarter, and shapely dropped to 600 million liters per quarter in 2000, perhaps due to the major economic crisis in Thailand during the period. From 2004 onward, the introduction of an alternative fuels, Gasohol 95, causes the declining trend in ULG95 consumptions until today.

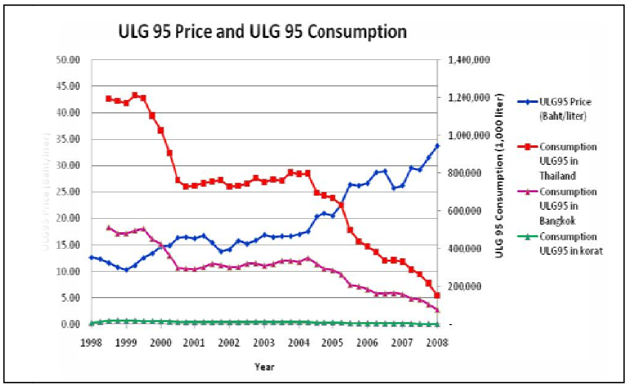

Figure 1 Historical Price and Consumptions of ULG95 between 1998 and 2008

The proposed demand function for ULG95 consumption is:

$$\ln G95_t = \alpha_0 + \alpha_1 \ln PG95 + \alpha_2 \ln GDP + \alpha_3 \ln POP + \alpha_4 \ln G95_{t-1} + \alpha_5 \ln CAR + \alpha_6 \ln PLPG + \alpha_7 \ln SNGV + \alpha_8 \ln PGAS95 + \alpha_9 DUM \quad (6)$$

where

$G95_t$ = consumption of ULG95(thousand liters) in quarter t.
PG95 = average ULG95 unit price in the quarter (baht/liter).
GDP = gross domestic products (million baht)
POP = population in Thailand.
$G95_{t-1}$ = consumption of ULG95in the previous quarter t-1.
CAR = number of registered vehicles (vehicles).
PLPG = price of LPG.
SCNG = station of CNG.
PGAS95 = price of gasohol 95.
DUM = represents the government campaign to promote ULG91 in replacing ULG95.

3.1.2 Consumption of ULG91:

Figure 2 below shows the historical trends of the ULG prices, and the ULG91 consumptions for the whole country, for Bangkok and for Nakhon Ratchasima (Korat) from 1998 to 2008. The prices of ULG95 and ULG91 vary in a similar fashion because they are both fully regulated by the government. They were relatively stable around 15 to 16 baht per liter during 2000 to 2004, and had been increasingly since 2004 to reach 35 baht per liter in 2008. In 1998, the consumptions of ULG91 were around 250 million liters per quarter, and had increased to 700 million liters per quarter in 2000. From 2000 onward, the consumption of ULG91 had gradually increased to 850 million liters per quarter in 2005. From 2007, the consumption has declined due to 2 main reasons: the skyrocketing increase of gas price and the promotion of the alternative fuel: gasohol 91.

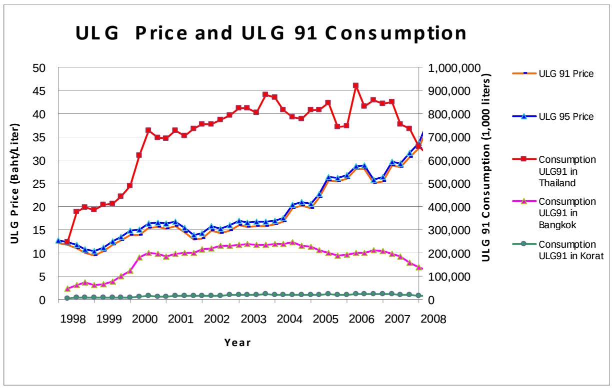

Figure 2 Historical Price and Consumptions of ULG91 between 1998 and 2008

The proposed demand function for ULG91 consumption is:

$$\ln G91_t = \alpha_0 + \alpha_1 \ln PG91 + \alpha_2 \ln GDP + \alpha_3 \ln POP + \alpha_4 \ln G91_{t-1} + \alpha_5 \ln CAR + \alpha_6 \ln PLPG + \alpha_7 \ln SNGV + \alpha_8 \ln PGAS95 + \alpha_9 DUM \quad (7)$$

where

$G91_t$ = consumption of ULG91 (thousand liters) in quarter t.
PG91 = average ULG91 unit price in the quarter (baht/liter).
GDP = gross domestic products (million baht)
POP = population in Thailand.
$G91_{t-1}$ = consumption of ULG91 in the previous quarter t-1.
CAR = number of registered vehicles (vehicles).
PLPG = price of LPG.
SCNG = station of CNG.
PGAS95 = price of gasohol 95.
DUM = represents the government campaign to promote ULG91 in replacing ULG95.

3.1.3 Consumption of Gasohol 95:

Figure 3 below shows the historical trends of the fuel price, and the consumptions of Gasohol 95 for the whole country, for Bangkok and for Nakhon Ratchasima (Korat) since the introduction of Gasohol 95 in 2005 until 2008. Since its introduction to the market, the demand of gasohol 95 has continuously increased to reach 500 million liters per quarter in 2008.

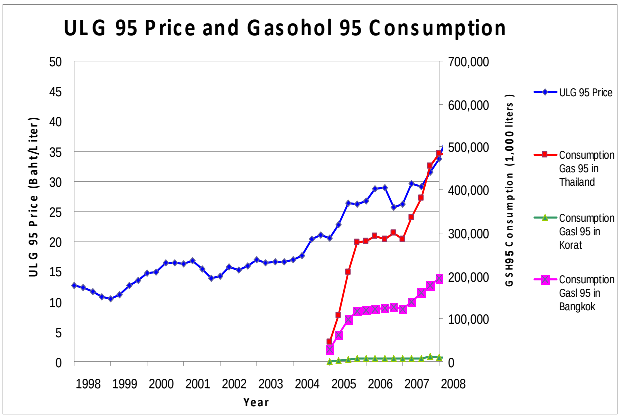

Figure 3 Historical Fuel Price and Consumptions of Gasohol 95 between 2004 and 2008

The proposed demand function for Gasohol 95 consumption is:

$$\ln GAS95 = \alpha_0 + \alpha_1 \ln PGAS95 + \alpha_2 \ln GDP + \alpha_3 \ln POP + \alpha_4 \ln GAS95_{t-1} + \alpha_5 \ln CAR + \alpha_6 \ln PLPG + \alpha_7 \ln SNGV + \alpha_8 \ln SGAS95 + \alpha_9 DUM \quad (8)$$

where
GAS95 = consumption of gasohol 95 (thousand liters)
PGAS95 = average gasohol 95 unit price in the quarter (baht/liter)
GDP = gross domestic products (million baht)
POP = population in Thailand.
$GAS95_{t-1}$ = consumption of gasohol 95 in the previous quarter.
CAR = number of registered vehicles (vehicles),
PLPG = average LPG unit price in the quarter (baht/kg).
SCNG = station of CNG.
SGAS95= station of Gasohol 95.
DUM = represents the government campaign to promote gasohol in replacing gasoline.

3.1.4 Consumption of Gasohol 91:

Figure 4 below shows the historical trends of the fuel price, and the consumptions of Gasohol 91 for the whole country, for Bangkok and for Nakhon Ratchasima (Korat) since the introduction of Gasohol 91 in 2005 until 2008. Since its introduction to the market, the demand of gasohol 91 has continuously increased to reach 150 million liters per quarter in 2008.

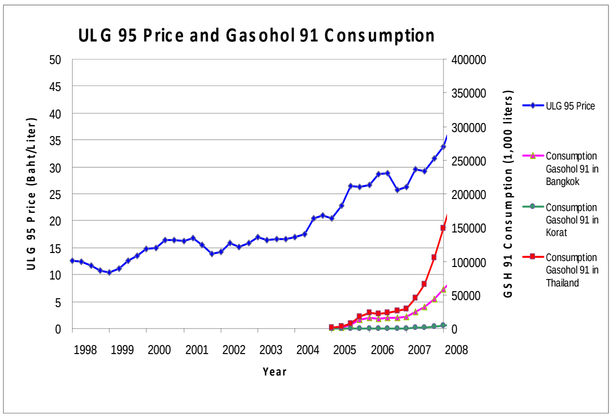

Figure 4 Historical Fuel Price and Consumptions of Gasohol 91 between 2004 and 2008

The proposed demand function for Gasohol 91 consumption is:

$$\ln GAS91 = \alpha_0 + \alpha_1 \ln PGAS91 + \alpha_2 \ln GDP + \alpha_3 \ln POP + \alpha_4 \ln GAS91_{t-1} + \alpha_5 \ln CAR + \alpha_6 \ln PLPG + \alpha_7 \ln SNGV + \alpha_8 \ln SGAS91 + \alpha_9 DUM \quad (9)$$

where
GAS91 = consumption of gasohol 91 (thousand liters)
PGAS91= average gasohol 91 unit price in the quarter (baht/liter)
GDP = gross domestic products (million baht)
POP = population in Thailand.
$GAS91_{t-1}$ = consumption of gasohol 91 in the previous quarter.
CAR = number of registered vehicles (vehicles)
PLPG = average LPG unit price in the quarter (baht/kg).
SCNG = station of CNG.
SGAS91= station of Gasohol 91.
DUM = represents the government campaign to promote gasohol in replacing gasoline.

3.1.5 Consumption of LPG:

Figure 5 shows the historical trends of the fuel prices, and the consumptions of LPG for the whole country, for Bangkok and for Nakhon Ratchasima (Korat) from 1998 to 2008. The price of LPG was gradually increased from 10 baht/kilogram in 2000, to 17 baht/kilogram in 2004, and maintains this price until 2008. The LPG consumption shows a significant increase since 2004 onward, perhaps due to the continuing increase of gasoline price from 2004 to 2008.

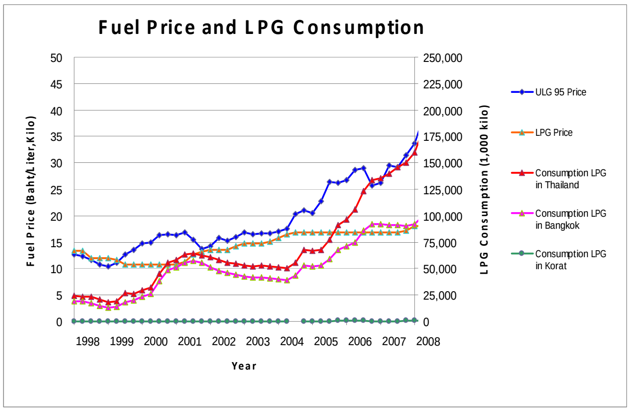

Figure 5 Historical Fuel Price and Consumptions of LPG between 1998 and 2008

The proposed demand function for LPG consumption is:

$$\ln LPG = \alpha_0 + \alpha_1 \ln PLPG + \alpha_2 \ln GDP + \alpha_3 \ln POP + \alpha_4 \ln LPG_{t-1} + \alpha_5 \ln CAR + \alpha_6 \ln PGAS95 + \alpha_7 \ln SLPG \quad (10)$$

where
LPG = consumption of LPG (thousand kilo)
PLPG = average LPG price unit price in the quarter (baht/kilo).
GDP = gross domestic products (million baht)
POP = population in Thailand.
LPG_{t-1} = consumption of LPG in the previous quarter.
CAR = number of registered vehicles (vehicles).
PGAS95= average gasohol 95 unit price in the quarter (baht/liter).
SLPG = station of LPG.

3.1.6 Consumption of CNG:

Figure 6 shows the historical trends of the fuel prices, and the consumptions of CNG for the whole country since its introduction in 2004. The price of CNG was relative stable from 7-8 baht/liter between 2004 and 2008. The CNG consumption has however shapely increased since 2004 onward to reach 4 billion cubic feet in 2008, perhaps due to the continuing increase of gasoline price during that period.

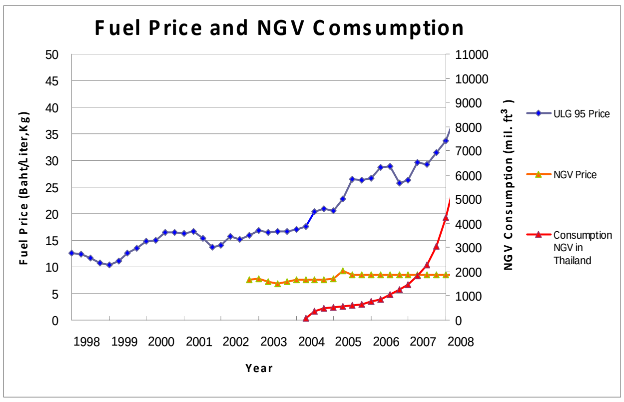

Figure 6 Historical Fuel Price and Consumptions of CNG between 2004 and 2008

The proposed demand function for CNG consumption is:

$$\ln NGV = \alpha_0 + \alpha_1 \ln PNGV + \alpha_2 \ln GDP + \alpha_3 \ln POP + \alpha_4 \ln NGV_{t-1} + \alpha_5 \ln CAR + \alpha_6 \ln PGAS95 + \alpha_7 DUM \quad (11)$$

where
CNG = consumption of natural gas for vehicle (thousand liters)
PCNG = average CNG price unit price in the quarter (baht/kilo).
GDP = gross domestic products (million baht)
POP = population in Thailand.
CNG_{t-1} = consumption of CNG in the previous quarter.
CAR = number of registered vehicles (vehicles),
PGAS95 = gasohol 95 price.
DUM = represents the government campaign to promote CNG in replacing gasoline.

3.1.7 Consumption of Diesel for Transport:

Figure 7 shows the historical trends of the fuel prices, and the consumptions of diesel for the whole country, Bangkok and Nakhon Ratchasima from 1998 to 2008. The price of diesel has a similar pattern to the price of ULG95, which continuingly increase since 2004. The consumption of diesel was 200 billion liters/quarter in 1998, and was slightly increase to approximately 250 billion liters/quarter in 2008. It should be noted that the diesel consumption for the whole country shows a cyclic trend, which implies that consumption vary by seasons of the year. Perhaps, a large portion of diesel consumption is used to carry agriculture products, which is seasonal by nature.

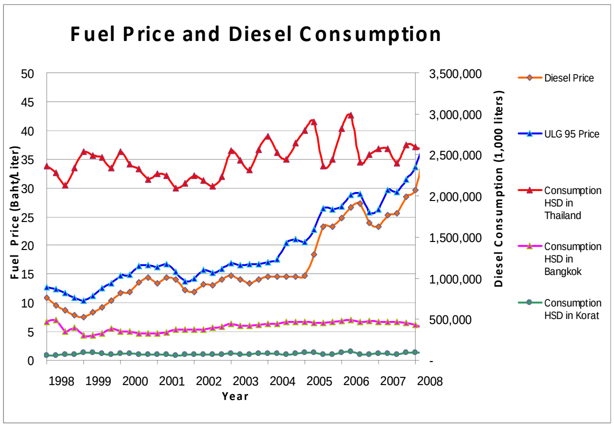

Figure 7 Historical Fuel Prices and Consumptions of Diesel between 1998 and 2008

Note: HSD is High Speed Diesel which has been commonly used in truck transport.

The proposed demand function for Diesel consumption is:

$$\ln DS = \alpha_0 + \alpha_1 \ln PDT + \alpha_2 \ln GDP + \alpha_3 \ln POP + \alpha_4 \ln DT_{t-1} + \alpha_5 \ln TRUCK + \alpha_6 \ln BUS$$

(12)

where

DS = consumption of diesel (thousand liters)

PDS = diesel price.

GDP = gross domestic products (million baht)

POP = population in Thailand.

DS_{t-1} = consumption of diesel in the previous quarter.

TRUCK = number of truck registered (vehicles).

BUS = number of registered buses (vehicle).

Travel demand function

3.1.8 Demand Function of Traffic on Expressway

Figure 8 shows the historical trends of the fuel prices, and the traffic volume on the 5 expressways in Bangkok. The total volumes on the 5 expressway combined was 60 million vehicles per quarter in Year 1998, and had generally increased to 100 million vehicles per quarter in Year 2008. It should be noted that the trend of traffic on expressways has a cyclic pattern, which implies that travel activities vary by seasons of the year. This is perhaps due to the fewer travel activities during the summer time when schools close. In this equation, we only include the price of PG95 in the analysis, because it strongly correlates with the price of PG91, ULG95 and ULG91, as they are all fully regulated by the government. The inclusion of the prices of all gasoline types will cause multicollinearity problems in the model. In additional, the prices of LPG and CNG are relatively stable throughout the study period due to the government control, thus, they were excluded from the analysis.

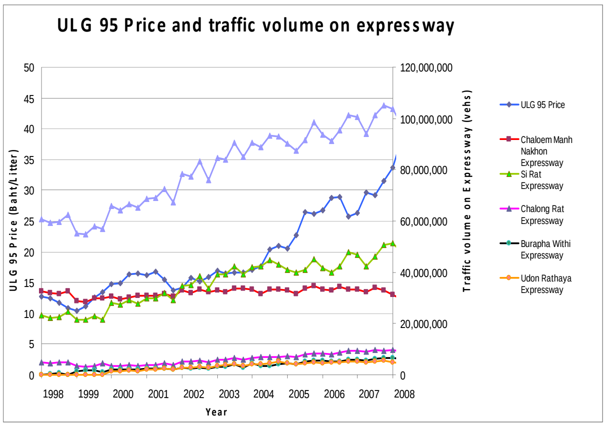

Figure 8 Historical Fuel Prices and Traffic Volumes on Expressways between 1998 and 2008

The proposed demand function for traffic on expressways is:

$$\ln Yt = \alpha_0 + \alpha_1 \ln GDP_t + \alpha_2 \ln PG95_t + \alpha_3 \ln INC_t + \alpha_4 \ln MT_{it}^{m} + \alpha_5 \ln CAR_t + \alpha_6 \ln Y_{t-1} + \alpha_7 Cycle \quad (13)$$

where

Y_{it} = traffic volume at the expressway section i and period t.

GDP_t = gross domestic products (million baht) in period t.

$PG95_t$ = average ULG95 unit price in the quarter (baht/liter).

INC_t = personal income in period t.

MT_{it}^{m} = motorway toll in section i and period t.

CAR_t = number of registered vehicles (vehicles) and period t.

Y_{it-1} = first order lagged traffic volume of expressway.

Cycle = seasonal variable.

3.1.9 Demand Function of Bus Ridership

Figure 3-9 shows the historical trends of the ULG95 prices, and the total BMTA bus ridership in the greater Bangkok area. The number of ridership has declined over the years, reducing from 300 million person-trips in 1998 to 150 million person-trips in 2008. Similar to traffic on expressway, the trend of BMTA bus ridership has a cyclic pattern, which implies that travel activities varies by seasons of the year. This is perhaps due to the fewer travel activities during the summer time when schools close.

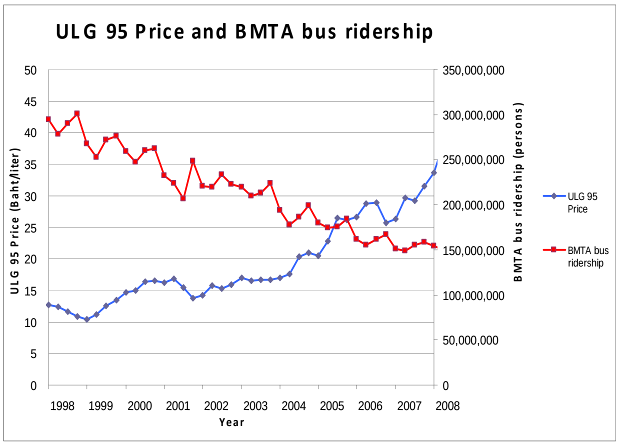

Figure 9 Historical Fuel prices and BMTA Bus Ridership between 1998 and 2008

The proposed demand function for BMTA ridership is:

$$\ln Rb_t = \alpha_0 + \alpha_1 \ln GDP_t + \alpha_2 \ln POP_t + \alpha_3 \ln PG95_t + \alpha_4 \ln Rb_{t-1} + \alpha_5 \ln Fbus_t + \alpha_6 \ln QS_t + \alpha_7 \ln Ut + \alpha_8 \ln CAR_t + \alpha_9 Cycle + \alpha_{10} DUM \quad (14)$$

where

Rb_t = ridership for bus in period t.

GDP_t = gross domestic products (million baht) in period t.

POP_t = population in Thailand.

$PG95_t$ = average ULG95unit price in the quarter (baht/liter).

Rb_{t-1} = first order lagged ridership of bus.

$Fbus_t$ = fares for bus in period t.

QS_t = Quantity of service for bus in period t.

U_t = unemployment rate in period t.

CAR_t = number cars in Thailand and period t.

DUM = policy bus free for BMTA.

Cycle = seasonal variable.

3.1.10 Demand Function of Bus MRTA Rridership

Figure 10 shows the historical trends of the ULG95 prices, and the total MRTA subway ridership in Bangkok from 2004 to 2008. Since the beginning of the operation in 2004, the number of subway ridership has a slight increasing trend until 2008. Unlike to the traffic volume on expressway nor the BMTA bus ridership, the trend of BMTA bus ridership has no obvious cyclic pattern, which implies that MRTA ridership does not much related to school trips.

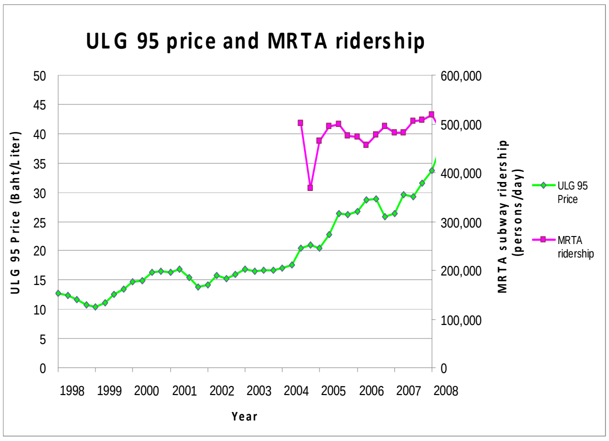

Figure 10 Historical Fuel Prices and MRTA Subway Ridership between 2004 and 2008

The proposed demand function for MRTA subway ridership is:

$$\ln Rm_t = \alpha_0 + \alpha_1 \ln GDP_t + \alpha_2 \ln POP_t + \alpha_3 \ln PG95_t + \alpha_4 \ln Rm_{t-1} + \alpha_5 \ln FMRTA_t + \alpha_6 \ln Fbus_t + \alpha_7 \ln Qs_t + \alpha_8 \ln U_t + \alpha_9 Cycle \quad (15)$$

where

Rm_t = ridership for MRTA in period t.
GDP_t = gross domestic products (million baht) in period t.
POP = population in Thailand.
$PG95_t$ = average ULG95unit price in the quarter (baht/liter).
Rm_{t-1} = first order lagged ridership of MRTA.
$FMRTA_t$ = fares for MRTA in period t.
$Fbus_t$ = fares for bus in period t.
QS_t = Quantity of service for MRTA in period t.
U_t = unemployment rate in period t.
Cycle = seasonal variable.

3.1.11 Demand Function of No. of New Vehicles Registered

Figure 3-11 shows the historical trends of the ULG95 price, and the total number of new vehicles registered in Thailand, Bangkok and Nakorn Ratchasima from 1998 to 2008. The number of new vehicles registered were approximately 150 – 200 thousand vehicles/quarter in 1998, and continuingly increase to its peak around 700 thousand vehicles/quarter in 2005/2006. Since 2006, the number of new vehicles show a slight declining trend.

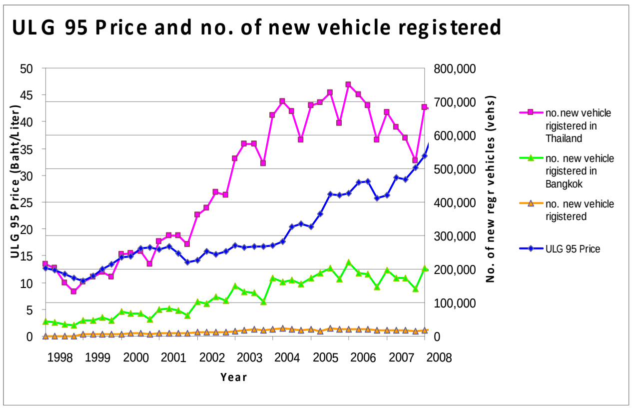

Figure 11 Historical Fuel Prices and The Number of New Vehicle Registered between 1998 and 2008

The proposed demand function of the number of new vehicles registered is:

$$\ln VR_t = \alpha_0 + \alpha_1 \ln GDP_t + \alpha_2 \ln POP_t + \alpha_3 \ln PG95_t + \alpha_4 \ln INC_t + \alpha_5 \ln Pnc_t + \alpha_6 \ln U_t \quad (16)$$

where

VR_t = demand of no. of new vehicles registered in period t.
GDP_t = gross domestic products (million baht) in period t.
POP = population in Thailand.
$PG95_t$ = average ULG95 unit price in the quarter (baht/liter).
INC_t = personal income in period t.
Pnc_t = price new car in period t.
U_t = unemployment rate in period t.

3.2 Data Collection

Data used in this study include the consumption of various fuels in the transport sectors, the historical gasoline price data, traffic volumes on major streets, subway ridership, bus ridership, the number and type of new vehicles registered, etc. Some of these data are readily available from the government agencies from the two ministries: the ministry of energy (department of energy business, energy policy and planning office) and the ministry of transport (office of traffic and transport policy and planning, department of land transport, mass rapid transit authority, Bangkok mass transit authority, department of highway).

4 ANALYSIS RESULTS

This section presents the results from the development of a suitable demand function for the gasoline consumption indicators and the transport demand indicators. In the gasoline demand analysis portion, there are a number of common fuel types available, and from the preliminary analysis found that it was inefficient to develop a separate model for each of the fuel types. Thus, we aggregated fuel types with similar usage characteristics into larger categories. Section 4.1 describes the categories of the fuels in this analysis. Section 4.2 provides a summary of model development for the demand functions. Then, the specifications of the selected demand models along with the implications on short-term and long-term elasticity are provided in Section 4.3.

4.1 Grouping of Fuel Types for Analysis

In Thailand, there are a variety of fuel types commonly available for the transportation sector, including unleaded gasoline 95 (ULG95), unleaded gasoline 91 (ULG91), Gasohol 95, Gasohol 91, Liquid Petroleum Gas (LPG), Compressed Natural Gas (CNG), Diesel and Bio diesel. The demand function development for each of the fuel types is a cumbersome process, and might not be able to provide meaningful results given that certain fuel types are exchangeable without any engine modifications, for example, recent automobile make/models are able to use either ULG or its counterpart Gasohol. In fact, we initially attempted to develop a separate demand function for each, but were not successful. Therefore, the researchers had aggregated a variety of fuel types with similar usage characteristics into 3 main groups. The first group includes regular fuels for passenger vehicles, as well as the alternative fuels that such vehicles can take without any major engine modification, nor a special fuel system needed. This fuel group includes ULG95, ULG91, Gasohol 95 and Gasoline 91. The second group represents the alternative fuels passenger vehicles consume that require engine modification or special fuel system installations: they are LPG and CNG. Note that the government regulates the price of LPG and CNG such that its real price remains stable during the gasoline price crisis, thus, they had attracted a large number of drivers to install a special fuel system and modify their automobile engine in order to use LPG or CNG. Such vehicles become a hybrid system, since they are able to use either ULG, Gasohol or LPG or CNG, depending on the system installed. It costed approximately 20,000 baht for installing the LPG fuel system, while approximately 50,000 baht for installing the CNG fuel system on a vehicle. The last group is the fuel that is typically consumed by trucks or large vehicles. It is a diesel. Although Bio-diesel is currently available on market during the study, but it is a new type of fuel that has a short history. It was only introduced to public in 2007.

The aggregation of various fuel types is not a straightforward task. Each fuel type has different mega joules which result in different gasoline consumption (km/liter or km/kg). For example, one liter of gasohol 95 could fuel a vehicle to travel 10 kilometers, while the same amount of ULG95 could provide up to 12 kilometers on the same vehicle. Thus, the simple aggregation of various fuel types is illogical. In this study, all of the various fuel types in the first group were converted into a unit of equivalent ULG95 liter using the information of its mega joules against the mega joules of ULG95. Similarly, the unit sale of LPG and CNG was converted into a unit of equivalent ULG liter using the similar mega joule info. The third fuel group include only diesel, thus it does not require any conversion for the aggregation process.

4.2 Demand Function Development

In this study, the demand models were developed using regression analysis using a commercial available software, SPSS. The initial form of the demand functions was described in Section 4.2. Basically, both dependent and independent variables of the model were secondary data available from various sources, collected in the past 10 years, starting from 1998 – 2008. We used the quarterly data (every three months); each year will have 4 data points, and the 10-year analysis period will provide a total of 40 data points. The demand function was developed using a least squared method. For each of the model, the researchers verified the logic of the estimated coefficients for each variable in the model, as well as avoided the multicollinearity problem among the independent variables. A few alternatives of the model is provided in Section 4.3, and the final one are selected based on its logic and free of statistical problems.

The demand functions would take a general form of

$$\ln Yt = \alpha + \beta \ln PG_t + \gamma \ln Z_t + \delta \ln Y_{t\ \ 1} \tag{17}$$

where

Y_t = fuel demand or travel demand in the period t

PG_t = fuel price in the period t

Z_t = a set of the key independent variables that influence the demand, for the period t

Y_{t-1} = lagged fuel demand or travel demand in the period t – 1

Once the demand function has been developed, we can obtain the demand elasticity with respect to fuel price as:

Short-term elasticity $= \beta$ (18)

long-term elasticity $= \beta /(1-\delta)$ (19)

where β is the estimated coefficient of the fuel price in the demand equation, and δ is the estimated coefficient of the lagged fuel demand or travel demand [2].

4.3 Demand Function and Elasticity

The consumptions of various fuel types were groups into 3 main categories as listed below. Note that the researchers developed a separate demand function for the three categories, and some categorizes were analyzed not only for the entire nation, but specific for Bangkok and Nakhon Ratchasima as well.

- Unleaded Gasoline and Gasohol
  (analyzed for the entire country, Bangkok and Nakhon Ratchasima)
- LPG and CNG
  (analyze for the entire country only)
- Diesel
  (analyzed for the entire country, Bangkok and Nakhon Ratchasima)

For the travel demand analysis part, we focus on 4 indicators.

- Traffic volumes on the expressway system
  (analyzed for the Expressway Stage 1 – 5, in he greater Bangkok area)
- Ridership on the BMTA bus system

(analyzed for all of the BMA-operating routes, in the greater Bangkok area)

- Ridership on the MRTA subway system (analyzed for the heavy rail – blue line, in Bangkok)
- Ridership on the BTS skytrain system (analyzed for the heavy rail – green line, in Bangkok)

4.3.1 Consumptions of ULG95, ULG91, Gasohol 95, Gasohol 91

The demand of ULG95, ULG91, Gasohol 95 and Gasohol 91 were aggregated as a single group, which represents the fuel types that are commonly used in regular passenger cars without engine modifications. The dependent variable of the demand function is in the unit of equivalent ULG95 liters per quarter (converted using the information of mega joule of each fuels). The independent variables analyzed include the price of ULG95, the Gross Domestic Product (GDP), the Population (POP), the number of registered vehicles (CAR), the number of CNG stations (SCNG), the number of gas stations that serve gasohol (SGAS), the number of gas stations that serve LPG (SLPG), and the lagged demand of these fuels in the previous quarter. In this fuel category, we used the actual price of ULG95 (represents as "PG95") to represent the general gasoline price trend during the 10-year analysis period. The price of other fuel types in the same group fluctuates in the similar pattern of PG95's.

The best demand model for the ULG and Gasohol consumption is:

$$\ln G = 12.599 - 0.058\ln PG95 + 0.389\ln G_{t-1} + 0.044\ln CAR \qquad (20)$$

Adjusted $R^2 = 0.672$

where

G = consumption of ULGs and Gasohols combined in the quarter (liters)

PG95 = average ULG95unit price in the quarter (baht/liter)

G_{t-1} = consumption of ULGs and Gasohols in the previous quarter (liters)

CAR = the number of registered vehicles for the entire nation (vehicle)

From the demand function, the short-term elasticity of ULG & Gasohol consumption is simply the coefficient of the PG95 variable or -0.06. The long-term elasticity is estimated to be -0.09.

In this study, we also developed separate fuel consumptions for Bangkok and Nakhorn Ratchasima, and estimated the short-term and long-term elasticity specifically for these two provinces (as described in the following sub-sections)

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4.3.1.1 ULG95, ULG91, Gasohol 95, Gasohol 91 Consumption in Bangkok

The estimation of the fuel demand specifically for Bangkok employed similar procedure to the model development for the entire country, except for using data that are specific to particular province rather than for the whole country. That is, we used the information of the Gross Provincial Product of Bangkok (GPPb), the population of Bangkok (POPb), the number of registered vehicles in Bangkok (CARb), the number of gas stations that serve CNG in Bangkok (SCNGb), and the number of gas stations that serve LPG in Bangkok (SGASb) as independent variables, along with the actual price of ULG95 (PG95) and the lagged demand in the previous quarter.

The best demand model for the ULG and Gasohol consumption is:

$$\ln Gb = 13.659 - 0.090\ln PG95 + 0.293\ln Gb_{t-1} + 0.081\ln CARb \qquad (21)$$

Adjusted $R^2 = 0.603$

where

Gb = consumption of ULG and Gasohol of Bangkok in the quarter (liters).

PG95 = average ULG95unit price in the quarter (baht/liter).

Gb_{t-1} = consumption of ULG and Gasohol of Bangkok in the previous quarter (liters).

CARb = the number of registered vehicles in Bangkok (vehicle)

From the demand function, the short-term elasticity of ULG/Gasohol consumption in Bangkok is estimated to be -0.09, while long time elasticity of ULG/Gasohol consumption is estimated to be -0.13.

4.3.1.2 ULG95, ULG91, Gasohol 95, Gasohol 91 Consumption in Nakhon Ratchasima

The estimation of the fuel demand specifically for Nakhon Ratchasima employed similar procedure to the model development for the entire country and for Bangkok, except for using particular data for the province. That is, we used the information of the Gross Provincial Product of Nakhon Ratchasima (GPPn), the population of Nakhon Ratchasima (POPn), the number of registered vehicles in Nakhon Ratchasima (CARn), and the number of gas stations that serve CNG in Nakhon Ratchasima (SCNGn) as independent variables, along with the actual price of ULG95 (PG95) and the lagged demand in the previous quarter.

The best demand model for the ULG and Gasohol consumption is:

$$\ln Gn = 3.108 - 0.070\ln PG95 + 0.468\ln GPPn + 0.559\ln Gn_{t-1} \qquad (22)$$

Adjusted $R^2 = 0.845$

where
Gn = consumption of ULG and Gasohol of Nakhon Ratchasima in the quarter(liters).
PG95 = average ULG95unit price in the quarter (baht/liter).
GPPn = the Gross Provincial Product of Nakhon Ratchasima (million baht).
Gn_{t-1} = consumption of ULG and Gasohol of Nakhon Ratchasima in the previous quarter (liters).

From the demand function, the short-term elasticity of ULG/Gasohol consumption in Nakhon Ratchasima is estimated to be -0.07, while long time elasticity of ULG/Gasohol consumption is estimated to be -0.16.

4.3.2 Consumption of Liquid Petroleum Gas (LPG) & Compressed Natural Gas (CNG)

The demand of liquid petroleum gas (LPG) and compressed natural gas (CNG) were aggregated as a single group, which represents the fuel types regular passenger cars can not take directly, but need a special equipment installation. The dependent variable of the demand function is in the unit of equivalent ULG-95 liters per quarter (converted using the information of Mega Joule of each fuels). The independent variables analyzed include the price of ULG95, the Gross Domestic Product (GDP), the Population (POP), the number of registered vehicles (CAR), the number of CNG stations (SCNG), the number of gas stations that serve gasohol (SGAS), the number of gas stations that serve LPG (SLPG), and the lagged LPG and CNG demand in the previous quarter. In this fuel category, we used the actual price of ULG95 (represents as "PG95") to represent the general gasoline price trend during the 10-year analysis period.

The best demand model for the LPG and CNG consumption is:

$$\ln G1 = 0.265 + 0.316\ln PG95 + 0.963\ln G1_{t-1} + 0.017\ln CAR \tag{23}$$

Adjust $R^2 = 0.990$

where
G1 = consumption of LPG and CNG in the quarter (liters)
PG95 = average ULG95unit price in the quarter (baht/liter).
$G1_{t-1}$ = consumption of LPG and CNG in the previous quarter (liters)
CAR = the number of registered vehicles for the entire nation (vehicle)

From the demand function, the short-term elasticity of the LPG & CNG consumption is estimated to be 0.32, while long time elasticity is estimated to be 8.54.

4.3.3 Consumption of Diesel

The fuel group includes only diesel, and represents the demand of fuel that large and hi-powered vehicles, such as trucks or buses, normally used. The dependent variable of the demand function is in the unit of liters per quarter. The independent variables analyzed include the price of diesel (PDS), the Gross Domestic Product (GDP), the Population (POP), the number of registered trucks (TRUCK), the number of registered buses (BUS), the number of gas stations that serve bio-diesel (SB5), and the lagged demand of diesel in the previous quarter. In this fuel category, we used the actual price of diesel (represents as "PDS") to represent the general price trend during the 10-year analysis period.

The best demand model for the Diesel consumption is:

$$\ln DS = -3.078 - 0.260\ln PDS + 0.375\ln GDP + 0.930\ln DS_{t-1} \tag{24}$$

Adjusted $R^2 = 0.774$

where
DS = consumption of Diesel in the quarter(liters)
PDS = average diesel unit price in the quarter (baht/liter)
GDP = the Gross Domestic Product (million baht)
$DS1_{t-1}$ = consumption of diesel in the previous quarter (liters)

From the demand function, the short-term elasticity of Diesel is estimated to be -0.26, while long time elasticity is estimated to be -3.71.

In this study, we also develop separate diesel consumptions for Bangkok and Nakhorn Ratchasima, and estimate the short-term and long-term elasticity specifically for these two provinces (as described in the following sub-sections).

4.3.3.1 Diesel Consumption in Bangkok

The estimation of the diesel demand specifically for Bangkok employed similar procedure to the model development for the entire country, except for using data that are specific to particular province rather than for the whole country. That is, we used the information the Gross Provincial Product of Bangkok (GPPb), the population of Bangkok (POPb), the number of registered trucks in Bangkok (TRUCKb), and the number of registered buses in Bangkok (BUSb) as independent variables, along with the actual price of diesel (PDS) and the lagged diesel demand in the previous quarter.

The best demand model for the diesel consumptions is:

$$\ln DSb = -2.875 - 0.090\ln PDS + 0.430\ln GPPb + 0.824\ln DSb_{t-11} \tag{25}$$

Adjusted $R^2 = 0.898$

where
DSb = consumption of Diesel in Bangkok in the quarter (liters).
PDS = average diesel unit price in the quarter (baht/liter).
GPPb = the Gross Provincial Product of Bangkok (million baht).
DSb_{t-1} = consumption of diesel in the previous quarter (liters).

From the demand function, the short-term elasticity of diesel consumption in Bangkok is estimated to be -0.09, while long time elasticity of diesel consumption is estimated to be -0.51.

4.3.3.2 Diesel Consumption in Nakhon Ratchasima

The estimation of the diesel demand specifically for Nakhon Ratchasima employed similar procedure to the model development for the entire country and for Bangkok, except for using particular data for the province. That is, we used the information of the Gross Provincial Product of for Nakhon Ratchasima (GPPn), the population of Nakhon Ratchasima (POPn), the number of registered trucks in Nakhon Ratchasima (TRUCKn), and the number of registered buses in Nakhon Ratchasima (BUSn) as independent variables, along with the actual price of diesel (PDS) and the lagged diesel demand in the previous quarter.

The best demand model for the diesel consumptions consumption is:

$$\ln DSn = 6.461 + 0.072 \ln PDS + 0.436 \ln DSn_{t-1} \tag{26}$$

Adjusted R^2 = 0.363

where

DSn = consumption of Diesel in Nakhon Ratchasima in the quarter (liters).

PDS = average diesel unit price in the quarter (baht/liter).

DSn_{t-1} = consumption of diesel in Nakhon Ratchasima in the previous quarter (liters).

From the demand function, the short-term elasticity of diesel consumption in Nakhon Ratchasima is estimated to be 0.07, while long time elasticity is estimated to be 0.11.

4.3.4 Traffic Volumes on The Expressway System

This study also investigates how gasoline price change impact the demand on the expressway system. The expressway system Stages 1-5 in the greater Bangkok area covers a total length of 173.2 kilometers of limited access freeway. It is one of the attractive options for travelers who would like to bypass traffic on normal streets and signalized intersections and reach the destination faster with a fee. During 2008 when the gasoline price at its peak (43.89 baht/liter), it is noticeable that traffic volumes on expressway reduces, traffic conditions on the expressway system improve in a noticeable manner. One of the plausible reasons is that, due to the high gasoline price, travelers adjusted their travel behavior to minimize travel cost. Thus, travelers might decide to generate fewer trips, to travel to a nearer destination, to switch mode of travel, or might even switch routes for a less expensive routes. These would result in a reduction of the traffic demand on the expressway system.

The dependent variable of the demand function is the accumulated total volumes on the expressway system (Stages I – V) in the unit of trips per quarter. The independent variables analyzed include the price of ULG95 (PG95), the Gross Provincial Product of Bangkok & vicinities (GPPbv), the number of registered vehicles in Bangkok & vicinities (CARbv), the expressway toll (MT), and the seasonal factor during the summer time (CYCLE), and the lagged traffic volume on the expressway system in the previous quarter. We used the actual price of ULG95 (represents as "PG95") to represent the general gasoline price trend during the 10-year analysis period. The price of other fuel types in the same group fluctuates in the similar pattern of PG95's.

The best demand model for the expressway usage is:

$$\ln Y_t = 6.369 - 0.043 \ln PG95 + 0.350 \ln GPPbv + 0.271 \ln Y_{t-1} + 0.199 \ln CARbv \tag{27}$$

Adjust R^2 = 0.941

where

Y = traffic volume at the expressway in the quarter (vehicle) in quarter t.

PG95 = average ULG95 unit price in the quarter (baht/liter).

GPPbv = gross provincial products of Bangkok& Vicinities in the quarter (million baht)

Y_{t-1} = first order lagged traffic volume of expressway (vehicle).

CARbv = the number of registered vehicles in Bangkok & Vicinities (vehicle).

From the demand function, the short-term elasticity of travel demand on the expressway is simply the coefficient of the PG95 variable or -0.04. The long-term elasticity is estimated to be -0.06. It should be noted that even though we included the expressway toll in the analysis, but the variable did not appear to be significant to the model at 95 percent confidence interval. It cannot simply interpret that toll is not a significant predictor of the traffic demand on the expressway in general. It is rather the toll imposed on the expressways in Bangkok has not changed much throughout the past 10 years, causing the variable toll does not show its impact statistically in this case.

4.3.5 Ridership on The BMTA Bus System

This project also analyzes how gasoline price change impact the number of patronage on the BMTA bus system. Bangkok Metropolitan Transit Authority (BMTA) currently operated 3,526 AC and non-AC buses on 113 bus routes covering the area of Bangkok and the vicinity provinces. During 2008 when the gasoline price at its peak (43.89 baht/liter), one can reasonably assume that some travelers would switch from driving their vehicle to use buses instead, thus increase the number of ridership on BMTA system.

The dependent variable of the demand function is the accumulated total number of ridership on the BMTA-operated bus route system, in the unit of passengers per quarter. The independent variables analyzed include the price of ULG95 (PG95), the Gross Provincial Product of Bangkok and vicinities (GPPbv), the number of population in the area (POPbv), the number of registered vehicles in the area (CARbv), the base bus fare (Fbus), and the seasonal factor during the summer time (CYCLE), and the lagged bus ridership on the BMTA bus system in the previous quarter. We used the actual price of ULG95 (represents as "PG95") to represent the general gasoline price trend during the 10-

year analysis period. The price of other fuel types in the same group fluctuates in the similar pattern of ULG95's.

The best demand model for the ridership on the BMTA bus system is:

$$\ln Rb = 25.769 + 0.057\ln PG95 - 0.904 lGPP bv + 0.278\ln Rb_{t-1} + 0.117Cycle \quad (28)$$

Adjusted $R^2 = 0.961$

where
Rb = ridership for BMTA bus in the quarter (person).
PG95 = average ULG95 unit price in the quarter (baht/liter).
GPPbv = gross provincial products of Bangkok& Vicinities in the quarter (million baht).
Rb_{t-1} = first order lagged ridership for BMTA bus (person).
Cycle = the seasonal factor during the summer time

From the demand function, the short-term elasticity is simply the coefficient of the PG95 variable or 0.06. The long-term elasticity is estimated to be 0.08.

4.3.6 Ridership on the MRTA Subway Line

We also analyzed how gasoline price change impact the number of patronage on the MRTA subway system. Currently, the MRTA subway (blue line) line is approximate 20 kilometers, connecting the high-density residential areas (Bang Sue, Lad Prao, Sutthisarn) to the commercial areas (Ratchadapisek) and center business districts (Petchburi, Sukhumbit, Rama V, Sathorn, Silom and Hua Lamphong). The line operates from 6:00 am to midnight with the frequent and reliable service. Since its operation in July, 2004 , it quickly gains popularity among Bangkokians. During 2008 when the gasoline price at its peak (43.89 baht/liter), one can reasonably assume that some travelers would switch from driving their vehicle to use subways instead, thus increase the number of ridership on the MRTA subway system.

The dependent variable of the demand function is the accumulated total number of ridership on the MRTA subway system, in the unit of passengers per quarter. The independent variables analyzed include the price of ULG95 (PG95), the Gross Provincial Product of Bangkok & vicinities (GPPbv), the number of population in the area (POPbv), the base subway fare (FMRTA), the base bus fare (Fbus), and the seasonal factor during the summer time (CYCLE), and the lagged bus ridership on the MRTA subway system in the previous quarter. We used the actual price of ULG95 (represents as "PG95") to represent the general gasoline price trend during the 10-year analysis period. The price of other fuel types in the same group fluctuates in the similar pattern of ULG95's.

The best demand model is :

$$\ln Rm = 4.554 + 0.024\ln PG95 + 0.912\ln POPbv + 0.220\ln Rm_{t-1} \quad (29)$$

Adjusted $R^2 = 0.176$

where
Rm = ridership for MRTA in the quarter (person/day).
PG95 = average ULG95 unit price in the quarter (baht/liter).
POPbv = number of population in Bangkok& Vicinities and the quarter (person).
Rm_{t-1} =first order lagged ridership for MRTA (person/day).

From the demand function, the short-term elasticity is simply the coefficient of the PG95 variable or 0.02. The long-term elasticity is estimated to be 0.03. It should be noted that the adjusted r^2 of the model is relatively low (0.176) due to the fewer number of the data points available, considering the MRTA subway line just open for 4 years only.

4.3.7 Ridership on the BTS Skytrain

We also analyzed how gasoline price change impact the number of patronage on the BTS skytrain. Currently, the BTS skytrain (green line) line extends approximate 23.3 kilometers, connecting the high-density residential areas (Mohr Shit, Sukhumvit) to the center business districts (Sathorn, Silom and Siam Square). The line operates from 6:00 am to midnight with the frequent and reliable service. Since its operation in December, 1999 , it gains popularity among Bangkokians. During 2008 when the gasoline price at its peak (43.89 baht/liter), one can reasonably assume that some travelers would switch from driving their vehicle to use skytrain instead, thus increase the number of ridership on the BTS skytrain system. The dependent variable of the demand function is the accumulated total number of ridership on the BTS skytrain system, in the unit of passengers per quarter. The independent variables analyzed include the price of ULG95 (PG95), the Gross Provincial Product of Bangkok and vicinities(GPPbv),the number of population in the area (POPbv), the base skytrain fare (Fbts), the base bus fare (Fbus), and the seasonal factor during the summer time (CYCLE), and the lagged ridership on the BTS skytrain system in the previous quarter (Rbts t-1). We used the actual price of ULG95 (represents as "PG95") to represent the general gasoline price trend during the 10-year analysis period. The price of other fuel types in the same group fluctuates in the similar pattern of ULG95's.

The best demand model is:

$$\ln Rbts = 4.081 + 0.159\ln PG95 + 0.936\ln GPPbv - 1.118Fbts \quad (30)$$

Adjusted $R^2 = 0.914$

where
Rbts = ridership on the BTS skytrain system in the quarter (person/day)

PG95 = average ULG95 unit price in the quarter (baht/liter)
GPPbv = the Gross Provincial Product of Bangkok& Vicinities and the quarter (million baht)

Fbts = the base skytrain fare (Baht)
Cycle = the seasonal factor during the summer time

From the demand function, the short-term elasticity is simply the coefficient of the PG95 variable or 0.16. The long-term elasticity is unable to estimate because the lagged ridership on the BTS skytrain system in the previous quarter ($Rbts_{t-1}$) is excluded from the model.

5 CONCLUSIONS

This study successfully developed demand functions for various fuel types for transportation as well as travel patterns on the transport system, in order to investigate the short- and long-term elasticity of gasoline consumption and travel demand with respect to gasoline price. In this research, the demand functions were developed for three groups of fuel categories (ULG/Gasohol, LPG/CNG, Diesel) and four groups of travel demand (volumes on expressways, riderships on BMTA buses, on MRTA subways, and on BTS skytrains). The independent variables for the demand function include major socio-economic factors (gross domestic products, gross provincial products, no. of population, numbers of registered vehicles, trucks, buses) that seem to be the main influencing factors as suggested in the literature, along with gasoline price. Given that new fuel types had been introduced to Thai market in the past few years, the level of market penetrations might play an important role on the fuel consumption. Thus, we collected and incorporated such data as the number of gasoline stations that serve LPG, CNG as well as Biodiesel into the model. Furthermore, a seasonal factor that represents the fluctuation of travel demand throughout the year was also included into some of the travel demands that possess an obvious cyclic pattern. The demand functions were developed using the regression analysis on the quarterly data for the 10-year periods from 1998 -2008.

The final demand functions for gasoline consumptions, diesel consumption and for the travel demand on various transportation systems are summarized in Tables 4 to 6, respectively.

Table 4 Demand Functions for Gasoline Consumptions

List of variables (include only the significant ones)	ULG/Gasohol Whole nation		ULG/Gasohol Bangkok		ULG/Gasohol Nakhon Ratchasima		LPG/CNG Whole nation	
	beta	t-stat	beta	t-stat	beta	t-stat	beta	t-stat
constant	12.599**	12.264	13.659**	13.242	3.108	1.933	0.265	-0.213
PG95	-0.058*	-2.127	-0.090**	-2.293	-0.070	-0.707	0.316	1.224
CAR	0.044*	2.079	0.081*	2.716	-	-	0.017	0.246
GPP	-	-	-	-	0.468*	2.456	-	-
Gt-1	0.389**	7.478	0.293**	5.172	0.559*	7.285	0.963**	15.002
Adjusted- r^2	0.672	-	0.603	-	0.845	-	0.990	-

* denotes significance at the 0.05 level, ** denotes significance at the 0.01 level

Table 5 Demand Functions for Diesel Consumptions

List of variables (include only the significant ones)	Diesel Whole nation		Diesel Bangkok		Diesel Nakhon Ratachsima	
	beta	t-stat	beta	t-stat	beta	t-stat
constant	-3.078	-1.387	-2.875	-1.010	3.955	1.709
PDS	-0.260**	-3.659	-0.090	-0.909	-0.072	-0.242
GDP/GPP	0.375**	2.986	0.430	1.541	-	-
DS_{t-1}	0.930**	10.824	0.824**	9.117	0.436*	2.814
Adjusted r^2	0.774	-	0.898	-	0.363	-

* denotes significance at the 0.05 level, **denotes significance at the 0.01 level

Table 6 Demand Functions for Travel Demand

List of variables (include only the significant ones)	Traffic volumes on expressways		Ridership on BMTA bus system		Ridership on MRTA subway system		Ridership on BTS skytrain system	
	beta	t-stat	beta	t-stat	beta	t-stat	beta	t-stat
constant	6.369**	3.183	25.769**	7.451	4.554	-0.236	4.081	1.492
PG95	-0.043	-0.467	0.057	0.714	0.024	0.261	0.159	1.500
POPbv	-	-	-	-	0.912	0.737	-	-
GPPbv	0.350	1.668	-0.904**	-5.916	-	-	0.936**	4.177
Yt-1	0.271*	2.038	0.278**	2.658	0.220	0.712	-	-
Fbts	-	-	-	-	-	-	-1.118**	-4.388
CARbv	0.199*	5.016	-	-	-	-	-	-
Cycle	-	-	0.117**	7.075	-	-	-	-
Adjusted- r^2	0.941	-	0.961	-	0.176	-	0.914	-

* denotes significance at the 0.05 level, ** denotes significance at the 0.01level

The short- and long-term elasticity of various gasoline consumption and travel demand on various transport system, can be obtained directly from the specifications of the developed demand functions. The estimated coefficient of the variable, price of gasoline (PG95 or PDS) in the demand function is in fact the short-term elasticity. To estimate the long-term elasticity, the estimated coefficient of the variable, price of gasoline, has to be adjusted by (1– x), where x is the estimated coefficient of the lagged demand in the previous quarter. The estimated short- and long-term elasticity of gasoline consumption and travel demand are summarized in Table 7

Table 7 Short Run and Long Run Elasticity of Fuel Consumption and Transport Demand

	Elasticity	
	Shot Run	Long Run
Gasoline consumption elasticity		
1.Gasoline&Gasohol Consumption (Nationwide)	-0.06*	-0.09
- Bangkok	-0.09**	-0.13
- Nakhon Ratchasima	-0.07	-0.16
2.CNG&LPG Consumption elasticity (Nationwide)	0.32	8.54
3.Diesel Consumption elasticity (Nationwide)	-0.26**	-3.71
- Bangkok	-0.09	-0.51
- Nakhon Ratchasima	-0.07	-0.11
Travel Demand elasticity		
4.Traffic on expressway (Greater Bangkok Area)	-0.04	-0.06
5.BMTA Bus ridership (Greater Bangkok Area)	0.06	0.08
6.MRTA ridership (Bangkok)	0.02	0.03
7.BTS ridership (Bangkok)	0.16	-

* denotes significance at the 0.05 level in the demand function

* * denotes significance at the 0.01 level in the demand function

As shown in Table 7, the price elasticity of gasoline demand and travel demand is inelastic, similar to the same elasticity revealed in other cities or other countries. The absolute magnitude of the elasticity is less than 1.0, which implies that when the gasoline price increase by 100 percent, the gasoline consumption and travel demand functions would change less than 100 percent, depending on the sign and the magnitude of the elasticity. Long-term elasticities are typically higher than short-term elasticities, as a typical trend worldwide, since it would take some times for some people to overcome the institutional barriers, technical barriers and financial barriers and adjust their travel behavior.

The nationwide short-term demand elasticities of fuel consumption are in the magnitude of -0.06 to -0.26, for gasoline and diesel. That is, when the gasoline price increases by 100 percent (for example; from 25 baht/liter to 50 baht/liter), the overall consumption of transport fuel (ULG & Gasohol as well as Diesel) would decrease by 6 to 26 percent from the original level. The reduction in fuel consumption was a result from behavior adjustment, from people and industries, on their travel and logistics in order to react to the gasoline price increase in a short term. However, the long-term elasticity of diesel consumption (-3.71) seem to be four times as much as the gasoline consumption (-0.09). One of the plausible explanations is that industries have to constantly improve their supply chain and operations in order to remain competitive in the businesses; otherwise they will soon lose market share. Thus, they intend to develop a substitute plan in order to reduce transport costs as much as possible; for example, using cheaper alternative fuels, switching to cheaper transport modes, employing new technology system in order to reduce travel cost, or even relocate their office/factory etc. The bus operators also plan to minimize their travel cost, by using larger buses, reduce empty bus trips. They all have to adjust themselves in order to stay competitive. Thus, the long-term elasticity of diesel consumption would reduce much more substantially in reaction to the gasoline price increase, compared to the long-term elasticity of gasoline consumption.

The nationwide elasticities of LPG/CNG consumption in Thailand are rather high. As shown, the short- and long-term elasticities were estimated to be 0.32 and 8.54, respectively. It should be noted that CNG has recently been introduced in Thailand, and it quickly gains popularities in Thailand due to several promotion packages issued by the national government. The demand function was developed based on the data during the introduction and the initial growth of the CNG, which could potentially attenuate the effect of gasoline price. Thus, care should be taken when using these numbers.

The elasticity of expressway traffic was found to be -0.04 and -0.06 for short- and long-term, respectively. That is, as the gasoline price increases by 100 percent from today price, the amount of traffic on expressways is expected to reduce by the magnitude of 4% in the short term and by 6% in the long run from the current usage. Recall that the expressway system offers a fast and reliable route for private vehicles traveling to the various destinations with minimal delay. Most drivers will have no other choices to do except for using the expressway system. The expressway toll generally costs 25-50 baht per trips, which is approximately 25-50% of the cost of an hour of travel delay of typical Bangkokians. That is, if the expressway would pay off if they save 25% or 50% of their travel time, which they typically do already. Moreover, most of the business/working trips can get a reimbursement on the expressway tolls anyhow, thus those drivers continue to use expressway as usual despite the gasoline price increases. Therefore, the gasoline price would not affect to their decision on using expressway. This is why traffic volumes on expressway are very inelastic to the gasoline price increases.

The elasticities of the three transit systems in the Bangkok area are also inelastic, approximately in the range of 0.02 – 0.16 short-term, and 0.03 – 0.08 long-term. This reveals that the gasoline price increase has relatively small impacts on mode switching in Bangkok. That is, when the gasoline price increases by 100 percent, the number of ridership on buses, skytrains and subways increase by 2 – 16 percent only. This is perhaps due to the low quality of the current bus systems that people are reluctant to use even though the gasoline price increase considerably, and due to the limited coverage area of the current subways and skytrains that people are not able to use to access many destinations. Thus, both short- and long-term of these public transit services are rather inelastic to the gasoline price.

Comparison within Thailand

A comparison of gasoline (ULG/Gasohol) demand elasticities between the two provinces in Thailand reveals that gasoline consumption in Bangkok (-0.09) is more elastic than the gasoline consumption in Nakhon Ratchasima (-0.07). The Bangkok's elasticity is also higher than the nationwide number (-0.06). There are a few plausible explanations for this phenomenon. First, Bangkok has a number of alternative modes of transport available. With an extensive coverage of transit system, a fast and reliable service of skytrains and subways, a plenty services of taxis, motorcycle taxis, tuk tuk, ferry service, Bangkokians have plenty of readily available alternative modes to use as a substitute of personal transport to use when the gasoline price increases. Second, there are also several gasoline stations that serve alternative fuels, such as LPG and CNG, with a reasonable price. Lastly, thanks to good telecommunication system in Bangkok, some of the works and shopping could be completed without making unnecessary trips everyday. Bangkokians are luxurious to enjoy these benefits, thus they are readily to adjust their travel behavior in reaction to the gasoline price crisis. Nakhon Ratchasima, as of other regional large municipalities outside Bangkok, has only limited-route transit system available and only few gasoline stations that serves alternative fuels, such as LPG and CNG, thus citizens would not have much choices to react to the gasoline price increase. Thus, the gasoline consumption in Nakhon Ratchasima tends to be inelastic when compared to the Bangkok area, both in the short run and the long run.

The estimated elasticities of diesel consumption reveal a different story. It was found that the short-term elasticity of diesel consumption in Bangkok is more than that in Nakhon Ratchasima. As commonly accepted, as diesel price increases, general businesses and public tend to save up money by reducing spending on other expenditures, thus it tends to slow down the activities in the area. Furthermore, businesses want to stay competitive in the business by reducing some operating costs, and they tend to pay more attention on the reduction of costly trips, such as a long trip to other provinces. In terms of alternative strategies, businesses in Bangkok seem to have more options to reposition themselves, such as, alternative fuels, or third party logistics. Thus, the diesel consumption in Bangkok appears to be affected by the diesel price increase more than those in regional cities during the short term. In the long term, the elasticity of diesel consumptions in Bangkok become much higher than in Nakhon Ratchasima, plausibly with the reasons that Bangkok has alternative fuels with reasonable price as well as the availability of professional delivery services that make the entire diesel consumption reduce in the higher magnitude in the long run.

Comparisons with other cities around the world

Table 8 illustrates the estimated elasticity from this study along with the estimated elasticity of gasoline consumption in other countries. As shown, the gasoline consumption elasticity in Thailand is rather inelastic, compared with the numbers of other countries as summarized by Goodwin (1992) and Goodwin et al. (2004), except for the gulf countries (Eltony, 1996). One plausible explanation would be that the restricted public transit service in Thailand, would resembles the transit condition on the gulf countries. People would leave with no choices but drive private vehicles to reach various destinations, unlike citizen in EU and north America that enjoy various quality transit systems. Furthermore, citizens in EU and north America are keen on environment than people in Gulf countries, and Thailand, thus they invented a number useful program to reduce gas consumption (e.g., telecommuting centers, car-pools, bicycle lanes) that turns successful after it adopted.

Table 8 Demand Elasticity of Fuel Consumption with Respect to Fuel Price per Litre

Country	Short Run	Long Run
Thailand(2009)	-0.06	-0.09
Goodwin *et al.*(2004)	-0.25	-0.64
M. Nagy Eltony ,Gulf Cooperation Council(1996)	-0.11	-0.17
Goodwin(1992)	-0.27	-0.73

Table 9 summarized the estimated demand elasticity of traffic on expressway in Thailand comparing with the demand elasticity of traffic on tolled roads in other countries. As shown, traffic volumes on the expressway system in Bangkok are very inelastic when comparing with international numbers. This is perhaps, the expressway system in Thailand is the only fast and reliable routes for private vehicles, and Bangkok drivers have no choice but to use the expressway system, or use normal street system that traffic are very congested. In other country/studies, drivers have a few parallel routes that can be used. Thus, the elasticity revealed in the Bangkok case was rather inelastic, as shown in Table 9.

Table 9 Demand Elasticity of Traffic on Expressway with Respect to Fuel Price per Litre

Country	Short Run	Long Run
Thailand(2009)	-0.04	-0.06
James Odeck, Norway(2008)	-0.56	-0.82
Anna Metas *etal.*, Spain(2002)	-0.30	-0.53
Ira Hirschman *et al.*, New York (1995)	-0.09	-0.50

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EVALUATION OF ALTERNATIVE METHOD TO PROMOTE TRAFFIC SAFETY IN THAILAND

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Traffic safety has become one of the critic problems in many countries across the globe. Particularly, a developing country like Thailand, the number of road accident fatalities still remains high, despite the government's efforts to cope with the problem. An improvement of road design through road safety audit is one among other that has been deployed to alleviate road traffic accidents. Stringent traffic law has been enforced occasionally through roadside inspecting points by traffic police to enforce traffic law against road traffic offenses. This method is quite effective however it requires a number of workforces, budgets and consecutive time to overcome the increasing number of violations. A measure on rising traffic safety awareness in community which is crucially important for traffic safety education was implemented but still impractical. Hence, this paper introduces a practical method of Japanese experiences so called Hiyari map development, a community-based approach to raise traffic safety awareness together with evaluating its methodological effectiveness. A face-to-face communicative method through Hiyari map developmental workshops was held to collect data from participants. The study targeted concerned agencies and local people with a variation of age groups in the selective communities in Thailand. The study utilized Hiyari map development for identifying hazardous spots in selected communities. The characteristic of hazardous spots derived from the developed Hiyari map was analyzed. The results show that the amount of Hiyari data collected from the Hiyari map identified by the local communities is much greater compared to the Japanese experienced case. The identified Hiyari experiences were mostly located at main intersections like the access roads to the community and center of the community. When comparing the collected Hiyari data with existing accident data from traffic police report, both represent similar characteristics. The participants were asked to state their opinions after Hiyari map was developed. Most participants indicated that Hiyari map development workshop was practical despite their great concerns of the cost of organizing the workshop, identification of leaders and participation of local people. It triggered traffic safety educational activity in the community which implies the utilization of Hiyari map development through workshop activities can be an alternative method of traffic safety education to identify potential black spots and raise awareness among people in communities.

Keywords: Traffic safety education, Traffic safety activity, Hiyari map development, Potential black spot

1 INTRODUCTION

In Thailand, the number of fatalities caused by traffic accidents is approximately 13,000 per year, which is three times higher than that in Japan (Fukuda et al, 2005 National Police Agency, 2004, Japan). Despite the government's efforts to implement countermeasures through 5-E strategic policy to tackle the road traffic accidental problems, its success lined in only at a certain level. For substantial reduction of fatalities, alternative methods to effectively support traffic safety measures in Thailand may be crucial. Especially, giving proper traffic safety education to community at grass-root level will help to raise public safety awareness. Importantly, because no one knows the local problems better than those who live and face the accidental problems everyday in their living neighborhood, an encouragement of public participation and empowerment will help eliciting traffic accident information through identification of hazardous spots and black spots. Local community can characterize the occurred accidents at their identified spots and propose the appropriate countermeasures to suit with local context (Fukuda et al, 2005, Fukuda et al, 2010).

This paper aims at introducing and evaluating an alternative method of Hiyari map development adopted from Japanese experience into Thai communities of Khon Kean, Chiang Mai and Samutprakarn Provinces.

2 HIYARI-HATTO CONCEPT

In Japan, there has been numbers of strategic policies and countermeasures implemented to tackle with the continual increasing road traffic accidents since 1974. One of the tactics used for traffic safety educational campaigns is the "Hiyari map development" (or identified hazardous spots map by community) workshop. Hiyari map development workshop is an activity to encourage local people to locate their Hiyari experiences by pasting the colored round stickers on the local map provided. This activity has been utilized nationwide since then and is used for black spots treatment as well.

Hiyari-Hatto or Hiyari in short is a Japanese word of expression represented a feeling of danger, fear or stunningly surprise when one is facing or has seen a nearly occurred traffic accident. This Hiyari-Hatto has been used as a traffic psychological method to encourage road users to participate in the traffic safety program in order to elicit information through their experiences of nearly occurred accident that almost caused them dead or injured (which may have similar meaning to 'nearmiss' but is not entirely the same.) and located those hazardous spots on the cognitive map provided. This method was originally used in the factories and hospitals and was adopted in traffic safety later for the sake of elderly peoples' safety which currently becomes broader used to raise traffic safety awareness among schools, NGOs, local communities, etc., across Japan (Fukuda et al, 2010).

The Hiyari-Hatto concept or hazardous spot identification by community participation activity marks a quantum leap towards the substantial reduction of road traffic accidents. Recently, there are Hiyari maps (or identified hazardous spots map by community) developed by local community available on the website (e.g., Kamagaya City, Chiba Prefecture), (Fukuda et al, 2005, Fukuda et al, 2010).

3 APPLICATION AND EXPERIENCE OF HIYARI MAP DEVELOPMENT IN JAPAN

In 1994, IATSS Research Project entitled "Study on Life Structure and Mobility in Aged Society" was launched by Prof. Haruo Suzuki. Through this project, an idea to apply Hiyari map development to raise traffic safety awareness among elderly people in community was proposed. Applicability of this idea was examined by the following IATSS Research Project and its result was published as the research report entitled "Proposal of Traffic Safety Measure (Traffic Education) for Silver by Silver" in 1996. After this proposal was introduced by Japanese newspapers, magazines, televisions, radios, etc., Hiyari map development approach has grasped attention from the Japanese society at large. The manual and the video entitled "Let's Develop Hiyari Map -Traffic Safety for Silver by Silver and Its Guideline" were developed and distributed to people who are interested in traffic safety activity as well as local government offices, local police and other related offices (H. Suzuki, 1997).

With support of Japanese government agencies such as Management and Coordination Agency, National Police Agency and municipality, Hiyari map development workshop became popular among Japanese communities. According to the investigative study of IATSS research project (IATSS, 2001), Hiyari map development workshops were organized 3,929 times at 46 prefectures and 172,787 persons were participated in the events during one year from August 1998 to July 1999. The IATSS research project indicates that there were 95.5 % of respondents answered satisfied or almost satisfied to participate in Hiyari map development workshop and 79.4 % of them answered having Hiyari map development workshop helped raising their traffic safety awareness. The study concluded that this approach is workable to motivate people to participate in traffic safety activity. However, most of Hiyari map development workshops were organized according to the proposal of local police. Thus, the study recommended an encouragement of the local community leaders to organize Hiyari map development workshop by community themselves. Also, the study recommended a workshop should include a participation of professional drivers and young generation like school children to make Hiyari map development workshop more effective.

Since Hiyari-Hatto or Hiyari data is qualitative information, many studies have tried to investigate an applicability of Hiyari map development approach. For instance, Takamiya (Takamiya, et al., 2004) developed Hiyari map based on two different approaches. First is an interview with elderly people and second is a questionnaire survey with elderly people in Tsukuba city and used it as supplemental information for traffic accident data to identify black spots. As a result, it found that there were some differences on obtained hazardous/potential black spots by a participant group and way to ask. Also, it was very hard to investigate the reason of traffic accident occurrence from obtained hazardous/potential black spots so that additional investigation including site visit were strongly recommended. For preparation of traffic safety countermeasures including improvement of road alignment or any other engineering works, analysis by professionals such as a traffic engineer is recommended.

To clarify the characteristics of obtained Hiyari data, several studies compared Hiyari data with traffic accident data from traffic police report and analyzed the differences between both data. Furuya, et al. (H. Furuya, et al., 2001) collected 137 Hiyari data at Tsukuba city through questionnaire survey and compared with police recorded traffic accident data. The study concluded that the Hiyari data shows similar tendency with police recorded traffic accident data for some accident types, but Hiyai phenomenon between pedestrians and vehicles was pointed out more than actual traffic accident occurrence. Shiraishi, et al. (N. Shiraishi, et al., 2000) compared the number of reported Hiyari phenomenon and traffic accident occurrence by road types in the area near Utsunomiya Station. The study found that the tendency is quite similar along trunk roads such as National highways. In contrast, the Hiyari identification of black spots was very low along local streets. It is expected that traffic accident occurrence rate might be very low on local streets due to high level of awareness of local communities through their Hiyari experiences at those identified black spots on local streets. This can be implied that local people in the communities might pay more attention on using the local streets for fear of the accident occurrence.

Hiyari map development approach has been used not only for increasing traffic safety awareness but also for identifying both black spots and potential black spots or hazardous spots in Japan. For example, Prof. Takada and his team from Nihon University developed the system to report and collect Hiyari experiences from public through internet in Kamagaya city, Chiba (S. Nanbu, K. Takada, et al., 2004). The Takada study team identified potential black spots from accumulated database and succeeded to help reducing 60% of traffic accidents at some of identified potential black spots by improved marking and installed a curve mirror.

Hiyari map development approach has become one of common traffic safety processes when community has to identify potential black spots or hazardous spots and propose traffic safety countermeasures in Japan.

Hence, this paper introduces Hiyari map development to Thai community together with evaluating its effectiveness whether it is feasible as an alternative method to promote traffic safety education activity since the traffic situation and road user behavior in Thailand are quite different from Japan. Also, it is interesting to compare whether this alternative method can help to identify potential black spots and raise traffic safety awareness of community people.

4 INTRODUCTION OF HIYARI MAP DEVELOPMENT TO COMMUNITY IN THAILAND

4.1 Introduced Conceptual framework of Community Based Approach for Hiyari Map Development

In recognition of the necessity to raise traffic safety awareness in community for a significant reduction of traffic accidents in Thailand, the study on an alternative method to promote traffic safety by introduction of Hiyari map development was carried out for 3 consecutive years from 2005 to 2007. Its objectives are to examine a possibility to apply Hiyari map development approach to Thailand and to evaluate its methodological effectiveness. The study introduces a Japanese experience and proposes the community based approach for traffic safety activity through Hiyari map development in Thailand as shown in Figure 1. The conceptual framework in Figure 1 represents a process of workshop organization in which firstly a leader to organize and moderate the Hiyari map development workshop must be sought through an introductory workshop or nomination by local governmental coordinators. A nominated leader could be a representative of a community or a local policeman, a local government official or a school teacher. Second, Hiyari map development workshop should be taken place in community. The leader who was nominated should be able to manage a Hiyari map development workshop including preparation of the workshop place, calling on participants and moderation of the session. The target group of this workshop may be local people in community or students. The objective of this workshop is to raise traffic safety awareness among local participants through asking them to identify the hazardous spots or potential black spots that they experienced or have seen the situation of nearly occurred accidents or incidents (so called “Hiyari experience”) on the local cognitive map provided to each participant (so called “Hiyari map”). Thirdly, a development of database based upon the collected identified potential black spots on local cognitive map by community or Hiyari map and Hiyari experiences (or potential accident experiences) was done and analyzed them. After that encouraged local people to propose countermeasures for improving potential black spots. In case if the proposed countermeasures can be implemented, an evaluation of the impact of their proposed countermeasures will be assisted. Through this process, it is expected that traffic safety awareness among local people would be raised.

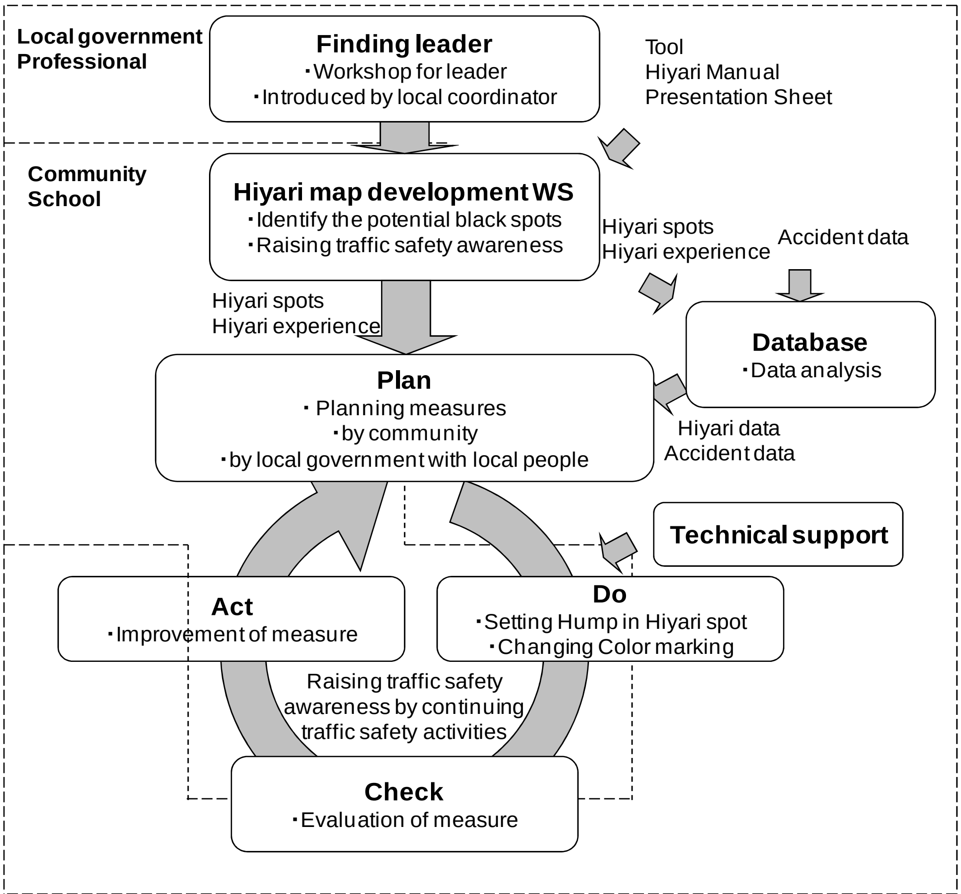

Figure 1 Approach of Traffic Safety Activity Using Hiyari Map Development in Communities in Thailand

4.2 Proposed an Alternative Approach for Traffic Safety Activity in Thai Community

This study selected 8 communities in Thailand as target groups and study areas. Outlines of eight Hiyari map development workshops which were organized at the selected local communities were summarized in Table 1. In most of the workshops organized in 8 communities, majority of participants are male, and middle age or elderly people. However, only participants of workshops held in Khon Kaen University and Samutpurakarn were mainly students or pupils.

Before organizing Hiyari map development workshops, a preparatory workshop was held to seek for an opinion leader who can moderate the workshop in Udonthani and Samutprakarn cities, see Table 1. In these workshops, the representatives from organizations concerned were invited as participants such as local government officials of planning bureau, traffic police and so on. In the case of Khon Kaen and Chiang Mai Cities, some community leaders who were interested in traffic safety activity were nominated by a local coordinator instead of organizing preparatory workshops to find an opinion leader.

During the workshop session, we firstly distributed cognitive maps covered community area in A3 size to participants and asked them to attach the round colored stickers on the spots where they had Hiyari experiences while driving a car or driving a motorcycle or walking on sidewalk/roadside or across streets. Then, gathered all those Hiyari spots which indicated on the cognitive maps given, and assembled altogether onto one map of A0 size. This is so called “Hiyari map development.” Thirdly, the session moderator (i.e., the selected or nominated leader by community) invited participants one by one and asked them to explain his/her Hiyari experiences in front of other participants. Through this process, every participant shared his/her Hiyari experiences. Lastly, before ending the session, all participants visited the selected top three Hiyari spots and observed with providing the reasons why Hiyari-Hatto phenomena happened in those spots and discussed countermeasures.

Table 1 Summary of Hiyari Map Development Workshops in 8 Communities in Thailand

	Target Area (Square-kilometers)	Date/ Place	Number of Participants	Gender	Age	Number of Hiyari experience	Number of Hiyari spot
in community	Arouund Pithayanukhun High School in Udonthani ($5km^2$)	2006.2.25 Auditorium on Pithayanukhun High School	17 local people	Male:13 Female:2	20-29:5 30-39:3 40-49:2 50-59:1 60-69:1	C: 118 M: 131 P: 72 Total 321	C: 72 M: 76 P: 46 Total 110
	Nongbua community in Udonthani ($7.5km^2$)	2006.8.9 Assembly hall in community	14 local people	Non	Non	C: 86 M: 51 P: 53 Total 190	C: 36 M: 25 P: 22 Total 51
	Kaakheha community in Khon Kaen (Khon Kaen municipality) ($2km^2$)	2006.9.6 Assembly hall in community	16 local people	Male:5 Female:11	30-39:4 40-49:6 50-59:3 60-69:3	C: 103 M: 126 P: 90 Total 319	C: 28 M: 34 P: 29 Total 49
	Kaakheha community in Khon Kaen (Mungkao county)($0.5km^2$)	2006.11.27 Assembly hall in community	23 local people	Male:12 Female:3	20-29:1 30-39:3 40-49:5 50-59:7 60-69:6	C: 205 M: 193 P: 249 Total 647	C: 43 M: 45 P: 49 Total 67
	Khon Kaen University ($10km^2$)	2006.9.5 Meeting room at University	18 students 11 guards Total 29 persons	Male:20 Female:7	10-19:1 20-29:17 30-39:1 40-49:4 50-59:3	C: 178 M: 256 P: 63 Total 497	C: 57 M: 70 P: 27 Total 88
	Khon Kaen University ($10km^2$)	2006.11.28 Meeting room at University	36 students	Male:24 Female:10	10-19:6 20-29:16 30-39:6 40-49:5 50-59:1	C: 371 M: 448 P: 177 Total 996	C: 88 M: 111 P: 68 Total 145
	Nonhoi community in Chiang Mai ($0.5km^2$)	2007.11.26 Assembly hall in community	24 local people	Male:13 Female:9	30-39:1 40-49:10 50-59:7 60-69:5	C: 170 M: 136 P: 155 Total 461	C: 32 M: 35 P: 38 Total 44
in school	West area in Samutprakarn ($20km^2$)	2006.8.11 HONDA Safety Riding Center	30 students of junior high school	Male:29 Female:1	10-19:30	C: 113 M: 185 P: 136 Total 434	C: 70 M: 98 P: 67 Total 192

C:Car driver, M:Motorcycle driver, P:Pedestrian

5 IDENTIFYING POTENTIAL BLACK SPOTS FROM HIYARI MAP

As previously mentioned, Hiyari derived from an emotional feeling of people. This study pioneer introducing a psychological concept of Hiyari-Hatto and collected its data from local people in Thailand. Hiyari data were analyzed to learn and understand its characteristics. Figure 2 shows the number of Hiyari experiences per participant. Compared to Japanese case (Suzuki, 1997), much number of Hiyari experiences were reported from Hiyari map development workshop in Thailand. The study also analyzed the characteristics of identified location of the occurred potential black spots (or Hiyari spots). As shown in Figure 3, 4 and 5. Hiyari spots were pointed out near participants' home in Nongbua community, Udonthani. Most of locations of Hiyari experiences were gathered at main intersections like the access roads to the community and the city center of the community. However, several Hiyari experiences were pointed on community roads as well. Thus, results can be assumed that most participants have their Hiyari experiences at the spots where they used to use on daily errands around their living areas. Figure 6 shows relationship between distances from participant's home to Hiyari spots and number of Hiyari spots. There is significantly negative correlation between them as well.

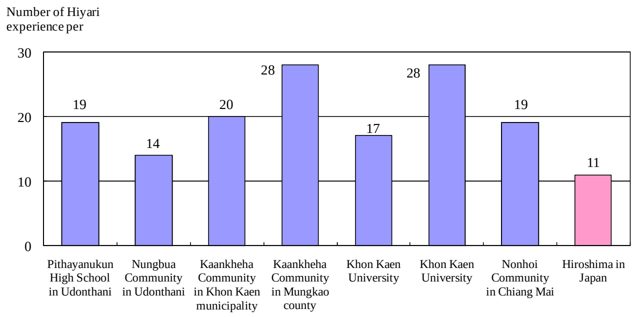

Figure 2 Number of Hiyari Experiences

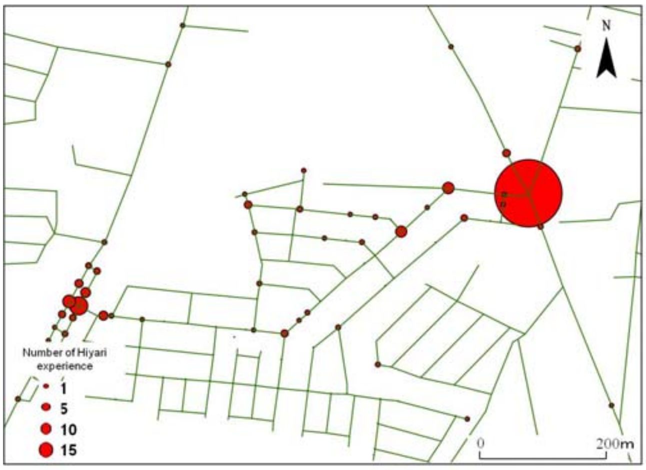

Figure 3 Hiyari Spots in Kaankheha Community in Khon Kean Province

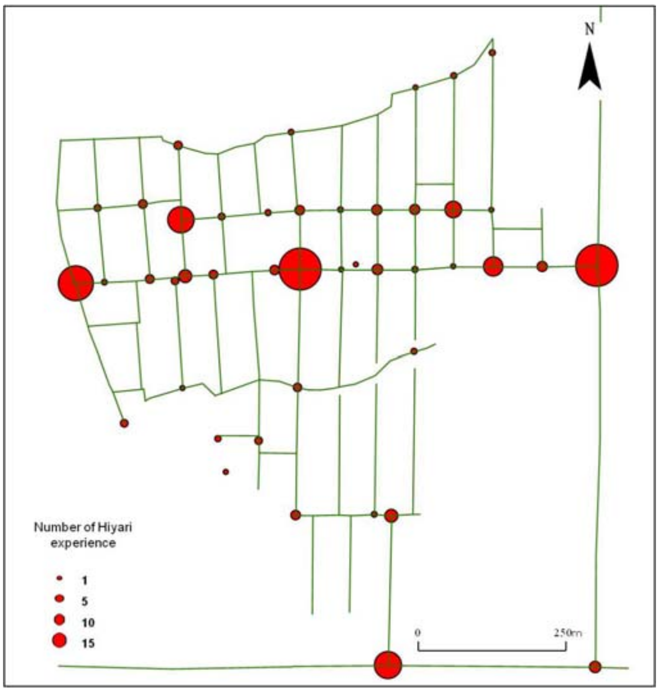

Figure 4 Hiyari spots in Nonghoi Community in Chiang Mai Province

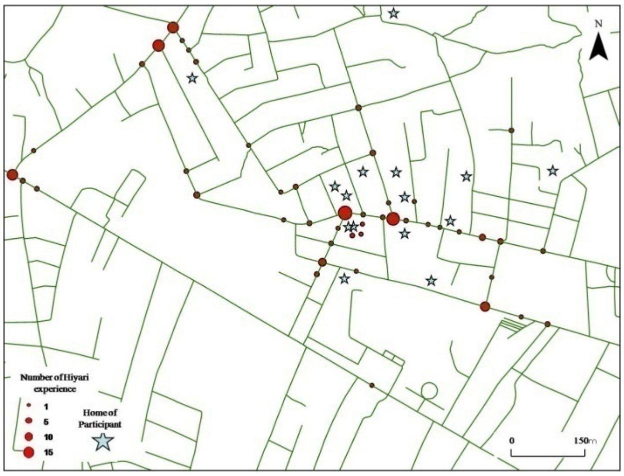

Figure 5 Distance between Hiyari Spots and Participants' Home in Nongbua Community in Udonthani Province

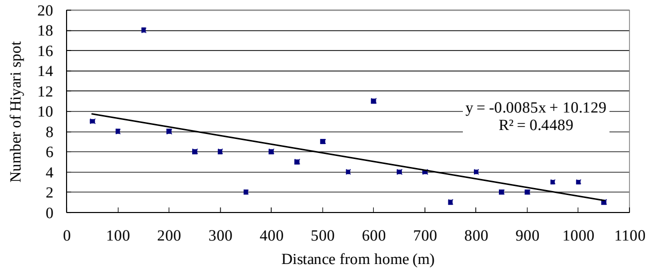

Figure 6 Relationships between Distance from Participants' Homes to Hiyari Spots and Number of Hiyari Spots

6 EVALUATING METHODOLOGICAL EFFECTIVENESS ON AWARENESS RAISING

To evaluate the effectiveness of Hiyari map development workshop, the study conducted interview surveys with the participants who participated in the Hiyari map development workshop in the selected communities including Nongbua community, both Kankeeha community (Khon Kaen municipality and Muangkao county) and Nonghoi community. The questionnaire comprised close-ended questions and open-ended questions.

The questions on willingness to participate in Hiyari map development workshop and understanding of the purpose of Hiyari map development workshop were asked. The answers to those questions are summarized in Figure 7. According to Figure 7, the results show that most participants wished to join this kind of workshop actively and felt comfortable to participate in because the location and the atmosphere of Hiyari map development workshop was familiar to their community activity. In addition to organization of workshop, the study had developed reading materials and used those reading materials (i.e., the manual, the leaflet and the presentation sheet) for pre-contemplation and urging participants to understand the workshop purpose and how to develop Hiyari map prior to beginning identified the Hiyari spots and Hiyari experienced session. Hence, almost all of participants could understand its activity purpose.

Figure 8 shows the answers to the questions on raising awareness of traffic safety which majorities gave positive responses. Especially, all participants answered "Yes" for the question of "After the Hiyari map development, do you pay more attention on the traffic safety or take care of yourselves more?" Even though the study may not be able to follow-up the workshops to confirm their behavioral change on traffic safety, it is believed that this activity could be a trigger for all participants to take this traffic safety awareness issue into their account.

In organization of any event, a certain preparation and management is essential. Obstacles or problems always happen if it is not thorough plan. In all of the eight workshops, the study team assisted the local people to organize the event. However, it is doubt whether without any technical assistance the community can carry out the workshop activity by themselves. Thus, an opinion toward a difficulty was raised. About 70% of participants answered "cost" is a major obstacle to organize a Hiyari map development workshop as indicated in Figure 9. It is apparent that budget plays an essential role in supporting the activity in local community not to mention a distribution of reading materials, location of the workshop, tools such as a map, stickers and so on. The second issue was seeking opinion leaders or leaders and trained them, see Figure 9. It is important for organizing a succeed workshop is to have a strong leader. Finding a participant who has a strong sense of leadership is a painstaking task.

In addition to the questionnaire, the sessions were opened to discussion among participants. Some participants had made comments and requests as follows: (a) The Hiyari map development project should continue until its success in proving a significant reduction of road traffic accidents in community; (b) The follow up of Hiyari map development workshop is needed; (c) If this kind of activity is pursued, those identified spots could be eliminated and Hiyari spots may change in the future. However, how to improve these spots, hence traffic safety facilities are needed in community.

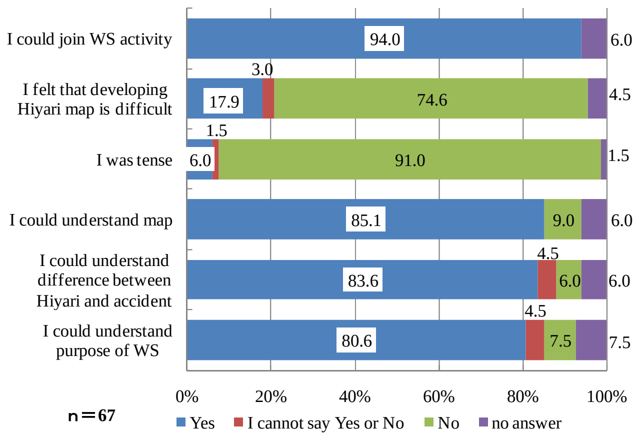

Figure 7 Evaluation of Hiyari Map Development Workshops

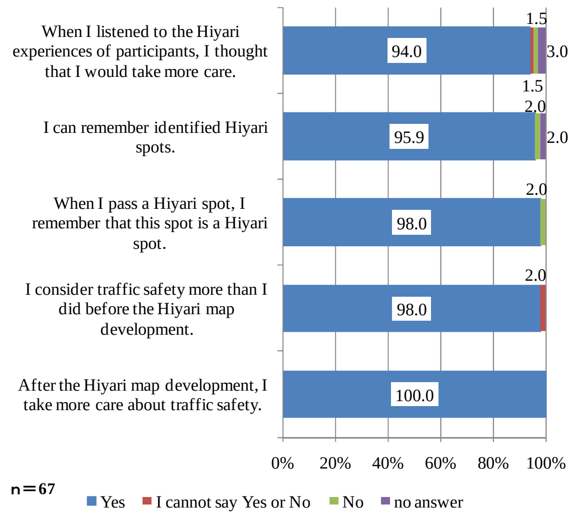

Figure 8 Raising Traffic Safety Awareness of Participants

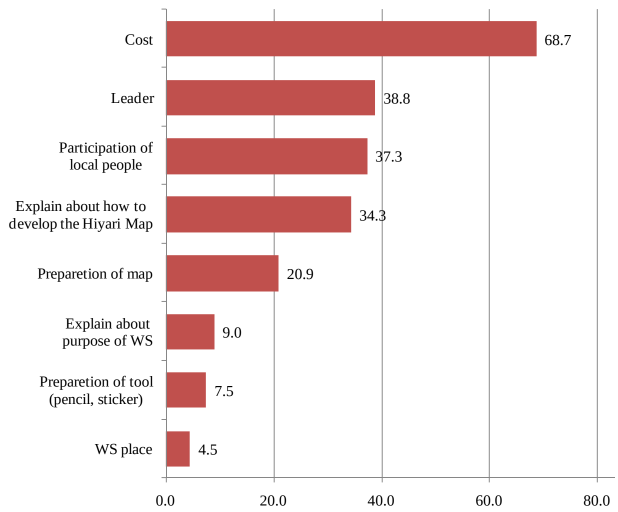

Figure 9 Problematic Issue in Organizing Hiyari Map Development Workshop

7 COMMUNITY ACTIVITY AFTER THE HIYARI MAP DEVELOPMENT WORKSHOP

In the final stage of the study, the representatives from all the selected communities where Hiyari map development workshops took place were invited to the Hiyari conference on March 22nd, 2008 in Bangkok to present their lesson learnt and sharing the information or the affects after having participated in Hiyari map development workshops. There were 13 representatives participated in the conference. The participants reported their activities after the workshops such as organized their own workshops, improvement of road facilities and so forth. The following section described activities of each selected community that has been done after having attended the workshops.

7.1 Communities of Pithayanukhun High School and Nongbua in Udonthani Province

It is significantly interesting in that each individual leader has their way of making a presentation. Some used visual aids and some used oral presentation. For instance, the leader of Nongbua community reported the lesson learnt from Hiyari map development workshop in their community by showing a video presentation. In this community, they installed speed humps at three identified Hiyari spots as proposed by participants themselves and with partially advised by the study team as depicted in Figure 10. The installed speed humps were financed by the local government.

Figure 10 Installed Hump

7.2 Kaankheha Community in Khon Kaen Municipality, Khon Kaen Province

As for Kaankheha community, the leader of the community reported that they installed traffic signals and reflective lights at the two identified Hiyari spots. In addition, they reported the continuation of traffic safety activities, like a traffic safety parade involving a local hospital as showed in Figure 11.

Figure 11 Traffic Safety Activity in Kaankheha Community

7.3 Kaankheha Community in Muangkao County, Khon Kaen Province

In this community, the leader only informed Hiyari spots on the poster and attached it on the community information center board so that local people can recognize those and pay more attention on safe driving when using the roads.

7.4 Khon Kaen University

Many improvements on road facilities had been done by the university. A student coordinator of the Hiyari map development workshop adopted Hiyari-Hatto concept in his research study to find the correlation between Hiyari spots and black spots comparing to the actual spots from traffic police reports.

7.5 Nonghoi Community in Chiang Mai

The community leader reported that after having observed the identified Hiyari spots during workshop session they visited the Hiyari spots again and checked dangerous points then they proposed an improvement of Hiyari spots as shown in Figure 12. However, the proposed idea for improvement was not implemented yet owing to insufficient budget and lack of local government support.

Figure 12 Proposed Improvement of Hiyari Spots

7.6 The West area of Samutprakarn

There were teachers from two selected junior high schools attended the Hiyari conference and introduced the new identified potential black spots in their school district. Even though they are interested in organizing another workshop, their schools have no plan in coming future.

8 CONCLUSION AND DISCUSSION

This paper evaluates an alternative method to promote traffic safety in the communities of Thailand utilizing a community based approach for Hiyari map development as a traffic safety educational tool to raise safety awareness. The study organized some Hiyari map development workshops for data collection of hazardous spots or potential black spots or in other word, Hiyari spots. An analysis of Hiyari data was carried out. The results can be concluded in that a process in which road traffic accident data are scarce or not available in the traffic police report or any other secondary data reports can be collected through Hiyari map developmental workshop. These data are considerably reliable as they were indicated by the local people who live and use the roads every day and by the local people who experienced the car accident themselves.

Most of the identified Hiyari spots were located at main intersections and around living areas of the participants. In addition, the results of questionnaire showed that the main difficulty for organizing a Hiyari map development workshop was a financial support and finding a key player to organize and moderate the workshop session.

In spite the termination of the Hiyari research project, some communities continue traffic safety activities after the Hiyari map development workshop as shown in Table 2 and only a few communities did not continue traffic safety activities. This implies that the communities that have strong leaders and routine community activities could continue traffic safety activities even after the research project ended.

Table 2 Activities after the Hiyari Map Development Work Shops (WS)

	Target Area (Square-kilometers)	Activity after The Hiyari map development WS
in community	Around Pithayanukhun High School in Udonthani ($5km^2$)	-
	Nongbua community in Udonthani ($7.5km^2$)	Speed humps were installed at three identified Hiyari spots.
	Kaakheha community in Khon Kaen (Khon Kaen municipality) ($2km^2$)	Traffic signals and reflection lights were installed at two identified Hiyari spots. Traffic safety activities, like a traffic safety parade involving a local hospital were continued.
	Kaakheha community in Khon Kaen (Mungkao county)($0.5km^2$)	-
	Khon Kaen University ($10km^2$)	Master student analyzed the correlation between Hiyari spots and blackspots.
	Nonhoi community in Chiang Mai ($0.5km^2$)	Local people visited Hiyari spots in the community and checked dangerous points, and they proposed improvement of Hiyari spots.
in school	West area in Samutprakarn ($20km^2$)	-

Nevertheless, taking the comments and requests from the participants into account, Hiyari map development workshop can be triggered to start traffic safety activity in community and raised traffic safety awareness among local people. Although, organizing Hiyari map development workshop seems positively applicable, the financial and technical supports still play a major role in consideration of the feasibility. Hence, it is recommended that the government should subsidize this kind of activities, or otherwise the community can gain support from private sector. This way will bring a sustainable development to the community as well. Therefore, it is certain to state that Hiyari map development is applicable and is quite effective to organize in Thai communities. By emphasizing on identifying potential black spots or hazardous spots or in other words, Hiyari spots, this in turn entails a natural instinct of safety consciousness among local community. As a result, it helps raising traffic safety awareness consequently.

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SUSTAINABLE TRANSPORT SYSTEM AND PARKING ORGANIZATION: A CASE STUDY OF BANGKOK'S PARKING STANDARD

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Parking organisation is a sustainable transport measure. In this paper, the author examined the link between an element of parking organisation; parking standard and sustainability using Bangkok as a case study. The review of current Bangkok parking standard concluded that the standard should be revised. A study on the parking standard's effect on the city's level of parking provision found that most office buildings in study sample provided more parking spaces than the required level. In addition, the study found that an average distance between office building and the nearest public transport stop is much more than an average distance between office building to a parking space. This difference promotes car use as human body perceives car use as an internal energy saving measure. The author presented the relationship between parking space and sustainability using casual loop diagram. It illustrated that parking spaces provision has an influence on car use, car ownership and the city's sustainability. It can be concluded that the current parking organisation of Bangkok encourages car use and car ownership. This must be changed to improve the quality of life in the city.

Keywords: Causal loop diagram, Car use, Car ownership, Mode choice decision

1 GENERAL INTRODUCTION

Parking organisation has been recognised as one of the most effective 'Push' transport demand management (TDM) measures. It can influence car use and car ownership and provide modal shift away from private car needed to achieve sustainable transport system in an urban environment (Topp, 1991; Department for Transport, 1998). Many transport studies on Bangkok undertaken in the past have included parking organisation as part of their recommendations to alleviate urban traffic problems (Asian Pacific Energy Research Centre, 2007; World Bank, 2007). However, its implementation has been limited perhaps, due to its controversial nature and the lack of understanding. The policies related to parking in Bangkok have undergone modest changed since it was issued in 1974.

In this paper, the author defined parking organisation as a systematic administration of parking spaces. Parking standard is defined here as an element in parking organisation that describes the physical aspects of how parking should be provided in development; quantity, type, location, design of parking, and provision of other facilities related to it. However, only the quantity or the parking standard rate; a ratio of a required parking space per total area or per residential unit and the specification on location of parking space are dealt with in this paper. Other elements such as the design of parking space and provision of other facilities related to parking are beyond its scope.

This paper divided into eight sections. The first section contains the general introduction. The second section details Bangkok parking standard and the third part its general review. The fourth and fifth section discuss the current standard's effects on parking provision level and the effect of parking location to mode choice decision and behaviour. Section six presents Equi-distance parking concept. Section seven presents the relationship between the current Bangkok's parking standard and the city's sustainability using CLD (causal loop diagramming) method. The final section concludes the paper and provides recommendations for further study in this area of science.

2 BANGKOK PARKING STANDARD

Bangkok imported its first car in 1915 and has since issued three sets of law related to parking provision in developments. The first was the Ministerial Regulation Number 7 issued in 1974. The regulation identified two different parking standard rates[1] for areas inside and outside Bangkok municipality. This boundary is defined by the Legislation Act 1936. This regulation contained recommendations on location and geometries of entrances, exits, turning facilities and parking bays. In addition, it specified that parking spaces should locate within development building or within a 200m radius distance from it. Access paths to the parking spaces should be provided if they are located outside the building.

[1] Parking standard rate is a ratio of a required parking space per total area or per residential unit. The required number of parking spaces for the development can be calculated by multiply the parking rate with either total floor area or number of residential units on the development.

Subsequently, the city issued two other parking related laws: the 1978 Bangkok's Multi-storey Car Park Building Ordinance and the 2001 Bangkok Building Ordinance which superseded the 1978 Ordinance. The 2001 Ordinance remains the latest parking law that applies to Bangkok Metropolitan area until today. It defines car parking standards for different types of developments and regulations on multi-storey car parks. It provides an improvement on the classification of developments from its predecessor, for examples types of resident developments increased from two to eight types (Mayor of Bangkok, 2001).

Overall, Bangkok's parking standard has undergone a modest change since 1974; the number of building category has increased from two to eight types but the boundary of Bangkok metropolitan area and the parking standard rates remain the same. The standard defines its parking space rate either in space per unit or space per area, depending on the type of building. The extract from the parking provision standard for development in Bangkok is shown in Table 1.

Bangkok's parking standard can be classified as a minimum parking space requirement standard (Barter, 2010). This type of standard is traditionally used to address the growth in demand for parking space resulted from increasing car ownership(Shoup, 1997; Barter, 2010). It aims to prevent parking overspill from development into adjacent neighbourhoods by setting a minimum number of parking spaces that development must provide, based on previous parking demand survey of a similar type of development during peak period (Shoup, 1997).

Table 1 Extract from the Parking Spaces Standard for Development in Bangkok

Type of building	more than	Number of parking space require (within Bangkok area)
Apartment and small condominium	60 m^2	1 : household
Large Size Building with total area more than 10,000	all cases	1 : 120 m^2
Office	300 m^2	1: 60 m^2
Shopping mall	300 m^2	1 : 20 m^2

Source: Ministerial order No. 7 (1974) with 1994 Addendum

3 REVIEW OF CURRENT PARKING STANDARD RATE

The author undertook a review of the current parking standard rate of Bangkok. This section contains the observation and evaluation accounts made by the author.

3.1 Changes Transport Infrastructure and Land Use Characteristic of the City

Bangkok's parking standard rate has remained the same since its first issue, despite changes in the city's land use and transport infrastructure since 1974; for example, all of the high rise office buildings in Section 3.1 study's sample were built after 1992, the city's transport infrastructure has undergone many developments: the opening of BTS Sky Train lines in 1999, a Mass Rapid Transit (MRT) line in 2004 and a recently commenced Airport Link and Bangkok Bus Rapid Transit, both in 2010. These reasons purport that the current parking standard need to be revised to take into account of the variations in land use and public transport accessibility in different locations of the city; it currently provides a single rate for each type of development.

3.2 The Variation in Parking Demand is not Accounted for

The current standard does not allow for variation in parking space demand. For example, the standard applies single rate for accommodation units with area above 60m^2, irrespective of the number of bedroom of the units. In addition, residential units that are smaller than 60m^2 do not need to provide any parking spaces. The change in urban density and land price of Bangkok has reduced unit's size typically provided by developments. A large proportion of Bangkok residential developments constructed in 2008 are one bedroom unit with average size between 44 and 55m^2(Property Focus, 2008). This illustrates that on average, one bed room residents unit in Bangkok are exempted from provision of parking space. This exemption seems incoherent against the high car dependency observed in Bangkok. It is probably not made intentionally but rather resulted from the standard's lack of circumspection.

3.3 Ambiguous Discounting Rate for Building with Large Area

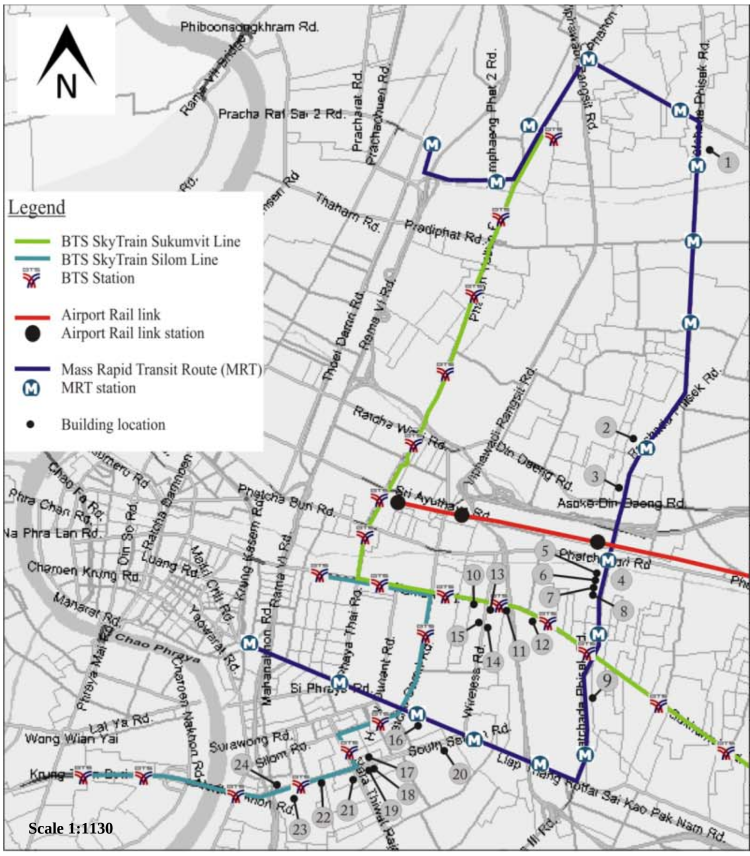
The standard contains ambiguous discounting rate for building with large area; development with total floor space area more than 10,000m^2 is eligible to apply for a Large Size Building planning permission. The permission will allow a reduction of the parking space requirement rate by 50%, from 1:60m^2 to 1:120m^2. Although, this type of discounted parking standard rate for larger development can be observed in other cities such as Hong Kong, the reduction rate is only applied to the floor area that exceeds the threshold value rather than to the whole development.

In conclusion, the review of the current parking standard rate suggested that it should be altered to take into account the change in public transport accessibility, variation in demand of parking space, and to clarify the ambiguity of the discount rate for development with large area.

4 MINIMUM PARKING REQUIREMENT STANDARD'S

EFFECT ON PARKING PROVISION LEVEL

Parking standard affects the level of parking provision in an urban environment. To investigate the effects of Bangkok's parking standard on its level of parking space provision, the author compared the actual number of off-street parking spaces provided in a sample of buildings against the number of spaces required by the standard. The sample group contained 24 office buildings, all of which situated in the area of Bangkok. These buildings are located within a close distance to a Sky Train (BTS) or a Mass Rapid Transit (MRT) stop. These distances were measured using Google Earth. The number of parking spaces required for each building was calculated by multiply the total area of the building with the parking space rate in Table 1. The actual number of parking space was obtained from various sources listed in Appendix A. Figure 1 and Table 2 show the -
- locations of the buildings and the summary of their information. The result shows that 16 out of 24 (67%) buildings provided parking spaces above their required level. On average, they provided parking space 24% more than the required level. The other 8 buildings that provided parking spaces below the standard had an average shortfall of 14% from the required values.



Sample ID	Building	Total Area (m^2)	Provided Parking space	Required parking space	Different %	Distance to BTS	Distance to MRT
1	Olympia Thai Tower	14,500	350	242	45%	n/a	100m Ratchadapisek
2	RS Tower	59,000	880	984	-11%	n/a	50m Cultural Center
3	Pakin Buildnig	30,000	620	500	24%	n/a	50m Rama 9
4	Q House Asoke	20,000	600	334	80%	n/a	350m Petchaburi
5	253 Asoke Tower	18,130	350	303	16%	n/a	350m Petchaburi
6	K Tower (CMIC)	35,036	600	584	3%	n/a	350m Petchaburi
7	Ocean Tower II	46,000	650	767	-15%	750m Asoke	450m Sukhumvit
8	Sermit Tower	51,000	1,000	850	18%	750m Asoke	450m Sukhumvit
9	Ocean Tower I	29,800	500	497	1%	610 m Asoke	470 m Sukhumvit
10	Tonson Tower	22,776	470	380	24%	300m Chidlom	n/a
11	Q House Ploenchit	55,000	800	917	-13%	50m Ploenchit	n/a
12	Two Pacific Place	22,500	240	375	-36%	50m Nana	n/a
13	Athenee Tower	40,000	800	667	20%	350m Ploenchit	n/a
14	GPF Witthayu	27,000	600	450	33%	800m Ploenchit	n/a
15	208 Wireless	12,795	300	214	40%	600m Ploenchit	n/a
16	Abdulrahim Place	47,000	1,065	784	36%	550m Saladang	260m Silom
17	Sengthong Thani	35,000	700	584	20%	350 m Chongnonsri	n/a
18	Asia Centre	27,410	350	457	-23%	370 m Chongnonsri	n/a
19	Bangkok City Tower	43,382	800	724	10%	250 m Chongnonsri	n/a
20	Bangkok Insurance	40,000	750	667	12%	n/a	360m Lumphini
21	Empire Tower	160,000	2,600	2,667	-3%	400 m Chongnonsri	n/a
22	Sala@Sathorn	17,000	254	284	-11%	500 m Surasak	n/a
23	Thai CC Tower	55,000	1,000	917	9%	50 m Surasak	n/a
24	Chartered Square	33,500	550	559	-2%	250 m Surasak	n/a

Figure 1 Provision of Parking Space in Office Buildings within the Area of Bangkok

The study's results purport that under the current minimum parking space requirement standard, office developments within the Bangkok area are likely to provide number of parking spaces exceeds the required standard. This observation is in accordance with (Shoup, 1997) that minimum parking requirement policy leads to surplus provision of parking space. In additional, (Shoup, 1997) criticised parking space rate as an ineffective method to calculate required parking spaces for a development. He argued that parking space rate are normally bases on an inconsistent and non-area specific sources and are calculated from peak period parking demands, thus yields surplus parking spaces for all periods except during the peak period. The excess parking space leads to ineffective use of area in the city and an unnecessary addition to property cost. In additional, it promote car use; availability of parking space has a positive correlations to car use (Weinberger, Seaman et al., 2008).

5 THE LOCATION OF PARKING SPACE AND MODE CHOICE DECISION

The current Bangkok's parking standard states that parking spaces should locate within the development building or within a 200m radius distance. However, in actual, most office and home parking are provided within the buildings; a study carried out by (Barter, 2010) shows that more than 80% of the study's subjects in Bangkok .

The difference in distance required to reach the point of access for car and public transport purports an unequal accessibility between the two modes of transport (Knoflacher, 2003). To investigate the effect of this difference, the author compared the internal, the external and the total energy uses by three different modes of transport: car, bicycle and walking to undertake a 315m distance trip, the average distance between an office building in Bangkok and a public transport stop, calculated from Section 4 result. The internal energy expenditure for each mode was obtained from (Becker, 1987). The external energy expenditures were obtained from (Pfaffenbichler, 1998; Emberger, 2009)'s calculations which considered energy used in vehicle production and the operation per trip. The whole life cycle and the average number of trips were taken into consideration. However, it did not take into account the additionally environmental burden from noise pollution, air pollution, greenhouse gas emissions and accident costs incurred. Table 2 summarised the results from the calculations.

The results show that driving save 25% of internal energy compares with walking and that driving car consumes 646 times more total energy than walking. This indicates that, car requires significantly less internal energy for travelling in comparison to other modes of transport. However it uses much more total energy. Furthermore, the result shows that higher internal energy is required to gain access to public transport by walking or bike than to drive car over the same distance. This difference in the internal energy expenditure can affect the mode choice decision making; human body perceives the internal energy saving benefit from car use and would prefers it over other modes of transport (Knoflacher, 2003). It is therefore important to provide an infrastructure that would eliminate the bias toward car, an unsustainable mode of transport. This concept is the key principle of (Knoflacher, 2003)'s Equi-distance parking organisation.

Table 2 External, Internal and Total Energy Usage for Using Different Modes of Transport to Undtertake a 315 m. Distance Trip

Mode	Internal energy use per trip (MJ)	External Energy use per trip (MJ)	Total energy use per trip (MJ)	Internal energy, relative to walking	Total energy, relative to walking
Driving (30 kph)	0.03	25.80	25.83	0.75	646
Bicycling (10 kph)	0.04	0.70	0.74	1.00	19
Walking (4 kph)	0.04	0.00	0.04	1.00	1

Source: Own calculation based on (Pfaffenbichler, 1998)

6 EQUI-DISTANCE PARKING ORGANISATION

Equi-distance parking organisation is proposed by (Knoflacher, 1981). It aims to balance the internal energy requires to gain access to car and public transport and make public transport a viable alternative to car by locates the point of access for both modes at equal distance. Figures 2 illustrates the existing arrangement of the parking organisation in most cities including Bangkok, the distance from home or the starting point of the trip is on the X-axis-and the level of acceptance function of car and bus on the Y-axis. It shows that at the point of trip origin the level of acceptance to use car is much higher than that of public transport hence car use would be more preferable under the existing parking infrastructure. Furthermore, the provision of parking spaces close to trip will reduce the urban activities such as shopping, working places or recreation places that could be reached within a walking distance from home. Economic forces will provide clusters of facilities that are easily access by car (i.e. Megamalls or out of town shopping centres). This creates a vicious cycle that will increase car use and decrease the quality of life.

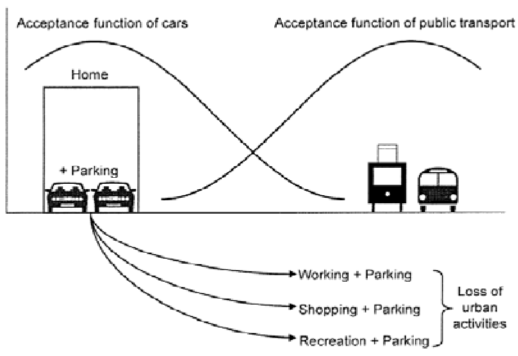


Figure 2 Existing Parking Organisation
Source:(Knoflacher, 1993)

Figure 3 shows the Equi-distance parking organisation. The access point to car (i.e. car park) is located at the same distance as the nearest public transport stop. The two modes of transport share the same level of acceptance function, hence eliminate bias toward car use. Furthermore, the walking trip toward the new point of access will stimulate urban activity such as work, shopping, and recreation. The overall result is a reduction car use and car dependency.

In order to achieve the proposed parking reorganisation, (Knoflacher, 2003)proposed that a major shift in transport policy is required. Financial measures that encourage car use, such as minimum parking requirement in commercial and residential building and free kerb side parking have to be abolished. A similar proposal was made by (Shoup, 1997). He argued that minimum parking requirements increase the cost of urban development, degrade urban design, burden enterprise, promote automobile dependency and encourage urban sprawl (Shoup, 1997).

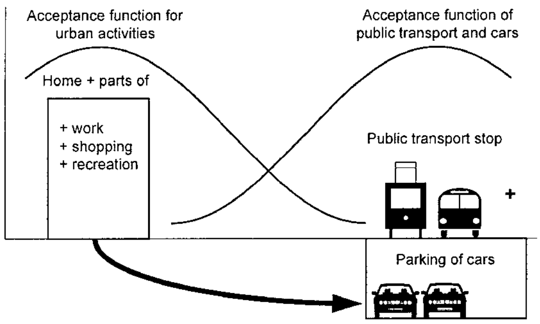


Figure 3 Equi-Distance Parking Organisation
Source:(Knoflacher, 1993)

7 MINIMUM PARKING REQUIREMENT STANDARD'S EFFECTS TO SUSTAINABLE TRANSPORT SYSTEM

Sustainable transport system can be defined as a transport system that meets mobility needs without polluting the environment or damaging human health. It should have social qualities such as equality, safety, and comfort for the system users and the surroundings. It should also contain economic qualities such as affordability and energy efficiency (Beella and Brezet, 2007; Williams, 2007).

Over the years, Bangkok has gained a reputation as a car dependent city and has become a synonym with unsustainable transport system (Kenworthy, 2000). (Barter, 2010) estimated that there are 330 cars per 1000 persons in Bangkok, this number is much higher in comparison to Hong Kong's value of 55, Singapore's 112 and Kuala Lumpur's 314. The number of car in the city continues to proliferate. This growth increases the demand for resources and facilities related to car use such as fuel, road space and parking space. Should this growth be restricted? There is a growing recognition that high car use is associated with air pollution, noise, congestion, traffic accidents, lower quality of life, and economic inefficiency.

Transport studies carried out in the past recognized the need to improve Bangkok's unsustainable transport system but rarely acknowledge parking organisation as an effective measure. (World Bank, 2007) proposed parking organisation as one of the measures to ensure efficient MRT investment. It recognised that densification of the city can be influenced by parking organisation but not as a sustainable transport measure in itself.

Let us focus on the relationship between the current Bangkok's parking standard and the city's sustainable transport system. To comprehend this correlation, a CLD (causal loop diagramming) method is used to construct a system diagram. The author made three assumptions to limit the boundary of the diagram. The first assumption is: there is a balance between population in city and population outside the city (suburb area) and that the population overall is growing exponentially as birth and immigration rates are higher than death and migration rates. Figure 4 and 5 summarised this assumption. The second assumption is: home (origin) and destination's demand for parking spaces can be combined into a single identity called Demand for parking spaces at home and destination. The third assumption is: the actual number of parking space for home and destination can be combined into a single identity.

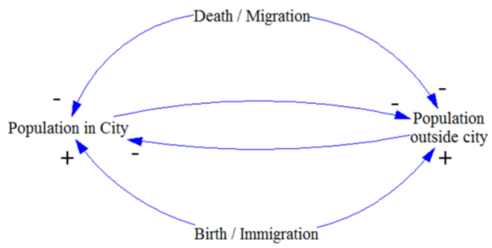


Figure 4 Assumption on Population Growth

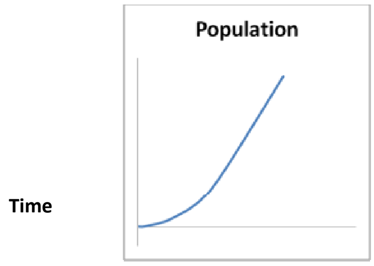


Figure 5 Assumption on Population Growth

The paragraphs below describe the system diagram by breaking it down into smaller system loops.

An increased in population in the city area would increase the demand for residential unit and office space. The newly built residential units and office spaces must comply with parking standard and provide certain amount of parking accordingly. These parking are mostly provided off-street which in turn increases the cost and rent of residential and office units. A study by (Jia and Wachs, 1998) found that single family houses and condominiums were over 10% more costly if they included off-street parking than if they did not. (Litman, 2010) estimates that housing cost is increased by 12.5% per parking space provide.

Parking spaces are then made available at very low cost or no cost both at home and work place. (Barter, 2010) demonstrated that only 10% of employees in Bangkok who drive to work pay for their parking spaces at the cost of less than 25$ per month. Similar trend was observed for home parking; less than 20% of the study's sample paid for home parking, at the cost of less than 25$ per month. The evidences above purport that the costs of parking spaces are heavily subsidised in Bangkok. It is believed that this subsidise increases the property price and contributes toward urban sprawling as people seek cheaper land around the peripheral of the city. The Rent cost causal loop is a self-balancing loop.

7.1 Rent Cost Loop

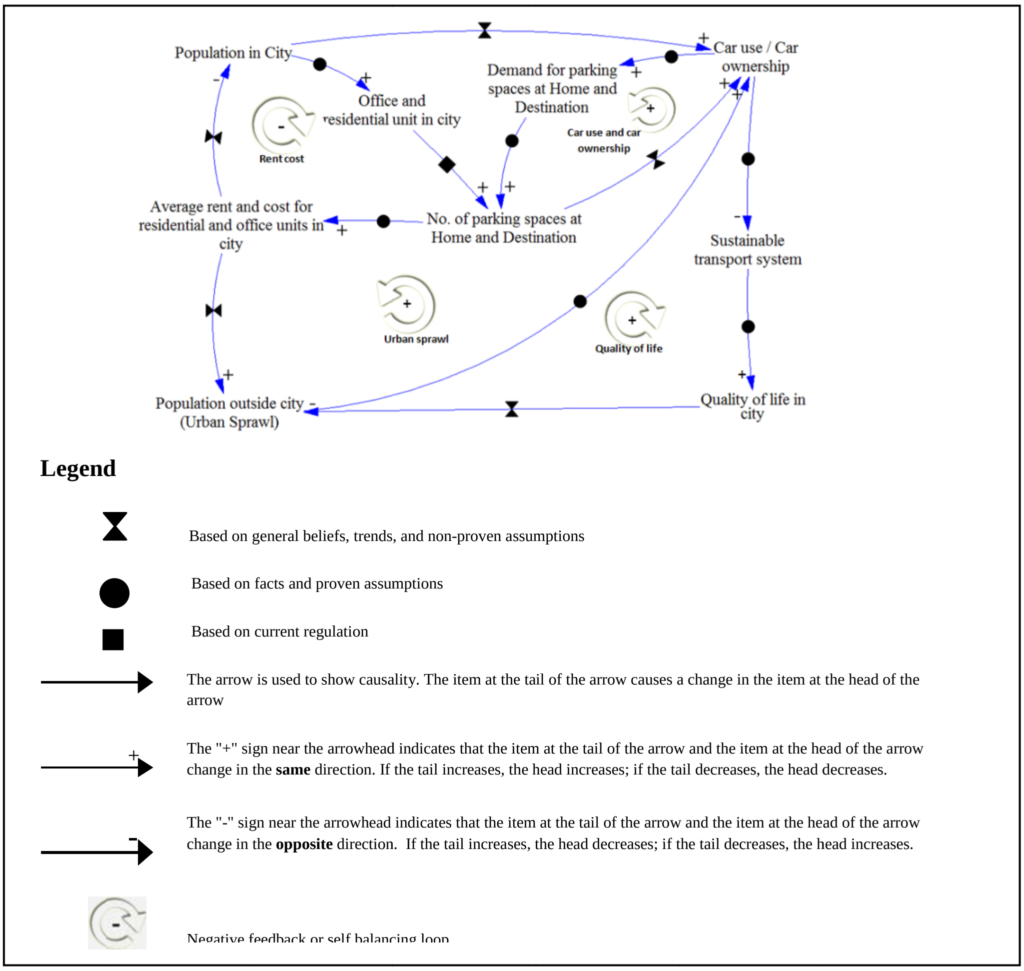


Figure 6 Causal Loop Diagramming (CLD) Shows Effects of Number of Parking Space in Urban Environment

7.2 Car Use and Car Ownership Loop

An increase in Bangkok's population will increase the number of car as other modes of transport cannot offer alternative (Kenworthy, 2000). An increase in number of cars is mirrored by an increase in the demand for parking spaces, and consequently, the number of parking spaces. It is believed that number of parking spaces supplies would be slightly higher than the actual demand; parking standard rate is based on peak hour demand. Furthermore, the current Bangkok parking standard enforces a minimum limit on number of parking spaces that development must have, however it does not impose maximum cap; development can freely set the upper limit of parking space to meet demand.

Availability of home parking space induces car ownership. (Weinberger, Seaman et al., 2008) found that New York City's residents in new development with dedicated parking spaces are 40% to 50% more likely to own cars. An increase in destination parking spaces will increase the car use. Another study by (Weinberger, Seaman et al., 2008) found that a guaranteed off-street parking spaces at home and work positively influence car use decision. An increase in car use will in turn, increase the demand for parking space at destination. This Car Use and Car Ownership causal loop is a reinforcing loop; the increase in each element will result in positive effects in others.

7.3 Quality of Life Loop

An increase in average land and rent cost increases the population live outside the city or urban sprawl as people and developer look for cheaper land to live and develop. An increase in urban sprawling raises the attractiveness of car use (Sheehan, 2002). A rise in car use increases energy consumption, air pollution, noise, congestion, and traffic accidents, hence reduces the sustainability of the city's transport system and in turn the quality of life in the city. This further increase the urban sprawling as people leaves the city to search for better place to live. This Quality of life causal loop is a reinforcing loop.

7.4 Urban Sprawling Loop

This loop contains Car use and car ownership loop, parts of the Rent cost and also the Quality of life loops. It provides connection between the three loops. The Urban sprawling loop is a reinforcing loop.

7.5 Discussion

In context of this paper, the CLD system diagram on Figure 6 shows that parking standard rate provides a link between an increase in office and residential unit in the city and the number of parking spaces at Home and Destination. By reduce the parking standard rate we can reduce the number of parking space at home and destination in Bangkok, car use and car ownership, increase the share of environmental friendly transport and improve the quality of life in the city.

8 CONCLUSION AND RECOMMENDATION

Parking organisation is an effective sustainable transport measure. However, the current parking standard of Bangkok encourages car use and car ownership as it allows developments to freely provide as many parking spaces as they want as long as it is above the required level.

The review of current parking standard shows its lack of circumspection and attentiveness, the author made three observations. Firstly, the standard does not make allowance for a parking demand variation in residential unit of different sizes. Secondly, it contains ambiguous discounting rate for building with large area. Lastly, it does not take into account the changes in land use and public transport infrastructures that have occurred since 1974. From these observations, the author purported a revision of Bangkok's current parking standard. The revise standard should provide parking rate that aims to reduce car use and car ownership. It should take into account the relationship between the availability of car parking spaces at Home and Destination and quality of life, presented in Section 7. It should make provision for variation in parking demand due to the variant in the size of residential unit and the availability of public transport. Hong Kong's parking standard can be used as an example.

An empirical study to investigate the effects of Bangkok's parking standard on its parking space provision level shows that that under current parking standard, 16 out of 24 Bangkok's office buildings in the sample group provided parking spaces above the standard's level. The author argued that the excess parking space leads to an ineffective use of area in the city and an unnecessary cost. In additional, it promotes car use; availability of parking space at destination has a positive correlation to car use. A similar study should be undertaken for residential development to investigate its trend.

Most parking spaces in Bangkok city are provided within building. In contrast, an average distance to public transport's access point calculated from the study's sample is 315m. The difference in this distance induces a preference toward car use; human body perceives it as an internal energy saving measure. A study to compare internal and external energy require to undertake a 315m distance trip by different modes of transport shows that car save 25% of internal energy compares with other modes but it requires much more total energy than walking, hence it is an unsustainable transport mode. However, the mode choice decision making is influenced by internal energy saving, hence the current parking infrastructure encourage car use. Sustainability of transport system can be achieved by a reorganisation of parking that aims to balance the internal energy requires to gain access to car and public transport as proposed by (Knoflacher, 1981).

There is a relationship between provision of parking space, car use, car ownership and quality of life. The author proposed a much simplify picture of this relationship using

CLD technique. Nevertheless, it illustrated the connection between the city's parking standard and its transport system's sustainability. This understanding should be developed further to provide a strong case for parking organisation as an effective sustainable transport measure.

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APPENDIX A

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AIRPORT NOISE IMPACT ON PROPERTY VALUES: A CASE OF SUVARNABHUMI AIRPORT

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Since Bangkok's Suvarnabhumi Airport began operations in 2006, complaints about aircraft noise from residents in the surrounding areas and property owners' demand for monetary compensation have been a major point of contention. The objective of this paper is to provide insights into the question of what appropriate amount of compensation for the decline in property value, due to the airport noise, should be. We developed a series of hedonic regression models of property values, based on residential properties sales data from 2002 to 2008. In addition to controlling for structural characteristics of properties, the hedonic models have two features that can help to test the hypotheses about the impacts of the airport operations. First, the timing and magnitude of noise effects can be tested by including noise variables generated from noise contour maps. Second, the beneficial effects of transportation access improvements brought about by the airport can be investigated by including in the models various forms of locational characteristics of properties, such as access to the airport and other transportation facilities, proxied by the distances to the entrances of these facilities. The results can be used as a basis for formulating appropriate policies for compensation of property owners, which takes into account not only the negative effects of airport noise, but also the beneficial effects of improved transportation accessibility.

Keywords: Airport Noise, Hedonic Model, Property Values

1 INTRODUCTION

Like any airports around the world, Bangkok's Suvarnabhumi International Airport provides both many benefits such as increase in service-related to employment, reduction in transportation costs for business and the general public, etc.; and serious environmental impacts, such as vibration, air quality degradation, traffic congestion, flooding, and especially noise from aviation activities. To examine and purpose measure to mitigate these impacts, Environmental Impact Assessments (EIA) was carried out before, during, and after the airport construction. Based on the EIA report prepared during the feasibility study period, there were more than 3,000 houses, 46 schools and universities, and 76 religious centers that would be affected by loud noise (PCD-ISC (2009)). Subsequently, the noise impact encompass 70 square kilometer around the airport in which the high impact zone has Noise Exposure Forecast (NEF) over 40 while moderate zone NEF values between 35 and 40 (EEAT (2006)).

Since Suvarnabhumi Airport began operations in September 2006, complaints about airport noise from residents in the surrounding areas and property owners' demand for monetary compensation have been a major point of contention. For example, in 2006, King Mongkut Institute of Technology, Latkrabang (KMITL), a major public university, located about 3.5 km north of the airport and suffered noise with NEF between 30 and 35, sued the Airport of Thailand PCL (AoT) for 214 million Baht for expenditures of soundproofing their 22 buildings (PCD-ISC (2009)). Later that year, AoT agreed to compensate 71 residents affected by noise higher than 70 decibels the amount of 300 million Baht (approximately US$ 7.8 million) for their suffering from noise caused by planes landing and taking off at the airport (PCD-ISC (2009)). Homeowners 32 communities were unhappy with AoT's tardy responses and in 2007 threatened to releasing balloons to hinder air traffic if the AoT did not resolve the problem of noise pollution (Bangkok Post (2009)). More recently, the Thai government approves AoT's budget in the amount of 11,233 million Baht for compensating owners of properties affect by noise over the period of 2009-2010 (Logisticnews (2009)).

Whereas it is generally agreed that the compensation must be made for homeowners who are affected by airport noise, details on how the amount of such compensation is calculated remain vague. In case of Suvarnabhumi Airport, there are still many people unhappy with the current financial compensation scheme while some affected parties are not eligible for compensation. With regards to the airport noise impact on property values, several studies have been found, using hedonic approach, in developed countries such as Canada and United State (e.g. in Nelson (2004)), United Kingdom (e.g. in Pennington et al. (1990)), etc. But, no such a study has been found in developing country, especially in Thailand. The purpose of this paper is to provide insights into the question of what appropriate amount of compensation for the decline in property value, due to the airport noise, should be.

The remainder of this paper is organized as follow. Section 2 provides the literature review on the basics of airport noise and the previous related studies, specifically hedonic studies of airport noise. Section 3 describes the methodology of hedonic modeling and data used in our modeling effort. Section 4 describes analysis results of our hedonic regression. Finally, Section 5 gives the discussions and conclusion of the study.

2 LITERATURE REVIEW

2.1 Airport Noise

The definition of airport noise is provided by Noise Quest (2009) as follows.

"Airport noise is defined as sound produced by any aircraft or its components, during various phases of a flight, on the ground while parked such as auxiliary power units, while taxiing, on run-up from propeller and jet exhaust, during take-off, underneath and lateral to departure and arrival paths, over-flying while en route or during landing."

As pointed out by Noise Quest (2009), there are many ways to measure the effect of noise on the environment. For example, three noise metrics are used by the U.S. Federal Aviation Agency, namely, 1) a measurement of the highest sound level occurring during and individual aircraft overflight (single event), 2) maximum level of single event plus its duration, and 3) the cumulative noise levels from multiple flights.

Single noise events can be described with Maximum Sound Level (Lmax) or Sound Exposure Level (SEL). Lmax is used to measure noise at its highest level during one noise event while SEL represent the total sound energy occurring during a flight event. Alternatively, Cumulated noise measurements combine all of the noise events and duration into one rating. In terms of the unit of measurement, there are several airport noise measurements units that have been used in different countries, as shown in Table 1. Note that in the case of Suvarnabhumi Airport, Noise Exposure Forecast (NEF) has been used to define affected areas. Readers who wish to learn more about these units are referred to Noise Quest (2009) (for LEQ, DNL and CNEL), Nelson (1979) (for NEF), Pennington et al. (1990) (for NNI), Praag and Baarsma (2005) (for Ku), Mieszkowski and Saper (1978) (for CNR).

Table 1 Some Common Metrics for Airport Noise

Noise Metric	Country
Community Noise Exposure Level (CNEL)	California
Composite Noise Rating System (CNR)	Canada
Day Night Average Sound Level (DNL or Ldn)	North America
Equivalent Noise Level (LEQ)	United Kingdom
Kosten Units (Ku)	Netherland
Noise and Number Index (NNI)	United Kingdom
Noise Exposure Forecast (NEF)	North America, California, Canada, Thailand

2.2 Airport Noise and Hedonic Modeling

In hedonic house price studies, researchers attempt to find the relationship between house price on the one hand and their multidimensional characteristics on the other. Blazing the trail was Rosen (1974) who first demonstrated how the regression technique can be used to estimate the implicit price of the different attributes of heterogeneous goods with the belief that goods are valued for their utility-bearing attributes or characteristics (Selim (2009). In addition, this technique has been employed to estimate the consequences of various amenities and disamenities on residential property values (Nelson (2004)). Although there were many similar hedonic price studies, the differences depend on the researchers' objective, variables used in analysis, as well as the data that are available.

Based on the previous studies, most researchers on hedonic modeling of property value have utilized the property prices as dependent variable while explanatory variables such as structural characteristics (description of the property), locational characteristics (access to economic and social facilities), neighborhood characteristics (quality of the neighborhood), and attributes of the social and natural environment. Besides, various functional forms have been used to model the hedonic relationships. Four of which have been most frequently utilized, namely, linear, semi-log, log-log, and box-cox transformation. The application of different functional forms provides different interpretations of the findings. For example, if we regress the housing price on aircraft noise (measured in decibel) and given noise estimated coefficient β, in the linear specification the coefficient β reflects the price discount due to an increase of one dB in noise. In the semi-log specification, the coefficient can be interpreted as the discount in percentage point, due to an increase of one dB in noise (see Mieskowski and Saper (1978), Pennington et al. (1990), Espey and Lopez (2000), and Pope (2008)).

In the previous literature, some econometric issues in hedonic modeling have been identified and addressed. These issues are reviewed as here.

Multicollinearity: The problem of multicollinearity occurs when there is correlation between explanatory variables and it does not cause the regression coefficients to be biased because their probability distributions are still centered over the true values, if the regression specification is correct, but they have unsatisfactorily large variances (Dougherty (2009)). As mentioned by Nelson (1979) the problem of multicollinearity can be solved by dividing the block property into group according to the distance and use dummy variable to represent the block in a particular circular distance ring. In the same way, Can (1992) also created a composite neighborhood quality index as a substitute of neighborhood characteristic measurements. Furthermore, the problem of large variances can be dealt with by various techniques, such as including additional variables, increasing the number of observations, and dropping certain correlated variables.

Heteroscedasticity: the problem exists when the variance of distribution of disturbance term is not the same for each observation (Dougherty (2009)). In this study, for example, the larger houses might have larger variance of disturbance term than those of smaller houses. This problem leads to two main consequences: one is that the standard errors of the regression coefficients are estimated wrongly and the *t*-tests are invalid. While another consequence is that the OLS estimation technique becomes inefficient. In other words, heteroscedasticity does not affect the unbiasedness and consistency properties of OLS estimators, but OLS estimates are no longer efficient. Heteroscedasticity causes OLS standard errors to be biased in finite samples, thereby leading to incorrect statistical inferences. However it can be demonstrated that they are nevertheless consistent, provided that their variances are distributed independently of the regressors. White's General Heteroscedasticity Test is performed to reveal the problem. And if the problem is detected, a method called "White's Robust Standard Errors is used to remedy it (Gujarati and Porter (2009)).

Heterogeneity and Spatial Dependence: When the cross-sectional data is used to estimate the econometric model, spatial effects should be considered for two reasons: the first is related to the underlying process based on theoretical or conceptual consideration; the second reason is associated with misspecification resulting from omitted variables, mistaken functional specification, and measurement errors (Can (1992)). It was reported in the paper that, the presence of spatial effects – spatial dependence and spatial heterogeneity – will violate the standard error assumptions under normality of the linear regression model (Regarding the test for these spatial effects, see Can (1992)). Additionally, it would not be sufficient to analyze and model the geographically referenced data by using traditional methods due to spatial effects. Anselin (1993) proposed spatial econometric approach to incorporate location information of each observation as an important attribute in the hedonic model. Regarding to the airport noise, Praag and Baarsma (2005) suggested heterogeneity that results from the psychological characteristics of affected persons who are not observable. Dwellers in the vicinity of the airport may vary in noise sensitivity due to noise and this would yield the imprecise estimation. Pope (2008) also argued about the heterogeneity that the property buyers with lack of information about the noise will cause downward biased estimate of airport noise effects on residential property prices. One possible solution in controlling market heterogeneity has been proposed in Theebe (2004) by generating sub-sample

Table 2 Summary of Findings from Previous Studies of Airport Noise Impact on Property Values

Authors (Publ. year)	Airport (Country), Area(s)	Data type, Sample size (study period)	Method	Noise Metric (year)	Functional form	NDI (|t|)	R^2
Miseszkowski and Saper (1978)*	Toronto(U.S), Mississauga	Indiv. prop., 509 (1969-73)	Hedonic	NEF (1971)	Semi-long	0.87% (4.10)	0.90
	Etobicoke	611 (1969-73)	Hedonic	CNR (1975-76) and NEF (1971)		0.95% (5.08)	0.92
Nelson (1979)*	Six airports (U.S)	Census blocks, 845 (1970)	Hedonic	NEF (1972)	Log-linear	0.50% (2.75)	0.84
Nelson (1980)*	13 airport (U.S)	Previous studies, 13 (1967-76)	Hedonic	NDSI (1967-76)	(Average)	0.4-1.1%	-
O'Byrne, Nelson, and Seneca (1985)*	Atlanta (U.S), Georgia	Indiv. Prop., 96 (1979-80)	Hedonic	LDN (1980)	Semi-log	0.67% (2.233)	0.71
		Census blocks, 248 (1970)	Hedonic	NEF (1972)	Log-linear	0.64% (3.2)	0.74
Pennington et al. (1990)	Manchester (England), Manchester	House Mortage, 3472 (1985-86)	Hedonic	NNI=40, 45, 50 (1985)	Semi-log	Statistically insignificant	0.80
Uyeno et al. (1993)*	Vancouver (Canada), Richmond,	Detached house, 645 (1987-88)	Hedonic	NEF =25, 30, 35, 40 (1987)	Log-linear	0.65% (3.969)	0.64
		Condos, 909 (1987-88)	Hedonic			0.90% (2.789)	0.79
		Vacant land sales, 319 (1987-88)	Hedonic			1.66 (2.919)	0.42
Collins and Evans (1994)	Manchester (England), Manchester	House mortage, 3472 (1985-86)	ANN	NNI=27,40 (1985)	-	8.02-9.54%	-
Levesque (1994)*	Winnipeg (Canada), Manitoba	Indiv. Prop., 1,635 (1985-86)	Hedonic	NEF (average) No. Events>75	-	1.3% (3.801)	0.80
Espey and Lopez (2000)	Reno-Tahoe (U.S), Nevada	Indiv. Prop, 1417 (1991-95)	hedonic	Ldn = 65 (1993)	Semi-log	2% (1.8)	0.85
Nelson (2004) (include *)	23 airports in Canada& U.S	Previous studies, 31 (1970-94)	Meta-analysis	NDI	-	U.S:0.5-0.6% Canada:0.8-0.9%	-
McMillen (2004)	Chicago O'Hare (U.S), Chicago	Indiv. Prop., 4012 (1997)	Hedonic	Ldn = 65 (1997)	Log-linear	9.2% (9.57)	0.68
Theebe (2004)	Amsterdam (U.S), Netherland	Indiv and multi. Prop., 160,000 (1997-99)	Spatial Hedonic	LAeq(100x100m) (road,rail, and air traffic noise1999)	Log-log	0.3-0.5%	-
Praag and Baarsma (2005)	Amsterdam (U.S), Netherland	Asking price, 1,400 (1998)	Hedonic	Ku = 20 to 35 (1967)	Ordered logit or probit	9% to deactivate Ku from 20 to35	-
Pope (2008)	Raleigh-Durham(U.S), Carolina	Indiv. Prop., 16,900 (1992-2000)	Hedonic	Ldn ≥ 55 (1996)	Semi-log	2.9% (2.071)	0.89
Cohen and Coughlin (2008)	Atlanta's Hartsfield-Jacson (U.S)	Indiv. Prop., 508 (2003)	Spatial Hedonic	DNL =65, 70 (2003)	Log-linear	20.8% (2.8)	0.52

Note: NDI = Noise Depreciation Index; ANN = Artificial Neural Networks;
LAeq = Equivalent Sound Pressure Level (A- Weighted) (Detail about A-Weighted, see Noise Quest (2009))

and dummy variables utilization. Likewise, Cohen and Coughlin (2008) constructed a model that corrects for the spatial independence by incorporating spatial effects by the use of spatial lagging of the dependent variable, spatial lagging of the error term, or a grouping of both.

Table 2 summarizes the findings of previous studies related to airport noise impact on property values between 1978 and 2008. As can be seen, a majority of studies have been conducted to determine the noise discount of property values in the vicinity airports in the U.S. and a few studies in Canada and the U.K. The most important methodological different between the studies is the treatment of aircraft noise measurements and quantitative methods for data analysis. In virtually all of the studies the hedonic approach was employed, with an exception of Collins and Evans (1994) who used an artificial neural network approach. Additionally, hedonic approach has been developed to spatial hedonic model for better estimating the impact of airport noise on property values. These spatial models can be found in Theebe (2004) and Cohen and Coughlin (2009) who has addressed spatial autocorrelation and spatial dependence, which could bias ordinary least squares (OLS) estimates, by using spatial regression technique.

The sample sizes in the studies reviewed in Table 2 range from 96 to 160,000 (O'Barne et al. (1985) and Pope (2008)). In addition, many studies use individual property type (or single family house) for the analysis. Meanwhile, property value proxies used in these previous studies are all transaction price, with the exception of Praag and Baarsma (2005), who analyzed the results use asking price. Semi-logarithmic model were used in many studies, the results of which can be used directly to estimate the property discount in percentage point due to airport noise effect.

The results of studies shown in Table 2 indicate significant airport noise discounts, except for Pennington et al. (1990), in which the authors found that NDI equals to 0.15 with insignificant *t*-statistic of 1.16. The lack of this statistical significance can be probably the consequence of neighborhood and other uncontrolled characteristics of the properties. Nelson (2004) found that the results of his study are consistent in the range of that in previous works (Nelson (1980)). With regards to the use of NEF in residential property valuation, the studies suggest noise discount in the range of 0.4% to 1.3% (Nelson (1980) and Levesque (1994)) while the coefficients of determination, R^2, in the studies range from 0.64 to 0.92.

Table 3 Summary Statics of Variables

Variable	Mean	Std. Dev.	Min	Max
Price (million B)	4.8436	6.1018	0.4394	65.4582
Floor area (sq. m)	174.486	96.976	18	750
Lot size (sq. wa)	55.432	44.625	16	530
Number of stories	2.17	0.4899	1	4
Distance to (km)				
airport entrance	15.63	53.37	2.80	30.73
train station (bts)	20.11	9.52	2.23	47.99
expressway ramp	11.79	7.71	1.09	36.55
% of sample sold in				
2002	3.67			
2003	9.72			
2004	23.33			
2005	16.20			
2006	17.71			
2007	15.34			
2008	14.04			
% of sample of property type				
Single-family detached	53.62			
Duplex	11.91			
Town house	34.47			

3 METHODOLOGY

3.1 Data

There are several data sources required to examine the impact of the airport noise impact on property values. First of all, Agency for Real Estate Affairs (AREA) provided the cross-sectional data for property sales in the vicinity of Suvarnabhumi International Airport, Thailand, from year 2002 to 2008. The data set includes sale prices and property characteristics of 44,923 property units which can be divided into 384 sale price categories. The types of properties include duplex, single-family detached house, and town house. The sale prices of the properties were expressed in million baht. See Table 3 for summary statistics of the variables.

Regarding property characteristics, structural control variables consists of the number of floor, floor area in square mater, lot size in square wa (one wa equals two meters), and the year in which the property is sold. To control for business cycle in real estate sector, year dummy variables were created for each year between 2002 and 2008.

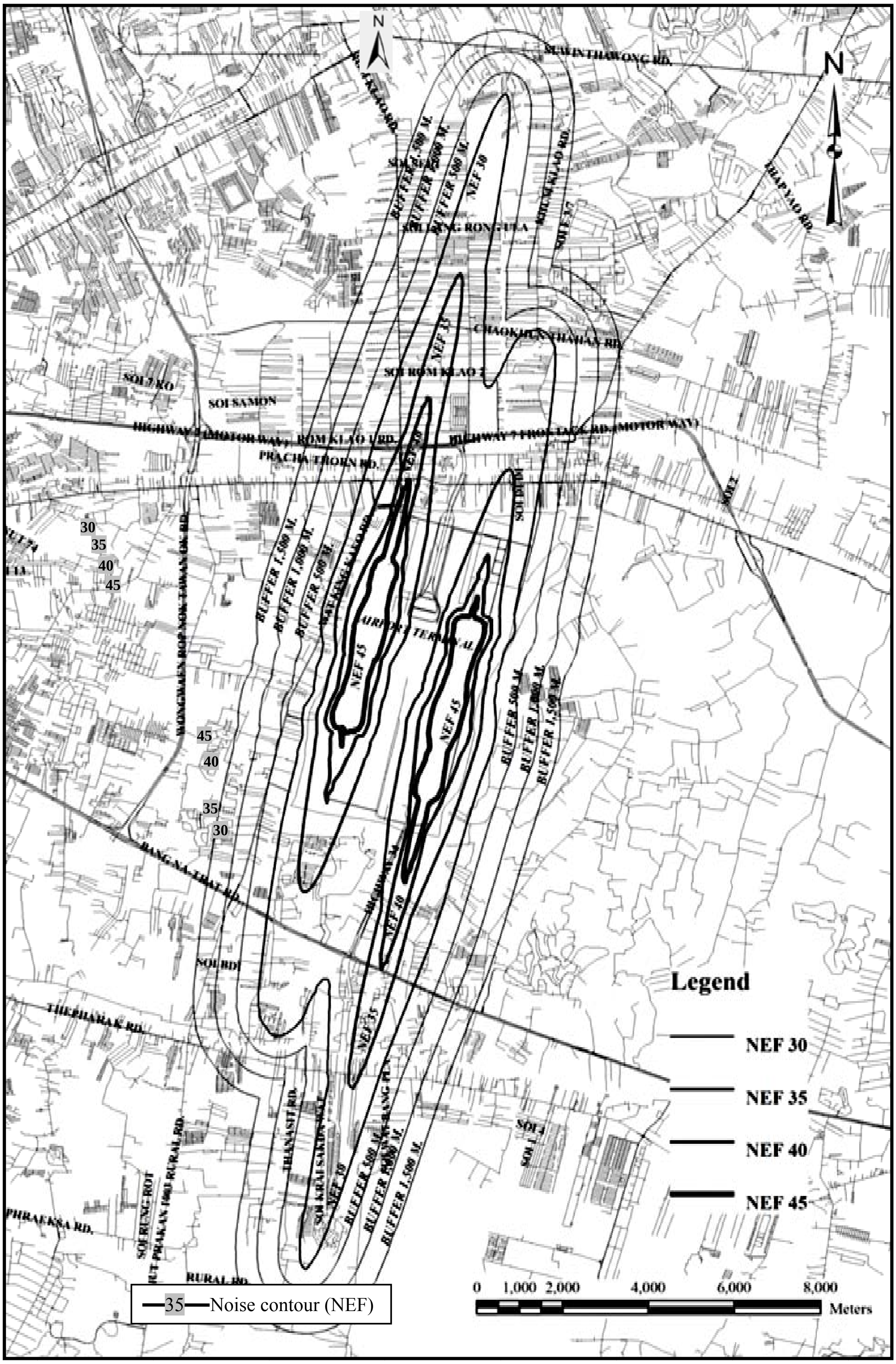

Figure 1 Suvarnabhumi Airport Noise Contours (Source: ESRI Bangkok GIS and AoT)

For example, Year 06 in Table 4 is equal to 1 if the property was sold in year 2006. The names of project developer are also provided in the data set. To control for the price premium attached to reputable developers, we generated brand variables for properties whose developers are major companies that are listed in the Stock Exchange of Thailand (SET).

In addition to the structural and sales characteristics, locational characteristics in the data sets, which are provided by the street address of property, are also utilized for hedonic modeling. The addresses were coded into Geographic Information System (GIS) map for further spatial analysis using the software ArcGIS 9.0. Based on the GIS map of property locations, additional location-related variables were generated, such as distance to the airport entrance and distance to major transportation facilities (i.e. distance to the nearest BTS station and expressway ramp).

Most importantly, the variables that capture airport noise impact were defined as dummy variables based on the noise contour map as appro-ved by the Thai cabinet in 2007 and publicly distributed by the AoT. The contour map is shown in Fig. 1. These dummy variables were created according to the levels of NEF. For instance, we created a dummy variable NEF30 taking value of 1 for a house situated in noise contour level between NEF 30 and NEF 35. In all, there are 1,442 property units that are located in the noise contour zone, with 1,262 units in the NEF 30-35 zone and 180 units in the NEF 35-40 zone. No property units are located in the zone where NEF is greater than 40.

Since we know that noise impact occurred only after the airport began in 2006 and because of the data available includes both property sold before and after this year, hence N30af and N35af, dummy variables, were also created to control for the effect of airport noise after airport operation began. These dummies are similar to those of noise, and the suffix *–af* was marked if the property was sold after the airport operation began. For example, N35af valued 1 if the property is located in the noise contour between NEF 35-40 and was sold after the airport operation began. Moreover, dummy variable buf5 and buf5aft which represent the buffer zone 500 meters extended from the NEF 30 contour line were additionally created to control for the effect of those properties located just outside the noise contour line NEF 30. For instance, buf5 takes value of 1 if the property is located in buffer zone, not further than 500 meters outside NEF30 contour line.

3.2 Hedonic Model of Airport Noise Impact on Property Prices

We tested various specifications of the hedonic model of property prices and selected the semi-log functional form. This allows the interpretation of regression coefficients as the percentage change due to marginal increase in the value of variables. Because this function form has been used by many researchers in the past, our choice of specification enables us to compare our estimation results with those in many previous studies. The hedonic model of property prices can be written as follows:

$$\ln Price_i = \alpha + \mathbf{X}_i\beta + \mathbf{S}_i\gamma + \mathbf{T}_i\delta + \mathbf{N}_i\pi + \varepsilon_i \quad (1)$$

where $\ln Price_i$ is the natural log of property sale price i (in million Baht); $\mathbf{X}_i$ is a vector of structural variables including floor area, lot size, number of stories, type of property, and names of project developer; $\mathbf{S}_i$ is a vector of location variables (i.e. distance to the airport entrance and other transport accessibilities); $\mathbf{T}_i$ is a vector of temporal dummy variables (2002 is set as base year); $\mathbf{N}_i$ is a vector of environment-tal dummy variables; α, β, γ, δ, and π are parameters to be estimated; and ε_i is the error term.

4 ESTIMATION RESULTS

The OLS estimation results of the best hedonic regression model with robust standard errors are shown in Table 4. As can be seen, the estimated model fits the data very well, with adjusted R-squared suggesting that 92.42 percent of variation in property prices explained by the model. The coefficients of property character-ristics variables are all significant at the 5-percent level and show correct signs.

The coefficient of floor area, lot size and number of stories are positive, and the magnitudes of these coefficients suggest that a marginal increase in the values of these variables would increase in the property price by 0.39, 0.25, and 28.09 percent, respectively.

As for the effects of property types, a single-family detached house has a sale price about 25.29 percent higher than that of a duplex unit, and both, on average, sell for more than a townhouse by 72.15 and 46.85 percent, respectively, all else being held constant. Based on average price, this can be interpreted that the townhouse sells for about 3.5 million Baht less than single-family and about 2.27 million Baht less than duplex unit, *ceteris paribus*. As mentioned earlier, people are more likely to purchase the single-family detached and duplex houses rather than townhouse. The reason behind this is probably due to the construction location where land is abundant and with convenient access to the transportation facilities as well as business district. Since the results showed significant effect of different types of residential property, it is important that these types of dummy should be included in the model as verified by Chow test.

The brand names of the reputable developers are generally believed to command a significant amount of price premium. This is reflected by the results, for example, the properties constructed by Land & House (LH), Noble Home (NH), and Sansari (SA) would sell for at least 21 percent or greater price premium compared to other less well-known developers. This is not surprising because these three developers are large and well-known real estate companies. Additionally, most people are likely to buy the houses these real estate companies with the belief of good quality of work and construction.

Table 4 OLS Estimation Results of Hedonic Model with Robust Standard Errors

Regression with robust standard errors					Number of obs =	384
					F(21, 362) =	179.72
					Prob > F =	0.0000
					R-squared =	0.9242
Dependent variable = ln (Sale Price)					Root MSE =	0.23399

	Coef.	Robust Std. Err.	t	P > | t |	[95% confident interval]	
Structural variables						
Floor area (sq.m)	0.003901	0.000265	14.70	0.0000	0.003379	0.004423
Lot size (sq. wa)	0.002503	0.001012	2.47	0.0140	0.000513	0.004494
Number of stories	0.280906	0.041550	6.76	0.0000	0.199197	0.362615
Single-family detached dummy	0.721465	0.060602	11.90	0.0000	0.602288	0.840641
Duplex dummy	0.468530	0.048113	9.74	0.0000	0.373915	0.563145
Developer dummy						
LH	0.210422	0.046589	4.52	0.0000	0.118804	0.302040
PS	-0.199168	0.047074	-4.23	0.0000	-0.291740	-0.106596
NO	0.275287	0.103128	2.67	0.0080	0.072483	0.478091
SA	0.330106	0.094148	3.51	0.0010	0.144961	0.515250
Location variables: distance to (m)						
airport entrance	-9.71E-03	2.75E-03	-3.53	0.0000	-1.51E-02	-4.30E-03
nearest train station (BTS)	-1.80E-02	1.73E-03	-10.45	0.0000	-2.14E-02	-1.46E-02
nearest expressway ramp	-2.62E-03	1.58E-03	-1.65	0.0990	-5.73E-03	4.93E-04
Temporal variables (year of sale)						
Year 03	0.124577	0.071757	1.74	0.0830	-0.016537	0.265691
Year 04	0.132714	0.064214	2.07	0.0390	0.006434	0.258994
Year 05	0.168101	0.063657	2.64	0.0090	0.042917	0.293285
Year 06	0.221716	0.068040	3.26	0.0010	0.087914	0.355519
Year 07	0.146817	0.065345	2.25	0.0250	0.018313	0.275320
Year 08	0.294978	0.065753	4.49	0.0000	0.165672	0.424284
Environmental variables						
N35af	-0.258967	0.044841	-5.78	0.0000	-0.347148	-0.170785
N30af	-0.095308	0.082034	-1.16	0.2460	-0.256630	0.066014
buf5af	-0.042532	0.049954	-0.85	0.3950	-0.140768	0.055705
Constant	-0.316336	0.131187	-2.41	0.0160	-0.574320	-0.058352

The coefficients of year dummies are all significant at 5-percent level except for 2003 which is significant at 10-percent level. The coefficient estimates of year dummies show a growing trend of residential property prices near Suvarnabhumi airport, except for a decline in 2007. The fall in price could probably be attributed by the ambiguity about the status of the nation's economy. In September 2006, the event of the coup d'état in Thailand might also influence on this drop in price. In the same period, another probable reason is that the problem of noise impact primarily started to be considered by buyers of the properties located nearby the airport. Nevertheless, the increasing trend resumed in 2008 after the reinstatement of democratically elected government in December 2007.

It is also shown in the Table 4 that the coefficients for location variables are highly significant, except for the coefficient of distance from each property to the nearest expressway ramps which is significant at 10-percent level. As can be expected, the negative coefficients of location variables suggest that there is a beneficial effect of being closer to the transportation facilities. The negative coefficient of distance from each property to the nearest BTS station is higher than the coefficients estimates for access to the airport entrance and the nearest expressway. This implies that every one kilometer further from the nearest transit station sells for 1.8 percent less. Besides, there is also reduction in property price of 0.97 and 0.26

percent for every one additional kilometer from the airport entrance and the nearest expressway ramp, respectively.

Finally, the estimated coefficients for noise dummy variables in the hedonic model are negative suggesting noise discount for residential properties located inside the noise contour zone. As can be seen, only the coefficient of N35af is highly statistically significant. The magnitude of the coefficient implies that the residential properties located between the NEF 35 and NEF 40 noise contour lines were sold at 25.9 percent discount compared to similar residential properties located elsewhere. This can be translated into a substantial 1.25 million Baht discount due to the airport noise, when computed based on the average price. Although the other two noise dummy variables are not significant at 10-percent level, the coefficient estimates imply the noise discount of 9.53 percent for properties located inside the noise contour lines of NEF 30 and NEF 35, and noise discount 4.25 percent for those properties located in the 500 meters buffer zone outside NEF 30 noise contour line. It should be noted that the noise discount described above refer only to those properties sold after the airport operation began and the amount of decline in prices is accorded with the level of noise impact.

5 CONCLUSION

In this paper, we examine the impact of airport noise on property prices by estimating hedonic model using sales data of properties located in the vicinity of Suvarnabhumi Airport from 2002 to 2008. As the analysis results reveal, there is no impact of the airport noise on property prices transacted before the airport operation began in 2006. Based on the insignificance of noise dummy variables NEF30 and NEF35, we can interpret that the buyers of new properties in the areas did not anticipate the upcoming noise effects. The hedonic model estimation shows a substantial impact of the airport noise on property prices transacted after 2006. The outcomes indicate that there is a reduction in price of about 25.9 percent if the new property is sold after the opening of airport in 2006 and located between the NEF 35 and NEF 40 noise contour lines compared with a similar property located elsewhere, all else being held constant. In addition, the noise discount would be 9.53 percent for properties located between NEF 30 and NEF 35 noise contour lines and were transacted after 2006. These two noise discounts can be interpreted to noise deprecia-tion index (NDI) of 3.27 percent per dB. In this study, the value of NDI found is relatively in the high range of those reported in the previous studies. The high noise discount should not come as a surprise, as in this study, the data provided by the AREA is unreliable because the data was self-reported by sellers who often underreport transaction prices. In addition, there were already many complaints about the airport noise generating form Suvarnabhumi airport in the year when the airport operation begun. The reactions from the protestors like KMIL and other affected homeowners might also encourage the decline in prices of properties located near the airport.

Although quite advanced compared to similar studies previously conducted on the topic in Thailand, this study can be improved on several fronts. For example, various econometric issues should be examined to ascertain that the modeling results possess desirable statistical properties. Among these are the test of spatial dependence and heterogeneity in the data set. Another avenue that can be taken to improve the research is to also include properties that are resold as the current study includes only new ones. In this way, the discount in property price due to airport noise can thus be more precisely estimated.

Finally, we hope that the value of NDI computed in this research would help the AoT in formulating an apposite policy in compensating the homeowners affected by the airport noise. Besides, the responsible authorities should also propose a rule to control for limits of noise annoyance level emitted by the aircraft, control over the land use regulation; so that the problem of the airport noise would decrease and also save the significant amount of public funds in the future, especially when the ultimate development plan of airport expansion takes place.

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   3. Published Report:

      International Association of Traffic and Safety Sciences. White Paper on Traffic Safety ’95. (1995).

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