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ATRANS RESEARCH
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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.

ATRANS Research: Journal of Asian Transportation Research Society is a free access on-line yearly journal aiming at publishing research papers, case studies and special research project reports on any aspect of transportation-related issues: planning, engineering, modeling, technology, logistics, economic, legal, medical, behavior, education, traffic safety, energy and environment.

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ASIAN TRANSPORTATION RESEARCH SOCIETY

Chairperson's message

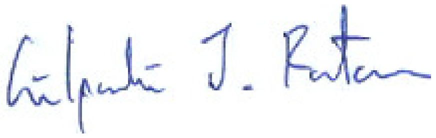
It is a great pleasure to launch this ATRANS Research: Journal of Asian Transportation Research Society. There are a lot of challenges which the growing economies and motorizations face in the realms of basic necessities in mankind. Research and development can play a very distinct role in bringing changes. One of the key objectives of research should be its usability and application. This journal attempts to document and spark a debate on the research focused on transportation-related in context of emerging energy and environment. The sectors could range from transport, traffic safety, energy, environment, education, social science, traffic psychology, and health care areas.

On the occasion of the launch of ATRANS Research: Journal of Asian Transportation Research Society, I extend my warm welcome to the readers and authors. I express my gratitude to the Editorial Board Members for their sustained support to make the launch of the ATRANS Journal possible. The support of the Editorial Advisory Board is vitally important and the input by the Editorial Board is crucially and greatly appreciated. We certainly could not publish ATRANS journal without the extraordinary efforts of our reviewers. The willingness and expertise of their professionals serving as reviewers are essential to maintaining technical and editorial standards. So, I offer my sincere thanks to each of the peer reviewers whose efforts help to ensure that this journal becomes one of the promising Transportation-related journals.

In particular, I would like to thank all contributors who work behind and who trust at the very beginning allows us to move the journal forward. While we are particularly focused on Asian Developing Countries research, we invite authors from all over the world to contribute to the new journal.

I look forward to a successful and rewarding first year of the journal as Chairperson and welcome any comments or suggestions you might have on how we can continue to improve our journal.

With best regards



Silpachai Jarukasemratana, Mr.
Chairperson
Asian Transportation Research Society (ATRANS)
Bangkok, December 2009

Editor-in-Chief's message

Welcome to ATRANS Research, Journal of Asian Transportation Research Society. This journal is initiated with efforts and supports from academic, scientists, transport engineers and transportation-related practitioners.

As the Editor-in-Chief of ATRANS Research, Journal of Asian Transportation Research Society, it is my pleasure to present you with the new issue. This first issue of ATRANS Journal deals mainly with the transport research challenges in developing countries. The journal will be published yearly by ATRANS. All papers are peer reviewed by at least two reviewers and the editorial board, formed by an international group of experts on transportation-related research.

Transportation is an essential and integral part of our mobile society. It bridges the gap between social exclusion and mobility which entails an equal accessibility and mutual interaction to all mankind. Transportation development has significant influence upon not only daily living and lifestyle but also social culture, human behavior and environment.

Asian Transportation Research Society (ATRANS), found on 1st April 2008, is a total non-profitable research institution in cooperation with the International Association of Traffic and Safety Sciences (IATSS), Japan. ATRANS' principal mission is to promote research activities and provide research funds for Asian academics and young researchers on conducting empirical and pragmatic research approaches regardless of transportation related problems, traffic safety, energy and environment in multidisciplinary manner.

I hope that ATRANS Journal will bring the up-to-date scientific knowledge in transportation 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 and beyond.

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

Secretary – General's message

It is my strong intention to address this message to students, faculty members, researchers, engineers and readers for the launch of the new source of gathering quality research papers from authors around the globe.

I am delighted to have created this new journal – ATRANS Research – Journal of Asian Transportation Research Society. The key focus is the emerging sectors and research which discusses application and usability in societal context whether individuals or organizations.

This first issue has been carefully put together covering a range of transportation and technologies in the domain of theoretical and practical applications. I thank the authors for their contribution and wish to encourage all of you to use the ATRANS Research as a tool for sharing thoughts, opinions, collaborative research projects and articles that may be of interest for our members/viewers/readers/authors and help us in our common effort to expand knowledge for transportation-related research and development.

The Journal is advised by an international Editorial Board of experts across a range of multidiscipline. We are welcoming papers from respected authors wishing to publish within the areas of experimental and analytical studies of Transportation-related research and technology. So, if you are faculty member, please encourage your students and post-docs or research fellows to submit their quality papers to ATRANS Research. If you are a student or postdoctoral fellow or research fellow, I wish to encourage you to be a trailblazer and submit your best efforts to ATRANS Research.

I would like to thank all the editorial committees. We have had an overwhelming response from very eminent editors and researchers globally to support as editorial team. Special thanks to the reviewers whose reviews have helped in making this journal possible. I hope that the research featured here sets up many new milestones. I also hope that our ATRANS Research: Journal of Asian Transportation Research Society will expand in the future and we will be able to accommodate the steady influx of manuscripts assuring progress, high quality and glorious success.

Tuenjai Fukuda, Dr. Eng.
Secretary - General
Asian Transportation Research Society (ATRANS)
December 2009

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UNDERSTANDING VEHICLE ACTIVITY IN DEVELOPING ASIAN CITIES

Huan Liu
Center for Environmental Research and Technology,
University of California-Riverside, U.S.A
International Sustainable Systems Research Center, U.S.A.
E-mail:Huanliu@cert.ucr.edu

Matthew Barth
Center for Environmental Research and Technology,
University of California-Riverside, U.S.A.
Phone: 951-781-5782 Fax: 951-781-5790
E-mail: barth@cert.ucr.edu

Nicole Davis
International Sustainable Systems Research Center, U.S.A.
Phone: 909-860-2286 Fax: 909-396-0595
E-mail: ndavis@issrc.org

James Lents
International Sustainable Systems Research Center, U.S.A.
Phone: 909-860-2286 Fax: 909-396-0595
E-mail: jimlents@issrc.org

Kebin He
Department of Environmental Science and Engineering,
Tsinghua University, Beijing,
People's Republic of China
E-mail: hekb@tsinghua.edu.cn

It is clear that in the next several decades, there will be significant growth in the transportation sector of many developing Asian cities. This poses a number of concerns, in particular increased greenhouse gas and pollutant emissions resulting from this transportation build-out. In order to estimate these mobile-source emissions, it is critical that we establish a better understanding of the vehicle activity and fleet composition in these developing cities. As part of a large International Vehicle Emissions (IVE) research program, a number of detailed vehicle activity/fleet composition studies have taken place in several Asian cities. These studies consist of an extensive measurement program, including videotaping and measuring traffic patterns, tracking representative vehicles with GPS dataloggers, monitoring start/stop patterns in instrumented vehicles, and conducting surveys in the field. This paper examines the results of these studies and draws comparisons between them. From these results, estimates of future transportation alternatives can be made, allowing for the development of better air quality and transportation management plans for these developing cities. It is also hoped that the collected data and analysis can be extrapolated to other cities to support further environmental improvement efforts.

Keywords: Vehicle activity, International vehicle emission, GPS, Transportation management

1 INTRODUCTION AND BACKGROUND

Many cities throughout Asia are experiencing substantial economic growth, leading to increased demand for mobility. Per capita income is increasing at a steady rate and is projected to continue to increase well into the future. Consequently, the ownership and use of personal vehicles is also increasing, putting significant pressure on existing transportation infrastructure. As a result, many large developing cities in Asia have experienced serious air pollution problems due to this rapid growth of automobile ownership (see, e.g., [Fenger J, 1999; Kahn M E, 2008]). In addition, there is now a very large concern about the contribution of this automobile growth towards greenhouse gases; in particular, carbon dioxide (CO2). In many developed countries where the degree of auto-mobilization is high, the transportation sector accounts for approximately one-third of the total CO2 emissions [IGPCC, 2007]. If developing cities are left to grow unbounded, transportation-related emissions will likely rise to similar levels, with increased air pollution in the cities, and significantly more CO2 in the earth's atmosphere.

It is clear that something must be done to deal with this problem. Policy makers are looking at a variety of strategies, including: 1) introducing cleaner, more efficient vehicles, such as vehicles with better power train efficiency and/or using alternative technology such as hybrid electric or pure electric vehicles; 2) introducing alternative fuels, especially those that are more carbon-neutral such as biofuels; 3) improving overall traffic operational efficiency, for example, introducing traffic congestion mitigation techniques; and 4) reducing the total amount of total driving, i.e., vehicle kilometers traveled or VKT, through travel demand management programs.

The problem, however, is that mobile-source emissions for many developing cities are not well understood. It is not only important to know the emission characteristics of the different vehicles, but it is also important to understand how these vehicles are being operated, i.e., the vehicle activity component. The vehicle activity component serves as the basis for establishing an emission inventory, both for criteria pollutants and CO2 (see, [Lyons T J, 2003] and [Yedla S, 2005]). In many cases, estimates of vehicle activity in developing countries is based on modified versions of U.S.- or European-based factors in the absence of readily available local information to predict their own vehicle activity. This is often problematic since there can be significant regional differences in vehicle activity around the world. As a result, significant errors in the overall calculations are possible when they are extrapolated to other areas with differing vehicles, infrastructure, and driving behavior [Costabile F, 2008].

To better estimate mobile source emission inventories in developing countries, an International Vehicle Emissions (IVE) model was previously developed that overcomes many of the problems associated with adopting emissions models from other countries (see [Davis et al., 2005] and [Lents et al., 2009]). The IVE model was developed by the International Sustainable Systems Research Center (ISSRC) and the University of California at Riverside (UCR) with funding from the U.S. EPA (see [Lents et al., 2009] and http://www.issrc.org/ive). This IVE model is a java¬based stand-alone computer model that estimates vehicle emissions for any area, given three types of inputs. These inputs consist of: 1) the vehicle technology and add-on control distribution in the vehicle fleet, as well as maintenance; 2) driving behavior of the different types of on-road vehicles traveling on local roadways; and 3) vehicle emission factors specific to the local vehicles. The IVE model is highly complex and incorporates many factors, vehicles, and fuel types. It can be used to estimate emissions from virtually any fleet, at any scale (micro to macroscale). It can also be used to predict future emissions given changes in the fleet, fuel, and vehicle flows and congestion.

The biggest challenge for an IVE model implementation is its data calibration for any particular city. With the development of the IVE model, methods have also been developed to capture pertinent vehicle activity and fleet composition data using only resources typically available in developing cities [Osses et al., 2004]. The methodology is centered on field studies that are designed to collect a large amount of initial data in several weeks. This information is useful to provide a first order estimate in the specific region studied. A major portion of the vehicle activity and fleet composition data collection includes videotaping and measuring traffic patterns, tracking representative vehicles with GPS dataloggers, monitoring start/stop patterns in instrumented vehicles, and conducting surveys in the field. Details of data collection methodology are provided in Section 2 of this paper.

As part of the overall IVE research program, a number of detailed vehicle activity/fleet composition studies have taken place in several Asian cities. From 2003 to 2008, studies were carried out in six cities, as illustrated in Figure 1. These include three cities in China (Beijing, Shanghai and Tianjin). In addition, a study in Pune India was carried out as an important example of India and also south Asia. The central Asian city of Almaty, Kazakhstan, was studied in 2003. At the western extent of Asia, both the Asian and European components of Istanbul, Turkey, were investigated and included in the overall analysis. All of these cities have experienced substantial economic growth in recent years, resulting in increased travel demand for both passengers and goods [Ghose M K, 2004; Liu H, 2007]. As a result, roadway congestion is increasing in many cities, putting significant pressure on city transportation infrastructure.

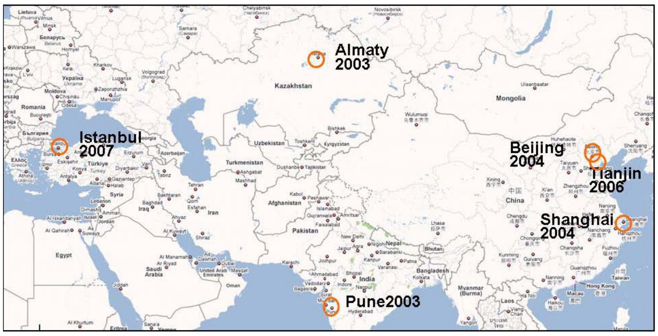

Figure 1 Schematic map of cities under study.

In this paper, the experimental methods to obtain vehicle activity and fleet composition data are described in Section 2. Data results are then given and comparisons are made, examining differences in the vehicle fleet, driving characteristics, and start characteristics. A short discussion is then provided describing the trends.

2 METHODOLOGY

As previously stated, a detailed vehicle activity data collection program has been carried out for each developing city listed in the previous section. The vehicle activity data collection program consists of videotaping and measuring traffic patterns, conducting parked-vehicle surveys in the field, monitoring start/stop patterns in instrumented vehicles, and tracking representative vehicles with GPS dataloggers. These methods are described in further detail below.

2.1 Roadway Video and Parked Vehicle Surveys

In general, it is desired to collect information on: 1) the vehicle fleet mix in different parts of each city; and 2) the technology distribution within each vehicle class (engine size, vehicle age, and emissions control technology). To collect information on the vehicle fleet mix in each city, video road surveys are conducted to identify the fraction of travel in each vehicle class, which typically include passenger cars, two-wheelers, buses, and trucks. The video survey allows for a continuous picture of all lanes of a roadway where an accurate count of each class of vehicle can be conducted. The video surveys typically take place on different roadway facility types, including highways, arterials, and residential streets. The video surveys also take place at different times of the day to help determine overall travel patterns. In addition to the video tape analysis, "parked" vehicle surveys are undertaken to determine the different vehicle technologies on the road and to quantify their contribution to the total fleet, with the basic assumption being that the vehicles parked along the roads and in public parking lots reflect the vehicles on the roads in the city. By observing a parked vehicle, it is possible to determine the vehicle's make and model, it's approximately year of manufacture, its fuel type (e.g., diesel or gasoline), and sometimes its odometer (by viewing through the window).

As part of the parked vehicle activity data collection process, approximately 1200 vehicles have been surveyed in each city, consisting primarily of passenger cars, light-duty trucks, and two-wheeled vehicles (e.g., motorcycles). In addition, similar data are collected on larger trucks and buses, using data sources provide by the local governments.

The resulting aggregate data is useful for determining a city's vehicle age and technology distribution. Combined with knowledge of the local emission control equipment requirements, it is possible to determine general emissions factors for the different vehicle types.

2.2 Vehicle Starts

Another important piece of information is the knowledge of when and how often vehicles are used. Vehicle activity data regarding vehicle start and stop times are gathered using small devices that can be plugged into a vehicle's power port (aka cigarette lighter) for extended periods of time. In the case of two wheeler vehicles and buses, these devices were connected directly to the vehicle's batteries.

The units continuously monitor the battery voltage and record the small fluctuations which occur when vehicles are started and stopped. Battery voltage is low when the vehicle engine is not running, however when it is turned on, the (charging) voltage is typically higher. When the vehicle is turned off, the voltage returns to its resting voltage. By recording when the start and stop events occur, it is possible to determine the number of vehicle starts per day, and the length of time the vehicle "soaks" prior to the next start. The number of starts and soak times play an important role in estimating emissions. These data loggers are typically installed for one week on up to 150 vehicles at each location so that general start patterns may be ascertained.

2.3 Vehicle Speed and Acceleration Characteristics

In addition to vehicle start patterns, it is useful to measure vehicle speed and acceleration characteristics of typical driving trips. To sample different trips at different times throughout the day, GPS (Global Positioning System) dataloggers are placed in a sample of vehicles. These data loggers measure each second of vehicle location, speed, and altitude for the different vehicle trips made throughout the day. Acceleration can be derived from the speed measurement and the vehicle characteristics can be matched to the different roadway facility types based on the acquired location information. For each study area, approximately 200 sample vehicles measured over a two week period are used to establish typical driving characteristics in different parts of each city, and consisted of passenger vehicles, 2-wheelers, buses and trucks.

3 RESULTS

3.1 On-Road Distribution of Vehicle Types

Based on the video surveys and subsequent data analysis, the overall average technology distribution for each road type in seven cities is given in Table 1. The distribution of vehicles varies with street type and time of day. The weighted averages are based on the vehicle counts and the observed technology distributions on the various types of streets. It is clear that the overall fleets in most cities are dominated by cars, including a large fraction of taxis in some cities. However, 2-wheel vehicles are the major vehicle type in India, followed next by 3¬wheelers (e.g., rickshaws). The data also show that the cities of Beijing, Shanghai, and Tianjin have a smaller truck percentage than other cities, however this is primarily due to local regulations that forbid trucks to enter the downtown regions during the daytime.

Table 1 Observational vehicle type distribution from traffic video

City	Pass. Car	Taxi	two-Wheeler	Small Bus	Med./Large Bus	Small/Med. Truck	Large Truck	three-Wheeler
Beijing	69.0%	24.0%	1.0%	1.0%	4.0%	1.0%	0.0%	--
Shanghai	37.0%	19.0%	24.0%	2.0%	7.0%	9.0%	2.0%	--
Tianjin	61.0%	17.0%	5.0%	4.0%	6.0%	6.0%	1.0%	--
Istanbul	69.0%	15.0%	--	10.0%	1.0%	4.0%	1.0%	--
Pune	14.6%	65.9%	0.2%	1.7%	1.4%	0.2%	15.9%	
Almaty	81.7%	0.1%	10.0%	4.0%	4.0%	0.2%	--	

Table 2 General characteristics of the surveyed passenger cars

PC	Fuel			AC		Transmission		Catalytic Converter	
	G	D	other	Y	N	M	A	Y	N
Beijing	99.9%	0.1%	0.0%	97.6%	2.4%	79.0%	21.0%	93.0%	7.0%
Shanghai	98.5%	1.5%	0.0%	96.0%	4.0%	55.0%	45.0%	94.0%	6.0%
Tianjin	100.0%	0.0%	0.0%	95.0%	5.0%	81.0%	19.0%	87.0%	13.0%
Istanbul	72.6%	26.6%	0.7%	86.9%	13.1%	93.3%	6.7%	89.4%	10.6%
Pune	74.1%	25.9%	0.0%	61.5%	38.5%	99.7%	0.3%	48.0%	52.0%
Almaty	95.0%	5.0%	0.0%	-	-	-	-	9.0%	91.0%

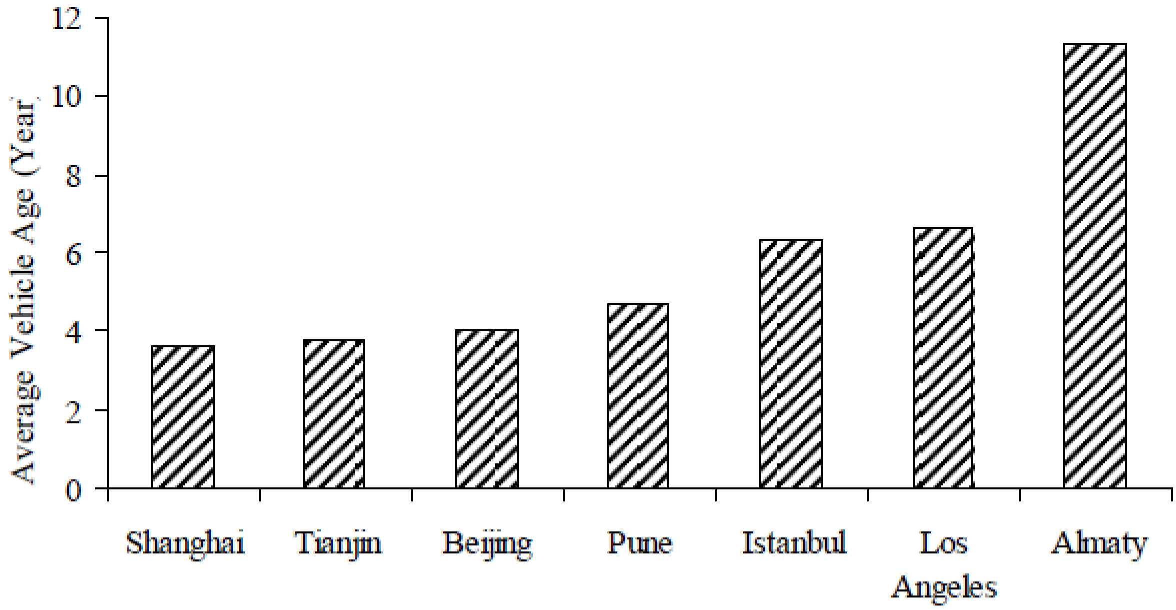

Figure 2 Average vehicle age comparison for passenger cars

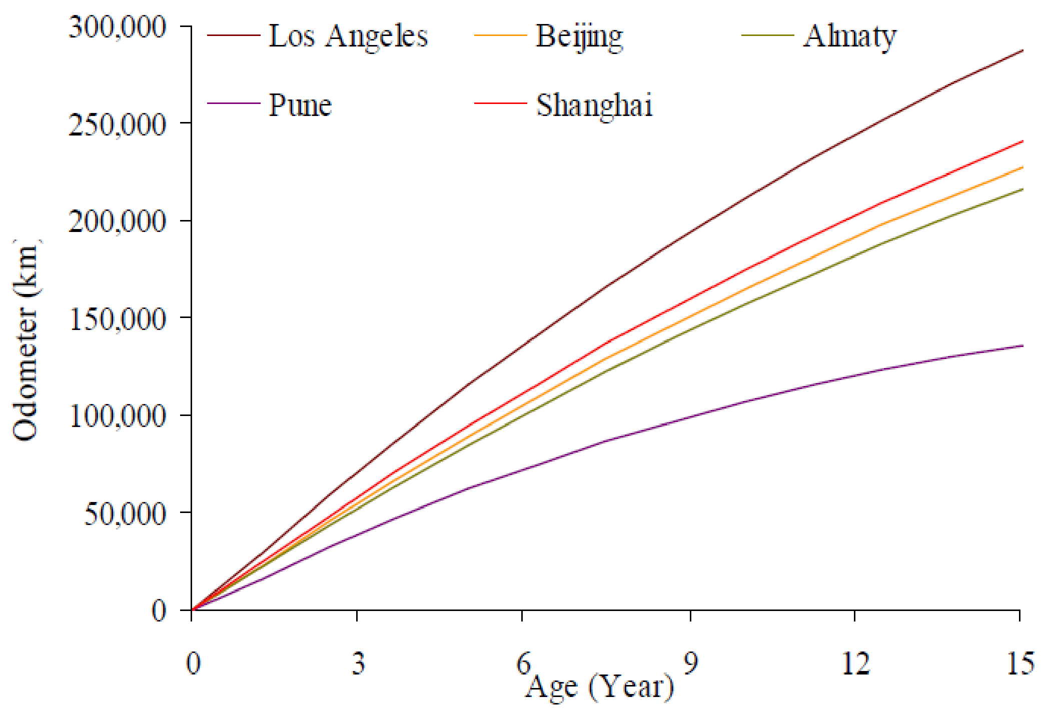

Figure 3 Odometer vs. average vehicle age for passenger cars (PC)

Table 3 Estimation of total daily driving in the cities of interest.

	Beijing	Shanghai	Tianjin	Pune	Almaty
VKT (km/day)	109,568,844	50,928,200	37,640,385	12,033,961	8,869,969
VKT density (km/day/km^2)	6677	8190	5087	8855	27309

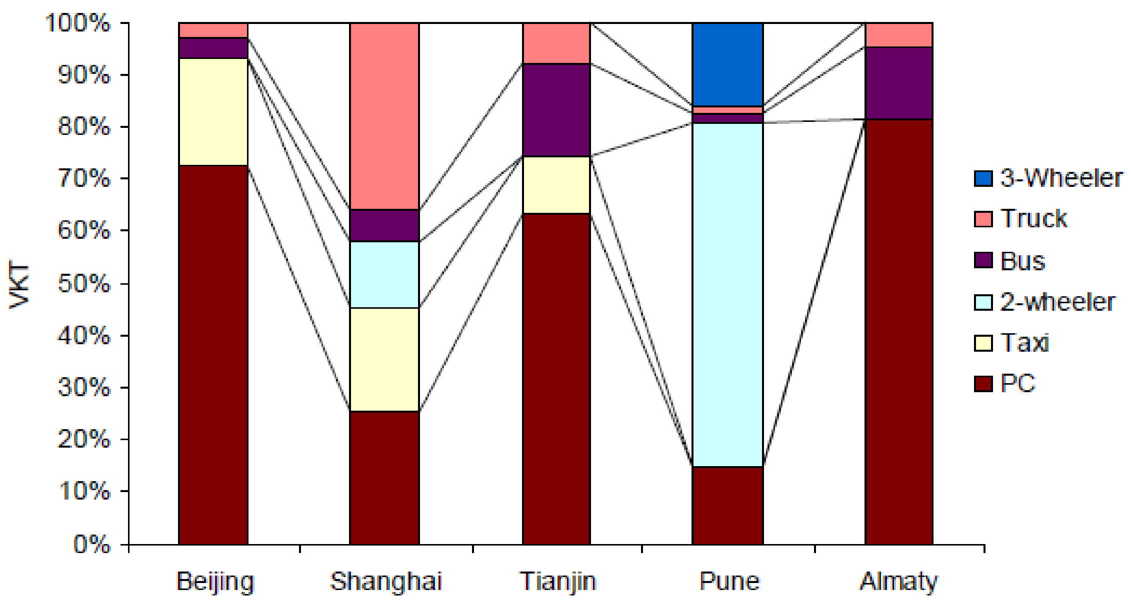

Figure 4 VKT distribution by vehicle types

3.2 Vehicle Fuels and Technologies

As described in Section 2.1, the general characteristics and technical information on the vehicle types in each city can be extracted from parked-vehicle surveys. General analysis shows that gasoline passenger cars are dominant in most cities (see Table 2), especially in China. Due to strong regulations on particulate matter, the Chinese government doesn't allow for the introduction of light-duty diesel vehicles. In contrast, in Istanbul and Pune, light-duty diesel vehicles make up one fourth of the total fleet. It was also found that most of the passenger cars in the developing cites are still manual transmission. Further, because catalytic converters are highly effective at lowering pollutant emissions, they have fairly high penetration in China (92%) and in Istanbul (90%). Due to higher cost and less stringent emissions standards, the penetration rate of catalytic converters is much lower in Pune and Almaty (based on 2003 data).

3.3 Average Annual Vehicle Use

Using the parked-vehicle survey data, it is also possible to examine the odometer data and vehicle age to determine typical daily driving amounts. Figure 2 illustrates the average age of passenger vehicles in the different cities. Los Angeles was selected as a reference here, since the average age of the car fleet in Los Angeles is relatively stable. Based on this figure, it is clear that China has the youngest fleet, followed by Pune and Istanbul. In most Asian cities, on-road passenger vehicles are very young compared to Los Angeles, with the exception of Almaty.

An analysis of the odometer data shows that vehicle usage decreases with vehicle age in the developing Asian cities, similar to other cities in the U.S. and other countries. Figure 3 illustrates the average vehicle accumulated driving distance by vehicle age for some of the developing cities (as well as Los Angeles to serve as a comparison), using curve-fitting techniques. The accumulated travel for passenger cars in Shanghai and Beijing increases relatively fast, second only to Los Angeles. Among the Asian cities, there are large differences of odometer reading, which shows the different usage of cars in these countries.

Based on the odometer data and the average passenger car age, an average daily driving calculation can be made for the passenger cars in each of the cities. The vehicle kilometers traveled (VKT) in the region can be estimated by multiplying the number of vehicles of a type in the region times the average driving per day for that vehicle type divided by the fraction of those types of vehicles observed on the road. Table 4 provides the overall estimates of total driving in the cities per day and Figure 4 illustrates the contribution percentage from each vehicle type.

It is interesting to note that when considering the daily driving in Chinese cities, taxi travel has a relatively high contribution. It is to be noted that the VKT distribution varies significantly from city to city because of local policies and economy status.

3.4 Average Daily Driving Speeds and Acceleration Patterns

In order to compare the driving speed and acceleration patterns in the different cities, a Speed/Acceleration Frequency Distribution (SAFD) analysis was carried out. The second-by-second speed data from the GPS data loggers is used first to derive acceleration rates. Both the speed and acceleration value for each second of driving are then put into a two-dimensional histogram, as shown in Figure 5 where the color of the graphs represent the accumulated values for those specific speed/acceleration instances. As an example, Figure 5 illustrates the SAFDs for highway driving at 8AM among the different cities. In addition, Table 5 lists the average speed of different roadway facility types (highway, arterial, residential street). It can be seen that some cities (e.g., Shanghai and Beijing) have similar average speeds on the highway; however, when examining the SAFD plots, it can be seen that the vehicle driving behavior is quite different.

In general, Beijing, Pune, and Tianjin have a relatively smaller range of speed distribution, compared with Almaty, Istanbul, and Shanghai. It can also be seen that Pune primarily has one mode of driving, compared to Shanghai which has two distinct modes (low and high speed). Secondly, the acceleration range among cities are different. In Almaty and Istanbul, the acceleration rate varies from -2 m/s2 to 2 m/s2, while in the Chinese cities and Pune, the values vary from -2 m/s2 to 1 m/s2, indicating perhaps a higher degree of congestion.

Table 5 provides a summary of daytime average driving speeds for each road type and vehicle class in different cities. Similar trends were found in all cities under study: vehicle speeds tend to be higher on highways compared to other roadway types, as designed. Taxi and truck speeds are typically lower than passenger car highway speeds, but higher than arterial speeds, while the bus speed is between the average arterial and residential speeds. These results make sense, since most of buses will not be operated on highways, however, taxies and trucks will drive on both highway and local roads.

3.5 Vehicle Start Pattern Analysis

From the start and stop data collection process described in Section 2.2, it is possible to determine the total number of starts per day as well as the average soak times, i.e., the amount of time between a stop and a start. For this analysis, the soak times were divided into three ranges:

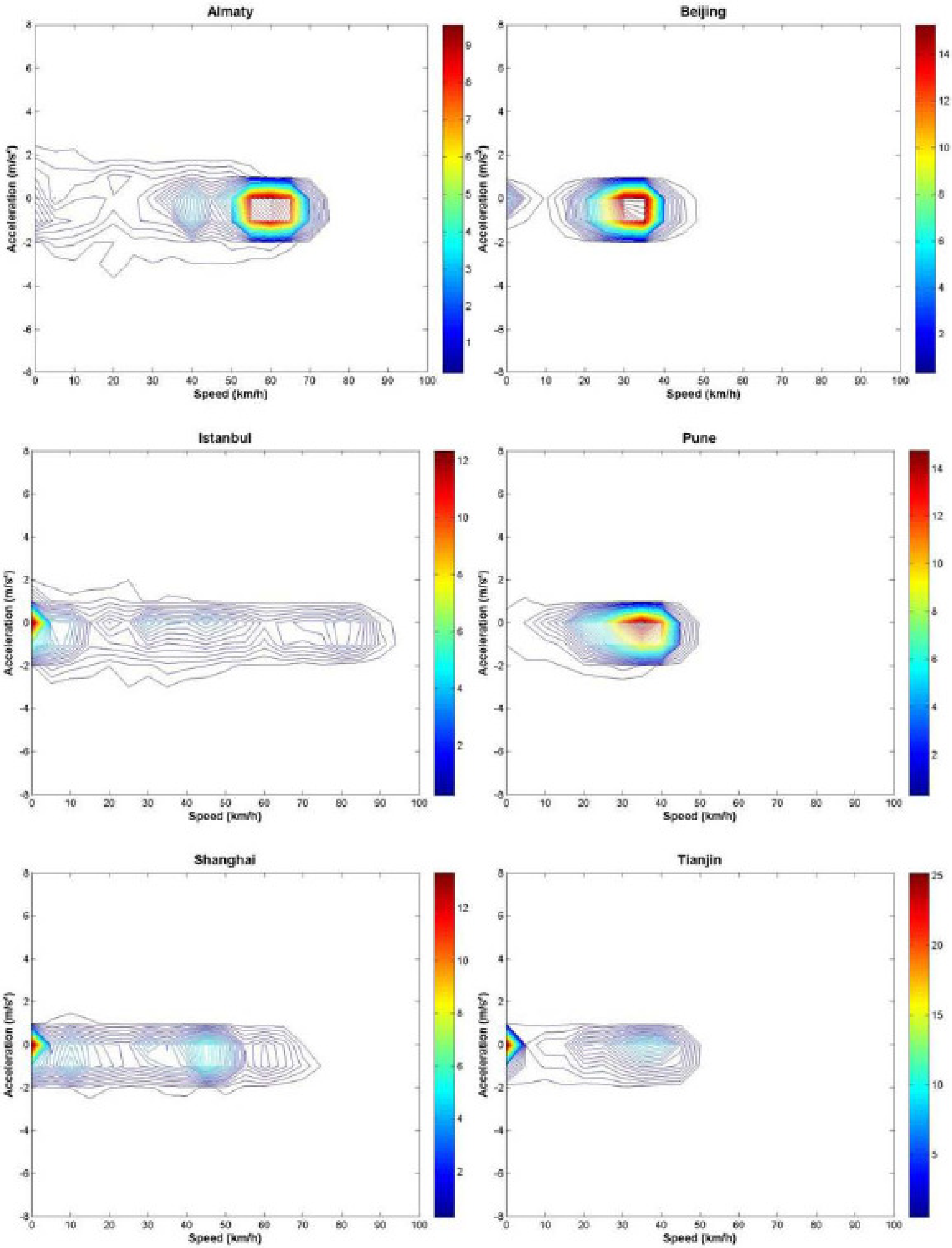

Figure 5 Speed and acceleration frequency distribution of highway driving at 8AM.

Table 4 Average speed in daytime (km/h)

	Hwy	Art	Res	Taxi	Bus	Truck
Beijing	36.2	16.2	15.5	19.8	17.1	17.2
Shanghai	32.0	12.6	17.1	20.5	15.4	23.6
Tianjin	29.3	15.1	21.0	20.1	15.0	29.4
Istanbul	40.4	22.6	19.9	29.5	15.4	24.9
Pune	35.5	28.4	24.4	--	--	23.6
Almaty	49.5	37.4	26.4	--	26.6	--

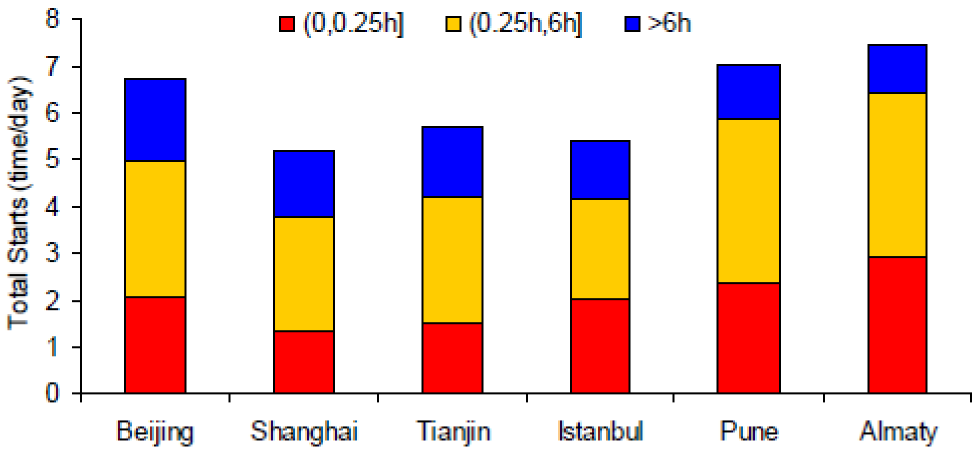

Figure 6 Start times and patterns of passenger cars

less than 15 minutes, greater than 15 minutes but less than 6 hours, and greater than 6 hours. A start that takes place after a 6 hour or greater soak time corresponds to a cold start.

Figure 6 shows the fraction of vehicle starts in each hour and the fraction of different soak times. In contrast to the driving activity and vehicle fleet analysis, the start patterns are relatively similar in the different developing Asian cities. The start patterns indicate that nearly 25% of the daily starts occur in the morning (6:00AM to 9:00AM in Chinese cities or 8:00AM to 11:00AM in other cities). In all the daily starts, approximately 25% are cold starts. As would be expected, the highest fraction of cold starts occurs in the early morning. These long soak times result in much greater start emissions. Start time of passenger vehicles typically ranged from 5.2-6.7 times per day, respectively.

4 CONCLUSIONS AND FUTURE WORK

In order to better understand the vehicle activity trends in developing Asian cities, various data sets were analyzed from recent research programs in Beijing, Shanghai, and Tianjin China, as well as Pune India, Almaty Kazakhstan, and Istanbul Turkey. These research programs were carried out to provide an initial inventory estimate of emissions. As part of the data collection process, specific vehicle activity measures were made.

Based on this analysis, it can be seen that the vehicle fleet mix is quite varied in the different cities. Further, the vehicle activity patterns also vary in different ways. For example, Beijing, Shanghai and Tianjin all have similar hourly variation of driving speed and starts, most likely due to similar working schedules in these cities. However, these cities have speed and acceleration characteristics that are quite different. Interestingly, the vehicle start patterns in the six cities studied were somewhat similar. This detailed information on the variation of the fleet and activity characteristics provide important new information for more accurately understanding current and future emissions from these cities.

Based on these initial research programs, it is clear that much improvement can be made in the air pollution conditions while continuing economic growth. There are still additional data that can be collected to better understand what control measures should be implemented, however these initial studies can serve as an initial first-order characterization. This characterization can be used as a baseline to map out new strategies for improved future air quality, using lessons learned from successful programs in other cities.

ACKNOWLEDGEMENTS

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A HYBRID COLUMN GENERATION AND LOCAL SEARCH ALGORITHM FOR PICKUP AND DELIVERY PROBLEM

Nakorn Indra-Payoong
Assistant Professor
Faculty of Logistics
Burapha University
Chonburi, Thailand
Phone: +66-3-874-5900 Fax: +66-3-839-3231
E-mail: nakorn@buu.ac.th

Agachai Sumalee
Assistant Professor
Department of Civil and Structural Engineering
Faculty of Construction and Land Use
Hong Kong Polytechnic University
Hong Kong
Phone: +852-3400-3963 Fax: +852-2334-6389
E-mail: ceasumal@polyu.edu.hk.

Kriangsak Vanitchakornpong
Faculty of Logistics
Burapha University
Chonburi, Thailand
Phone: +66-3-874-5900 Fax:+66-3-839-3231
E-mail: kriangsv@buu.ac.th

The paper proposes a heuristic algorithm for solving pickup and delivery problems (PDP). The PDP involves an assignment of pickup and delivery jobs to different fleets in optimal sequences to minimize the total logistic costs whilst satisfying several practical constraints (e.g., time-window constraint). An efficient pickup and delivery plan can reduce empty hauls and transportation cost of logistic operators significantly. The PDP in the real world is a large NP-hard problem. The paper handles this by combining column generation (CG) technique with constrained local search method (CLS). The paper applies the proposed algorithm to several well-known benchmark tests. The test results show satisfactory performance of the proposed algorithm in all cases compared to the benchmarks. The paper also applies the proposed algorithm to an actual PDP of a vehicle-carrier company in Thailand. The test result shows potential significant saving of the logistic cost through reductions of empty hauls.

Keywords: Pickup and delivery problem, Column generation method, Constrained local search, Logistics efficiency, Freight scheduling and planning

1 INTRODUCTION

A pickup and delivery problem (PDP) underpins the efficiency and cost of logistics operations. The PDP is an instance of the vehicle routing problem but involves more complex structures and constraints. In the PDP, the customers put requests to logistics operators to pickup and delivery commodities from and to certain locations potentially within certain time windows. There may be several requests involving multiple pickup and delivery points in the network. The main aim of the PDP is to assign these jobs to different vehicles in optimal sequences so as to minimize the total transportation costs whilst satisfying several constraints (e.g., time-window constraint or job sequencing). The problem has drawn a significant attention from researchers in the past few decades (Bent and Hentenryck, 2006).

The PDP is an NP-Hard problem with complex constraints and large problem size. Often an optimal solution may not be found within a limited time. The PDP solution algorithms proposed thus far are based on either exact method, heuristics method, or meta-heuristics method (Desaulniers et al, 2005; Indra-Payoong et al, 2005). Recently, due to the complexity of the practical constraints of the PDP and the need to find a good solution within a limited time different heuristics have been employed either as the main search algorithm or as a part of the hybrid approach (e.g., combined with an exact method or other heuristics).

Nanry and Barnes (2000) proposed the Relative Tabu Search (TS) for solving the PDP. The algorithm was tested with the modified version of the Solomon's benchmark problem. Li and Lim (2003) proposed an approach which combines the TS and Simulated Annealing (SA) methods. Their approach uses the SA to restart the search in a new feasible partition after the TS cannot improve the solution anymore. This helps the algorithm to escape from local optima. Bent and Hentenryck (2006) proposed the hybrid algorithm with two stages in which the SA is used to reduce the number of feasible routes or vehicles in the first stage. Then, in the second stage the large neighbourhood search (LNS) method is applied to minimize the total travelled distances of vehicles. The algorithm was reported to perform well with the test problem with around 600 pickup and delivery points. Ropke and Pisinger (2006) also proposed the adaptive LNS approach.

Xu et al. (2003) tackled the problem size issue of the PDP by using column generation (CG) technique to set up a relaxed master problem (linear program) which then iteratively generates a number of sub-problems. Each sub-problem (also an NP-hard problem) corresponds to each vehicle and includes all complex PDP constraints (e.g., time window constraint). Thus, they proposed two fast heuristics, called MERGE and TWO-PHASE to solve the sub-problems and generate a new column for the relaxed master problem. The algorithm developed in this paper follows the framework of Xu et al. (2003) which integrates the strengths of the CG and heuristics. However, our algorithm utilizes constrained local search (CLS) approach (TetraSoft, 2003) to solve the sub-problem. The main impetus for using the CLS is to increase flexibility of the algorithm in handling complex constraints of the PDP. The framework of the CLS can be easily adjusted to handle new types of such constraints.

The rest of the paper is structured into four sections. The next section formulates the PDP. Then, the third section explains the proposed hybrid solution algorithm which combines the CG and CLS. The proposed algorithm is then tested with different well-known PDP benchmark cases in the fourth section. The algorithm is also applied to a real-world case of a car-carrier company in Thailand. The final section concludes the paper and discusses future research issues.

2 PROBLEM FORMULATION

Consider a directed graph G = (A, N) where A and N are sets of links and nodes respectively. Each link is defined by its start and end nodes, i.e., (i, j) where $i, j \in N$. Each node can be a pickup point, a delivery point, or a vehicle depot. Let $L \subseteq N$, $U \subseteq N$, and $D \subseteq N$ denote the sets of pickup points, delivery points, and vehicle depots respectively. Each link, $(i, j) \in A$, is associated with c_{ijk} and t_{ijk} which are the transportation cost and time for vehicle $k \in V$ (V is the set of vehicles) to traverse from nodes i to j respectively. Each vehicle $k \in V$ has the capacity of Q_k. q_s denotes the amount of commodity with order s = 1,…,S which will be picked up from node $o(s) \in N$ and delivered to node $d(s) \in N$. For each node i, let y_{ik}, a_{ik}, and s_i denote the amount of commodity carried by vehicle k to node i, arrival time of vehicle k to node i, and service time required at node i respectively. The decision variable for the PDP includes the binary variables $x_{ijk} \in \{0,1\}$ in which $x_{ijk} = 1$ if vehicle k traverses through link (i, j), and $x_{ijk} = 0$ otherwise. Also, the decision variable $e_{sk} \in \{0,1\}$ represents the dummy variable in which $e_{sk} = 1$, if the order s is assigned to vehicle k, and $e_{sk} = 0$ otherwise. The PDP can thus be defined mathematically as follows:

$$
\begin{aligned}
&\min_{x_{ijk}, e_{sk}} \sum_{k \in V} \sum_{i \in N} \sum_{j \in N} c_{ijk} x_{ijk} \\
&s.t. \\
&\quad \sum_{j \in N} x_{jik} - \sum_{\tilde{j} \in N} x_{i\tilde{j}k} = 0 && \forall i \in L \cup U; \forall k \in V \\
&\quad \sum_{k \in V} \sum_{j \in N} x_{ijk} = 1 && \forall i \in L \\
&\quad \sum_{j \in N} x_{o(s),j,k} - \sum_{j \in N} x_{j,d(s),k} = 0 && \forall s \in S; \forall k \in V \qquad (1) \\
&\quad \left(y_{jk} - y_{ik} - \sum_{\forall s | o(s)=i} e_{sk} q_s + \sum_{\forall s' | d(s')=i} e_{sk} q_{s'} \right) x_{ijk} = 0 && \forall i, j \in N; \forall k \in V \\
&\quad Q_k - y_{ik} \geq 0 && \forall i \in N; \forall k \in V \\
&\quad \left(a_{jk} - a_{ik} + s_i + t_{ij} \right) x_{ijk} = 0 && \forall i, j \in N; \forall k \in V \\
&\quad l_{o(s)} - a_{o(s)} \geq 0; \tilde{l}_{d(s)} - a_{d(s)} \geq 0 && \forall s \in S \\
&\quad x_{ijk}, e_{sk} \in \{0,1\} && \forall i, j \in N; \forall k \in V; \forall s \in S.
\end{aligned}
$$

The objective function of the PDP is the total transportation cost. The first and fourth constraints are related to the flow conservation of the vehicles and commodities at all nodes. The second constraint ensures the solution to assign each order to only one vehicle. Each vehicle, after pick up the order, is required to deliver the order on the same itinerary which is represented by the third constraint. The fifth constraint imposes the capacity constraint on each vehicle. The sixth constraint defines the relationship between the arrival times of each vehicle to a sequence of nodes on a vehicle's route. The seventh constraint represents the time-window constraints for the arrival times of vehicles to different nodes in which $l_{o(s)}$ and $\tilde{l}_{d(s)}$ denotes the latest times to pick up and deliver job s at nodes $o(s)$ and $d(s)$ respectively. The last constraint defines the decision variables to be binary variables. (1) represents the standard PDP formulation. The structure of the PDP as formulated in (1) involves a large number of decision variables and constraints. To remedy this, the method of column generation (CG) (*3*) will be adopted. To apply the CG, the PDP is reformulated on the basis of vehicle routes.

Let $p \in P_k$ be a feasible service route of vehicle k in which P_k is a set of feasible service routes of vehicle k. Any feasible service route included in P_k should satisfy all practical constraints as defined in (1) Each service route is already associated with a number of job, i.e., the value of e_{spk} is already defined in which if order s is assigned to route p of vehicle k, then e_{spk} = 1, and e_{spk} = 0 otherwise. The sequence of these jobs which will be picked up and delivered by vehicle k is also already determined by the sub-problem which will be described later. From the sequence of the assigned jobs, the arrival time of vehicle k to node i on route p (a_{ipk}), can be calculated. Let $\lambda_{pk} \in \{0,1\}$ denotes a binary decision variable in which $\lambda_{pk} = 1$ if the route p of vehicle k is selected, and $\lambda_{pk} = 0$ otherwise.

The PDP now involves the selection of the best route from the set of P_k for each vehicle such that all jobs are assigned to one and only one vehicle (route), i.e., $\sum_{k \in K} \sum_{p \in P_k} e_{spk} \lambda_{pk} = 1$. Note that under this formulation all other constraints are already satisfied since P_k contains only feasible service routes. Note that at most one route can be selected for each vehicle, i.e., $\sum_{p \in P_k} \lambda_{pk} \leq 1$, in which vehicle k may not be used at all at the optimal solution of the PDP. The time-window constraint is also included as $\sum_{k \in K} \sum_{p \in P_k} a_{ipk} \lambda_{pk} \leq l_i$ where l_i is the required arrival time at node i for pickup or delivery tasks. Thus, the PDP can be reformulated as:

$$\begin{aligned} & \min_{\lambda_{pk}} \sum_{k \in K} \sum_{p \in P_k} \overline{c}_{pk} \lambda_{pk} \\ & s.t. \\ & \sum_{p \in P_k} \lambda_{pk} \leq 1 && \forall k \in K \\ & \sum_{k \in K} \sum_{p \in P_k} e_{spk} \lambda_{pk} = 1 && \forall s \in S \\ & \sum_{k \in K} \sum_{p \in P_k} a_{ipk} \lambda_{pk} \leq l_i && \forall i \in N \\ & \lambda_{pk} \in \{0,1\} && \forall k \in K; \forall p \in P_k. \end{aligned} \tag{1}$$

Note that $\overline{c}_{pk}$ denotes the transportation cost for the service route p of vehicle k in which $\overline{c}_{pk} = \sum_{i \in N} \sum_{j \in N} c_{ij} \delta_{ij,kp}$ where $\delta_{ij,kp} = 1$ if service route p of vehicle k uses link (i, j), and $\delta_{ij,kp} = 0$ otherwise. In (1), each column of the decision variable vector corresponds to a feasible service route of each vehicle. The set P_k can be extremely large and difficult to enumerate at once. Nevertheless, the structure of (1) allows us to iteratively generate a new feasible route (and hence a new column/decision variable) as needed. The next section will present the application of the CG and CLS to solve the PDP as defined in (1).

3 HYBRID SOLUTION ALGORITHM

3.1 General Framework and Column Generation Method

The general framework of the proposed hybrid algorithm is similar to that proposed in Xu et al. (2003) in which the CG is used to solve the relaxed problem (RP) of (1). However, in our proposed algorithm the time-window constraint remains in the RP and the relaxation is only made against the integer requirement of the decision variables in (1). Each feasible service route with an assigned sequence of the jobs is considered as a column in (1) in which a new decision variable associated with this route, λ_{pk}, is created. The CLS is used to solve a sub-problem which is to find a new route that minimizes the reduced cost (defined by the dual variables of the RP). The CLS also takes into account all practical constraints of the PDP. The new route found by the CLS, if its reduced cost is negative, is then included as a new column in the RP. The algorithm then solves the RP again as a linear program (e.g., using CPLEX) to find a new solution and to form a new sub-problem. The proposed hybrid algorithm iterates between the RP and sub-problem until a set of new routes with negative reduced costs can not be found from the sub-problem. The outputs from the RP of (1) may not be integer solutions. Thus, the Branch and Bound (B&B) method will be applied to (1) but formulated with only those columns generated by the CG.

Let RP be the relaxed problem of (1) by excluding the integral requirement:

$$(\text{RP}) \quad \begin{aligned} & \min_{\lambda_{pk}} \sum_{k \in K} \sum_{p \in P_k} \overline{c}_{pk} \lambda_{pk} \\ & s.t. \\ & \sum_{p \in P_k} \lambda_{pk} \leq 1 && \forall k \in K \\ & \sum_{k \in K} \sum_{p \in P_k} e_{spk} \lambda_{pk} = 1 && \forall s \in S \\ & \sum_{k \in K} \sum_{p \in P_k} a_{ipk} \lambda_{pk} \leq l_i && \forall i \in N \\ & 0 \leq \lambda_{pk} \leq 1 && \forall p \in P_k; \forall k \in K. \end{aligned} \tag{3}$$

Let RP' be the restricted version of the RP problem with a subset $P' \equiv \bigcup_{k \in K} P'_k \subseteq \bigcup_{k \in K} P_k \equiv P$ of all possible service paths of all vehicles and P' be the set of the service routes with assigned jobs as generated by the CLS. The RP' can then be formulated as:

$$(\text{RP}') \quad \begin{aligned} & \min_{\lambda_{pk}} \sum_{k \in K} \sum_{p \in P'_k} \overline{c}_{pk} \lambda_{pk} \\ & s.t. \\ & \sum_{p \in P'_k} \lambda_{pk} \leq 1 && \forall k \in K \\ & \sum_{k \in K} \sum_{p \in P'_k} e_{spk} \lambda_{pk} = 1 && \forall s \in S \\ & \sum_{k \in K} \sum_{p \in P'_k} a_{ipk} \lambda_{pk} \leq l_i && \forall i \in N \\ & 0 \leq \lambda_{pk} \leq 1 && \forall p \in P'_k; \forall k \in K. \end{aligned} \tag{4}$$

The general framework of the algorithm can be summarized as follows:

Step 1 Generate a set of service routes (columns) P' which satisfies all constraints in (2) by using CLS, i.e., find the set of services that gives an initial feasible solution to the PDP. Note that in this step the CLS is only used to find a feasible solution with the minimum number of vehicles.

Step 2 With P', formulate RP', as defined in (2), and then apply the Simplex method to solve RP' to obtain λ_{pk} and dual variables.

Step 3 Define the reduced cost for each route based on λ_{pk} and dual variables obtained from Step 2, and then use the CLS to find a set of new service routes (one for each vehicle) to minimize the total reduced costs. Let $\tilde{P}$ be the set of these new service routes found by the CLS.

Step 4 If the reduced costs from $\tilde{P}$ is negative, then let $P' = P' \cup \tilde{P}$, and return to Step 2; otherwise proceed to Step 5.

Step 5 If all λ_{pk} obtained from the Simplex method in Step 2 are binary variables, then terminate the algorithm in which λ_{pk} is the solution of the PDP. Otherwise, apply the B&B approach to the RP' with the integral constraint to get an integer solution of λ_{pk}.

As reported in Xu et al.(2003), λ_{pk} found by the Simplex method are often already binaries. Thus, the B&B approach should not take too much time in solving the problem in Step 5.

The optimal solution from RP' will be the solution of the original RP, if a new set of service routes (columns) with a negative reduced cost can be found. The reduced cost is defined from the optimal dual variables associated with the solution to the RP'. From (2), the reduced cost can be defined as:

$$\hat{c}_{pk} = \overline{c}_{pk} - \sum_{\forall i \in N} \sum_{\forall j \in N} \left(c_{ij} - \pi_i \right) x_{ijk} - \pi_o , \quad (3)$$

where π_i is the optimal dual variable associated with the third constraint in (2) for node *i*; π_o is the dual variables associated with the first constraint in (2) for route *p* of vehicle *k*. To find new columns, one needs to solve (3) for all vehicles simultaneously. This sub-problem is a set-partitioning problem. The CLS will be used to solve this sub-problem which is still a NP-hard problem. In fact, it is also possible to solve the sub-problem separately for each vehicle if (2) only involves constraints defined separately for each vehicle. This may limit the flexibility of the PDP to include more complex constraints involving the whole fleets. In addition, the complexity for the CLS in solving the sub-problem with all vehicles simultaneously is not significantly higher than solving the sub-problem for each vehicle separately. Note that using the CLS alone can also find a feasible solution for PDP, but in the expense of the solution quality. Therefore, we only apply the CLS to construct an initial set of feasible columns and to find the solution of the sub-problem (SP).

3.2 Constrained Local Search Method for Generating New Service Routes

The CLS is a type of meta-heuristic optimization method. The algorithm will start with an initial solution and then iteratively moves to neighbour feasible solutions. Thus, the definition of the neighbourhood solutions must be defined. The CLS will decide on the move to a neighbour solution probabilistically.

The sub-problem of RP' can be considered as a set partitioning problem (SP). The SP involves assigning each job, $s \in S$, to different vehicles, $k \in K$. Fig. 1 illustrates the problem in the structure of a set-partitioning problem. The upper column represents vehicle $k \in K$ (e.g., K1 or K2). Under each upper column, the sub-columns (e.g., columns 1-4 under K1) are associated with the job sequence for that vehicle. The number of sub-columns for each vehicle is defined by the maximum number of jobs that vehicle is allowed to take. Each job, $s \in S$, is associated with two rows (pickup and delivery tasks). For instance, rows 2+ and 2- represent the pickup and delivery tasks for job 2 in this example.

If the job *s* is assigned to vehicle *k* in which the pickup task is defined as the w_k-th job of vehicle *k*, then the value in the sub-column w_k of vehicle *k* and in the row s+ will be set to 1, i.e., $\theta_{s+}^{k,w_k} = 1$. Consequently, the delivery task of job *s* must also be allocated to vehicle *k*, say defined as task w'_k ($w_k < w'_k$), in which $\theta_{s-}^{k,w'_k} = 1$. Otherwise, $\theta_{s+}^{k,w_k} = \theta_{s-}^{k,w'_k} = 0$. Denote o_{s+}^{k} and o_{s-}^{k} as the job numbers of the pickup and delivery of job *s* by vehicle *k* respectively. Denote $\hat{l}_t = l_i - \pi_i l_i$ as the upper bound of the pickup and delivery late times for each customer.

From Fig. 1, there are two jobs with four tasks (pickup and delivery). There are two vehicles, K1 and K2, and each vehicle can accept only four tasks. The cell values in the current example indicate that the job 2 is assigned to vehicle K1 in which the pickup and delivery tasks are its first and third tasks respectively. Similarly, job 1 is assigned to vehicle K2. This matrix representation will be adopted in the CLS to solve the SP.

	K1				K2			
	1	2	3	4	1	2	3	4
1+	0	0	0	0	0	1	0	0
2+	1	0	0	0	0	0	0	0
1-	0	0	0	0	0	0	1	0
2-	0	0	1	0	0	0	0	0

Figure 1 Example of representation of PDP as a set-partition problem

Two types of constraints are defined for the SP following the CLS setting *(3)*: soft and hard constraints. The hard constraints involve all practical constraints of the PDP which are (4)-(7) below where W denotes the maximum number of tasks allowed for each vehicle. Note that any other constraints can also be introduced without changing the search operators of the CLS. This allows for a more flexible formulation of the PDP.

$$h_o = \max\left(0, \sum_{s\in S}\left[\left|\sum_{k\in V}\sum_{w_k=1}^{W}\left(\theta_{s+}^{k,w_k}-1\right)\right|\right]\right), \tag{4}$$

$$h_{c1} = \max\left(0, \sum_{s\in S}\sum_{k\in K}\left[\left|\sum_{w_k=1}^{W}\left(\theta_{s+}^{k,w_k}-\theta_{s-}^{k,w_k}\right)\right|\right]\right), \tag{5}$$

$$h_{c2} = \sum_{s\in S}\sum_{k\in V}\left(\max\left(0, o_{s+}^{k}-o_{s-}^{k}\right)\right), \tag{6}$$

$$h_l = \sum_{k\in K}\sum_{i\in N}\left(\max\left(0, y_{ik}-Q_k\right)\right)\varepsilon_l, \tag{7}$$

$$h_t = \sum_{k\in K}\sum_{i\in N}\left(\max\left(0, a_{ik}-\hat{l}_i\right)\right). \tag{8}$$

(4) requires each order to be assigned to only one vehicle. (5) requires the order to be picked up and delivered during the same trip. (6) and (7) ensure that the orders of pickup and delivery tasks are in the correct sequences, and the vehicle load is less than vehicle capacity. Note that ε_l is an additional weight given to the h_l constraint. (8) imposes the constraint on the pickup and delivery times. Let $H = h_o + h_{c1} + h_{c2} + h_l + h_t$ to be the total violation function of the hard constraints. H is required to be 0 due to the definition of the hard constraint. The soft constraint is associated with the objective function of the sub-problem, i.e,

$$\gamma_v = \max\left(0, \sum_{k\in V} v_k\right), \tag{9}$$

$$\gamma_d = \max\left(0, \sum_{k\in V}\sum_{i\in N}\sum_{j\in N}\hat{c}_{ij}x_{ijk}\right), \tag{10}$$

where γ_v is the total number of vehicles used (v_k = 1 if vehicle k is used and v_k = 0 otherwise). γ_d is the total reduced costs in which $\hat{c}_{ij} = c_{ij} - \pi_i$. Let $\Omega = \gamma_v + \gamma_d$ which represents the total soft constraint level.

The CLS will move from a current solution to its neighbour solutions with the aim to reduce $\Theta = \Omega + H$. The neighbourhood search operators adopted in the CLS are (i) intra-vehicle trial flip and (ii) inter-vehicle trial flip. The CLS will ensure the satisfaction of the hard constraints as defined in (4)-(6) by the specifications of the search operators. The constraint (7) and other additional constraints will be considered by the neighbourhood movement decision. The overall steps of the CLS can be defined as follows:

Overall CLS algorithm

Step 1 Initialize by forming the SP matrix (denoted by A) (see Figure. 1) and then for each job $s \in S$ randomly select a vehicle for the job. Then, randomly select a task sequence, $1 \le w_k < W$, for the pickup task, and then set the row s+ and column w_k to be 1. Similarly, randomly select w'_k , $W \ge w'_k > w_k$, for the delivery task and set the row s- and column w'_k to be 1. After assigning all jobs, evaluate $\Theta = \Omega + H$ for the solution A.

Step 2 Set u = 1.

Step 3 Perform the intra-vehicle trial flip to define a set of neighbourhood solutions.

Step 4 If all neighbourhood solutions of A as found by the intra-vehicle trial flip cannot improve $\Theta = \Omega + H$, then perform the inter-vehicle trial flip.

Step 5 Set u = u +1; if u > *maxIter* then terminate; otherwise return to Step 3.

Note that the *maxIter* parameter is predefined by the user. The details of the intra-vehicle trial flip and inter-vehicle trial flip are as follows:

Intra-vehicle Trial Flip

There are two stages in the intra-vehicle trial flip operation: the exchange of the job sequences and the insertion of the jobs into empty job sequences. The pseudo code for the exchange phase of the intra-vehicle trial flip is as follows:

Intra-vehicle trial flip: exchange phase

Step 1 Randomly select a vehicle $k \in K$ and a column $1 \le w_k \le W$ with an assigned task (either pickup or delivery). Let r_1 be the row with value of 1 of the randomly selected column. Set $e = 0$.

Step 2 Set $e = e + 1$. Randomly select another column, w'_k , with an assigned task (either pickup or delivery). Let r_2 be the row of column w'_k with the value of 1.

Step 3 Exchange the values in the rows r_1 of columns w_k and w'_k. Similarly exchange the values in the rows r_2 of columns w_k and w'_k. Define the new solution as $A'(e)$. Evaluate $\Theta'(e)$ and h_{c2}. If $h_{c2} \neq 0$, return to Step 3. Otherwise, go to Step 4.

Step 4 If $e > maxSampling$, go to Step 5. Otherwise return to Step 2.

Step 5 Let $\Theta' \ \min\left(\Theta'(e) : e = 1,\ldots,\text{maxSampling}\right)$.
If $\Theta < \Theta'$, then set $A = A'(e)$ and call the insertion phase. Otherwise, call inter-vehicle trial flip.

Note that the parameter *maxSampling* is predefined by the users and represents the number of neighbourhoods explored by each step of the CLS.

The exchange phase involves a random selection of a vehicle (normally those with constraint violation) and a column of that vehicle with an assigned task. This is illustrated in Figure 2a in which column 3 of vehicle K1 is randomly selected. Then, row 2+ is identified as the row with 1. In Step 2, the operation then randomly selects the second column which is assumed to be column 1 in this example in which row 3+ is identified. The values in these two rows of columns 3 and 1 are then exchanged as shown in Fig. 2b. For this example the new solution (in Fig. 2b) violates the constraint on the sequence of the tasks, i.e., the pickup task of job 3 is after the delivery task of the same job. Thus, this neighbour solution will not be considered. A new column will then be randomly selected instead (assume to be column 2 in this example). The exchange of the values can then be carried out as shown in Fig. 2c. For this solution, the sequence of the tasks is feasible. Thus, the algorithm will evaluate the $\Theta'(e)$ of this solution.

The algorithm will carry out the same operation for a number of times as defined by the users (i.e., *maxSampling* parameter). Then, the solution with the lowest $\Theta'(e)$ among all feasible neighbourhood solutions will be selected (as define in Step 5). If $\Theta'(e)$ is less than the value of the original solution, then the search will move to this new solution and perform the insertion phase. Otherwise, the search will remain at the original solution and perform the inter-vehicle flip instead.

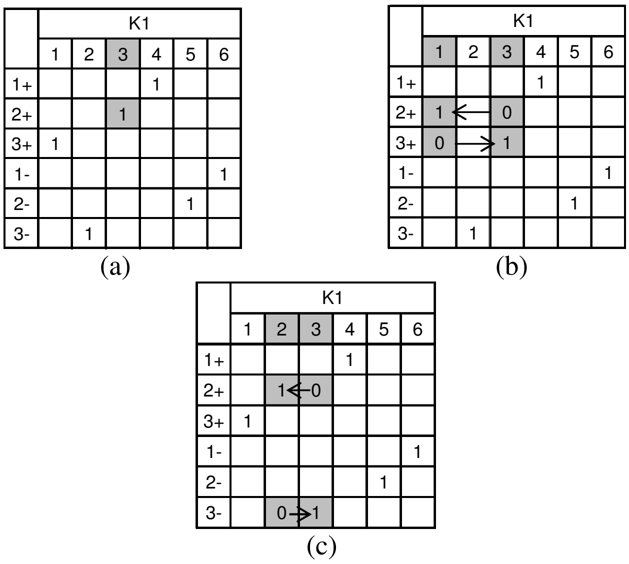

Figure 2 Intra-vehicle trial flip operation: exchange phase.

The insertion phase is described as follows:

Intra-vehicle trial flip: insertion phase

Step 1 Randomly select a vehicle $k \in K$ and a column $1 \le w_k \le W$ of that vehicle with a pickup task. Let r_1 be the row with the cell value of 1 under the randomly selected column. Let s be the pickup task associated with column w_k. Set r_2 to be s- and w'_k to be the column of the cell in row r_2 with the cell value of 1. Set $e = 0$.

Step 2 Identify all columns in which all cells under those columns have value of 0 (i.e., no task assigned to these vehicle sequences). Let Δ be the set of these column numbers in the ascending order in which $\Delta(b)$ refers to the column number in the order b in the set Δ.

Step 3 Change the value of column w_k and row r_1 to 0 and the value of column $\Delta(1)$ and row r_1 to 1. Then, exclude $\Delta(1)$ from Δ and include column w_k to Δ. Let $|\Delta|$ denote the size of this set.

Step 4 Set $e = e + 1$.

Step 5 Change the value of column $\Delta(e)$ and row r_2 to 1 and the value in the cell under column w'_k and on row r_2 to 0. Define this solution as $A'(e)$ and evaluate $\Theta'(e)$.

Step 6 If $e = |\Delta|$ then go to Step 7. Otherwise, return to Step 4.

Step 7 Compare the values of $\Theta'(e)$ for all e = 1,…, $|\Delta|$ and define e' as the solution with the lowest $\Theta'(e)$. Set A = $A'(e')$.

Figure 3 illustrates the insertion phase of the intra-vehicle flip operation. From this example, let suppose that column 4 of vehicle K1 is randomly selected (see Fig. 3a) in Step 1. Then, as defined in Step 1, row 2+ can be identified, and also column 6 and row 2- can be identified (as the corresponding delivery task of job 2). Then, the list of columns without any tasked assigned to can be identified as {1, 2, 5, 8} in Step 2. The values in columns 4 and 1 on row 2+ are then exchanged as shown in Fig. 3b. Then, $\Delta = \{2,4,5,8\}$. With this set, there are only four possible moves. Fig. 3b, 3c, and 3d show three examples of the exchanges (out of four possible moves) of the delivery task of job *w* from under its original column 6 to columns 2, 4, and 8 respectively.

Inter-vehicle Trial Flip

The inter-vehicle trial flip will be called if the exchange phase of the intra-vehicle trial flip cannot find a solution with lower Θ'. With a selected vehicle and column from the intra-vehicle trial flip (from the exchange phase), the inter-vehicle flip will randomly select other vehicles. Then, the insertion phase will be carried out but with the columns of other vehicles. With a randomly selected vehicle, the set Δ will be created and then Steps 3-7 of the insertion phase will be carried out. The CLS will move to a new solution whether $\Theta' < \Theta$ or not. This will help the CLS to avoid local optima.

4 EXPERIMENT WITH BENCHMARK PROBLEMS AND REAL-WORLD CASE

4.1 Benchmark Tests Results

The proposed hybrid algorithm is applied to the benchmark tests as defined in (*5*). The benchmarks are categorized into two types, LR (100 randomly distributed pickup/delivery points) and LRC (100 randomly combined cluster pickup/delivery points), shown in Table 1a. See the detail definitions of these two problem classes in (*5*). In addition, the LRC typed-problem with 200 pickup/delivery points as tested in Ropke and Pisinger (2006) are also considered (see Table 1b). The algorithm is implemented in JAVA language. The tests are carried out with Pentium IV (2.8 GHz) computer under Windows OS. ε_l in (7) and *maxIter* are set to be 10 and 20,000 respectively.

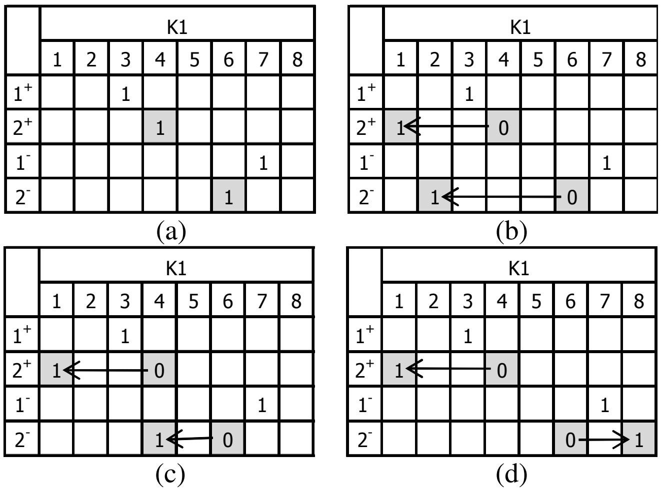

Figure 3 Examples of in-vehicle trial flip operation: insertion phase

Table 1 a) Test Results against 100 Points PDP Benchmarks

Problem	Best known			Full				
	veh	dist	ref.	avg. dist	avg. veh	best dist	best veh	avg. time (s)
LR101	19	1650.8	Li & Lim	1650.8	19	1650.8	19	127
LR102	17	1487.57	Li & Lim	1529.11	17	1515.88	17	103
LR103	13	1292.68	Li & Lim	1349.39	13	1317.45	13	114
LR104	9	1013.39	Li & Lim	1061.54	9	1016.93	9	132
LR105	14	1377.11	Li & Lim	1406.32	14	1386.27	14	98
LR106	12	1252.62	Li & Lim	1257.82	12	1256.66	12	146
LR107	10	1111.31	Li & Lim	1111.31	10	1111.31	10	145
LR108	9	968.97	Li & Lim	968.97	9	968.97	9	123
LR109	11	1208.96	SAM	1228.58	11	1208.96	11	134
LR110	10	1159.35	Li & Lim	1191.02	10	1159.35	10	166
LR111	10	1108.9	Li & Lim	1108.9	10	1108.9	10	183
LR112	9	1003.77	Li & Lim	1005.43	9	1003.77	9	177
LRC101	14	1708.8	Li & Lim	1717.61	14	1708.8	14	131
LRC102	12	1558.07	SAM	1570.12	12	1558.07	12	146
LRC103	11	1258.74	Li & Lim	1272.33	11	1258.74	11	130
LRC104	10	1128.4	Li & Lim	1138.96	10	1128.4	10	125
LRC105	13	1637.62	Li & Lim	1644.05	13	1637.62	13	147
LRC106	11	1424.73	SAM	1424.73	11	1424.73	11	134
LRC107	11	1230.15	Li & Lim	1231.18	11	1230.15	11	124
LRC108	10	1147.43	SAM	1155.58	10	1147.43	10	112

Table 2 b) Test Results against 200 Points PDP Benchmarks

Problem	Best known			Full				
	veh	dist	ref.	avg. dist	avg. veh	best dist	best veh	avg. time (s)
LR1_2_1	20	4819.12	Li & Lim	5324.58	20	4948.79	20	1397
LR1_2_2	17	4621.21	RP	4749.88	18	4614.82	18	594
LR1_2_3	15	3612.64	TS	3912.3	15	3870.36	15	1111
LR1_2_4	10	3037.38	RP	3400.55	11	3111.16	11	852
LR1_2_5	16	4760.18	BVH	4721.72	17	4392.35	17	626
LR1_2_6	14	4175.16	BVH	4329.93	15	4218.42	15	699
LR1_2_7	12	3550.61	RP	3715.76	13	3468.55	13	1039
LR1_2_8	9	2784.53	RP	3005.28	9.63	2915.95	9	2235
LR1_2_9	14	4354.66	RP	4650.48	14.57	4404.79	14	1540
LR1_2_10	11	3714.16	RP	3792.87	12	3602.41	12	1324
LRC1_2_1	19	3606.06	SAM	3639.96	19	3625.46	19	1265
LRC1_2_2	15	3673.19	BVH	3958.43	16	3719.88	16	1407
LRC1_2_3	13	3161.75	BVH	3291.08	14	3371.52	14	1584
LRC1_2_4	10	2631.82	RP	2913.63	11	2713.94	11	2323
LRC1_2_5	16	3715.81	BVH	4043.92	17	4015.44	17	1425
LRC1_2_6	17	3368.66	SAM	3463.06	17	3441.72	17	1338
LRC1_2_7	14	3668.39	RP	3677.115	17	3580.77	15	1659
LRC1_2_8	13	3174.55	RP	3316.6	14	3228.94	14	1506
LRC1_2_9	13	3226.72	RP	3433.04	14	3307.79	14	1131
LRC1_2_10	12	2951.29	RP	3258.5	12.83	3409.05	12	744

BVH (Bent and Hentenryck, 2006)*; Li & Lim* (Li and Lam, 2003)*; SAM and TS* (TetraSoft, 2003)*; RP* (Ropke and Pisinger, 2006)

Table 1 presents the best known results from the literature in terms of the number of optimal vehicles used (column 2) and total transportation distant (column 3) for all benchmark tests. Due to the heuristic nature of the proposed algorithm, the algorithm is applied to each benchmark case 20 times separately to collect the statistics of the results, e.g., best found and average. Table 1 reports the results found by the proposed hybrid algorithm (average values over 20 runs and the best found) for all benchmark tests; in which the results in columns 5-9 show the average travel distance, average number of vehicles used, best found total distant, best found number of vehicles used, and average processing time used in seconds in that order. From Table 1, the algorithm proposed performs satisfactorily against all benchmark tests as compared to the best found solutions reported in the literature. In particular for the tests with 100 jobs (Table 1a), the numbers of vehicles used found by our proposed algorithm are the same as the best results reported in the literature for all benchmark tests. In some cases (i.e., LR109, LRC102, LRC106, and LRC108), the algorithm can even find better solutions compared to those reported in (*5*). However, for the tests with 200 orders (Table 1b), the solutions found by the proposed algorithm are slightly worse than the best results reported in the literature. This illustrates the trade-off between the performance of the algorithm and its flexibility. The proposed algorithm is very flexible for including additional constraints. On the other hand, most algorithms with the best known results are problem specific to some extent in which some specific heuristics are designed and used in the algorithms. Thus, with these specific heuristics other PDP constraints cannot be introduced without modifying the algorithms. This issue will be illustrated in the next section when a constraint on the arrival times of vehicles back to depots is introduced.

4.2 A Real World PDP Case Study of a Vehicle-Carrier Company

The real world case study considered in this paper is related to a vehicle-carrier company in Thailand. The company offers services to transport cars in different areas in Thailand. The main origins of its customers are car factories and second-hand car depots. Similarly the main destinations of the jobs are official car dealers and second-hand car dealers around Thailand. The car PDP problem in this case involves an additional constraint on the arrival times of the trailers back to the company depot (due to security and safety reasons). This constraint can be defined as:

$$h_t = \max\left(0, \sum_{k \in V} \sum_{i \in D} \left(a_{ik} - l_i\right)\right) \cdot \alpha \qquad (11)$$

where *D* defines the set of company depots and α is the multiplier similar to *ε*. This is similar to the time-window constraint for the jobs or working-hour constraint for drivers. The proposed algorithm, in particular the CLS, can solve the PDP with this new constraint straightaway without any modification to its search operators or solution algorithm. In the test, α is set to be 10 and h_t is included in the hard constraint violation function of the CLS. Table 2 shows five datasets for the tests with different numbers of depots, types and numbers (#) of trailers, and numbers of jobs. The datasets 1-3 are typical problems encountered in the day to day by operation of the company. The datasets 4 and 5 are occasional cases with relatively large numbers of jobs. These occasional cases normally occur when several car manufacturers release new models during the same period.

Table 2 Datasets for the Real-World Problem

Data Set	Depot	Trailers		Orders	PD Points
		#	Types		
1	1	13	2	100	42
2	2	15	2	150	52
3	2	17	3	200	70
4	3	18	3	250	86
5	3	22	3	300	110

Table 3 Test Results with the Real-World Problem

Data Set	Laden KM			Empty KM			CPU (s)
	Manual	DSS	Diff (%)	Manual	DSS	Diff (%)	
1	7,232	6,445	10.87	7,010	6,108	12.86	18
2	12,756	11,576	9.25	13,516	12,100	10.47	23
3	29,975	26,548	11.43	20,350	17,553	13.74	46
4	37,550	32,453	13.57	34,811	30,090	13.56	63
5	39,953	34,259	14.25	38,055	32,182	15.43	112

In the Table 3, columns DSS and Manual show the results obtained by the proposed algorithm and current plans of the company (generated manually) respectively. The columns Laden KM and Empty KM show the total vehicle-kilometres covered by the loaded and empty vehicles respectively. From Table 3, the algorithm can potentially help reducing the vehicle-kilometres covered by both the loaded and empty vehicles at least 9.25% and 10.47% respectively for all test cases. This can potentially result in a substantial saving in terms of the company logistics costs. The computational times in all cases are also acceptable in which the runtime for the largest problem (Data Set 5) is only around 2 minutes. This illustrates the practicality of the proposed algorithm in handling a large scale realistic PDP.

5 CONCLUSION AND DISCUSSION

The paper proposed a hybrid method combining the column generation technique (CG) and constrained local search (CLS) algorithm for tackling the Pickup and Delivery problem (PDP). The algorithm developed is non-domain specific which allows any additional practical constraints to be flexibly considered in the PDP. The hybrid CG and CLS also enhances the stability and robustness of the algorithm in which the CG helps reducing the problem size (which is typically very large for the realistic PDP) and the CLS provides the robustness in handling complex constraints of the PDP. The algorithm proposed was tested against the well-known benchmark cases. The proposed algorithm performed satisfactorily in all tests compared to the best-known results. The algorithm was also applied to the real-world PDP based on the problem of a car-carrier company in Thailand. Five different scenarios of job requests were chosen for the tests. In all scenarios, the plans found by the proposed algorithm can significantly decrease the total distances of the loaded and empty vehicles operated by the company compared to the current manual plans (at least around 9%-14% and 10%-15% respectively). Future research will extend the algorithm to take into account uncertainties of travel times and dwell times of vehicles in the PDP.

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EVALUATION OF RAIL TRANSIT NETWORK IN BANGKOK

- Mobility, Accessibility and Polycentrism Perspectives –

Varameth Vichiensan
Assistant Professor
Department of Civil Engineering
Faculty of Engineering
Kasetsart University,Bangkok, Thailand
Phone: +66-2-942-8555, Fax: +66-2-579-4575
E-mail: fengvmv@ku.ac.th

This paper presents the scenario analysis of rail transit network in Bangkok from the perspectives of mobility and accessibility. It firstly identifies the present mobility and accessibility level as well as the travel-to-work trip pattern. Mobility is expressed in terms of travel time from different places in Bangkok to city center and presented in a so-called travel hazard map. Accessibility is presented as employment opportunity from certain locations and calculated by gravity expression for simplicity. It is found that employment accessibility on private transport is far larger than that of public transport. As a result, the mobility and employment accessibility reflects the location-associated travel-to-work trip pattern, as observed by location-specific travel preference curve. It indicates that some areas have potential to form sub-centers where its workforces are captured largely from the nearby areas. The paper also presents scenario analysis where different railway network scenarios are evaluated. It is found that the mobility and accessibility are totally improved as the rail transit network is extended. Moreover, certain areas are greatly benefited, i.e., the planned sub-urban sub-centers. The location-specific travel preference curves have shown, however, that the improved railway network has negative impact some sub-centers where development potential and attractiveness may be reduced.

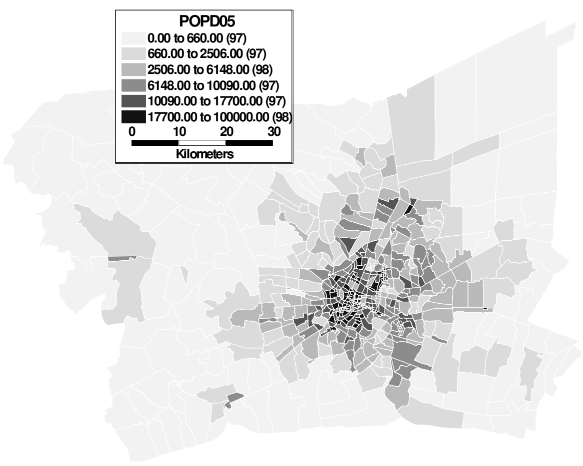
Keywords: Mobility, Accessibility, Travel Preference, Employment Center

1 INTRODUCTION

Most of the developing countries and its cities are now facing such urban problems as severe traffic congestion, traffic safety, air pollution, social inequity and etc. Solutions seem to be policies aiming at improving accessibility, use of the space, increase the environment-friendly modes' share (public transport, cycling, walking), reduce congestion, improve safety, and reduce air pollution, noise, and visual nuisance. Meanwhile, they must develop and maintain a wealthy and healthy urban economy, and ensure social equity and transport opportunities for all community sectors. In Bangkok, Thailand, several transport-related projects have been planned and implemented in the past decade; these include urban road network, urban expressway, public bus improvement, or the recently completed urban rail transit. However, none has been proved to be the most effective in alleviating the aforementioned problems, especially the traffic congestion problem, which causes not only economic loss but also degradation of the environment and quality of life of people. Therefore, it is important to evaluate to what extent a certain transport policy is effective and appropriate in tackling the problems. The evaluation must be comprehensive and provide relevant information to the decision makers. This study presents an evaluation framework that focuses not only transport but also land-use related issues. From transport viewpoint, mobility is evaluated; from land use viewpoint, accessibility is evaluated.

The objective of this study is to evaluate the recent rail transit network in Bangkok, Thailand, based on mobility and accessibility. The study covers an area of 7,758 square-kilometers of Bangkok Metropolitan and its five surrounding provinces, namely Nonthaburi, Pathumthani, Samut Prakarn, Samut Sakorn, and Nakorn Pathom so called Bangkok Metropolitan Region (BMR), Thailand. Since 1960, BMR has undergone rapid urbanization and industrialization. Population growth has been dramatically rapid due to the extensive investment in road network together with the boom of real estate business. However, from 1987 to 2000, population of the inner area has declined, but the outer area has continuously increased. The inner area population density decreased from 15.27 to 11.09 thousand/sq.km. (3.25 to 2.36 million people) while the outer increased from 0.77 to 1.28 thousand/sq.km. (0.67 to 1.12 million people). The total population in BMR in 2005 accounts for 16.8% of the country population and produces 44.2% of the country's GDP. This means that BMR is the major economic center of the country, where every economic activity are centered in the high-density business districts, high-density residential areas, heavy industrial estates, etc. Travels in Bangkok are mostly based on road transport; largely on private vehicles. The private transport share in 2005 is approximately 53%; while the public mode is just 44%; less than half. The reason is that private transport has been far superior to public transport, which is provided mostly by crowded public buses. From recently, the urban rail transit has been introduced. The 23-kilometer elevated urban rail transit named BTS has started operation in 1999. Two lines of service are available and having over 400,000 daily passengers. Five years later, a 20-kilometer urban subway line (so-called called MRT) operated by Mass Rapid Transit Authority has started in 2004. Connecting BTS and MRT, there are three transfer stations. In addition to the urban rail transit, there are also sub-urban railway lines operated by the State Railway of Thailand (SRT).

The data used in this study is the official transportation planning data and obtained from the Office of Transportation Policy, (Office of the Commission for the Management of Land Traffic 2000). Total population in 2005 is 10,661,047 and the total employment is 5,962,497. The distribution of population and employment are shown in Figure 1a and b respectively. It is obvious that population and employment are mostly concentrated in the inner core; only some portions are scattered to the northern and eastern parts. This study has employed the official transport model of Bangkok, which is based upon CUBE proprietary software (Office of the Commission for the Management of Road Traffic 1997); in which the multi-modal transport consists of road network, bus lines, ferry lines, urban railways, sub-urban railways. Specifically, the model is used to calculate the inter-zonal travel time in the subsequent analysis.



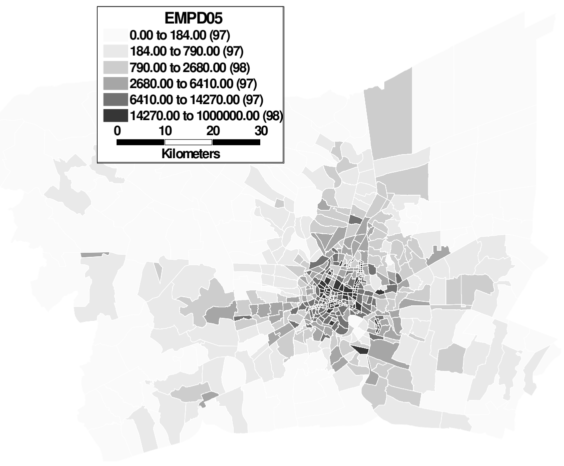


Figure 1 Population and Employment Distributions

2 PRESENT STATUS

2.1 Mobility

Traditional measures of the performance of transportation system assess mobility. The mobility indicators include travel time, level of service, travel speed, average speed, peak-hour speed, delay, transfer time at intermodal transfer terminals, hours of delay, etc. Data on travel time and congestion-related measures are typically estimated with existing analytical or simulation models, while mode shares and levels of service (inter-modal connecting times) can be ascertained using surveys of individual facility users. This study expresses mobility as the travel time from different places to a city center. In this paper, the travel time from every zones to Silom, a financial district, is calculated and plotted on a map that is so-called *Travel Hazard Map*, as shown in Figure 2a and b for private and public transport travel times respectively. It is obvious that travelling to the CBD from the outer residential area such as Don Muang, Nonthaburi, Phutthamonthon, or Bang-Na (the second darkest shaded areas in Figure 2a), could take two hours on private mode; but would possibly take longer than two hours on public transport (comparing the same area in Figure 2a and b). Recalling that residential places are sprawling out (previously shown in Figure 1a) but employment are concentrating at the center (Figure 1b). Those people living in the outer areas have poor mobility on public transport comparing with private transport, so they will never choose to take public transport but prefer to drive into the center. This has generated large travel demand on private mode and causes severe traffic congestion, particularly during rush hours.

Figure 2 Mobility in 2005: a) Private, b) Public

2.2 Accessibility

As well accepted, an important function of transportation is to provide for people accessibility to residences; places for employment, recreation, shopping, and so on. Performance measure for accessibility usually reflects the ease that passengers reach their destinations and the opportunity or attractiveness of the destination. The accessibility indicators include the ease of access to the transportation system, the ease of connecting at transfer facilities, the percentage of the population located within a certain distance or travel time from a specific transportation facility. In the other word, it measures the opportunity to complete certain activity at other locations at a distance away. Regions with well-developed transportation networks generally have high degrees of accessibility. A typical accessibility measure has two components. One is related to the destinations and is commonly called the attractions portion of the measure. For example, attractions measures for shopping may be number of employees, amount of sales, or square meter of space. The second component describes the ease of reaching those attractions. Since difficulty increases over distance, this component is commonly called the impedance factor. Typical impedance factors include distance to the attraction, the amount of time it takes to reach the attraction, or cost of traveling to the attraction. Expression of accessibility measures vary from simply minimum-travel-time indices, cumulative opportunities within specified time thresholds (Srour et al. 2002), to more complicated measures of various forms (Kim and Kwan 2003).

This study considers the employment accessibility because large amount of travel in Bangkok in peak hours is related to work or employment. In this study, an exponential expression of Hansen type of accessibility is used, i.e., $A_i = \sum_j Emp_j \exp(\alpha t_{ij})$ where A_i is employment accessibility of zone i, E_j is the number of employment or workforce available in the other zones j, t_{ij} is the inter-zonal travel times either on private and public transport, and α is a parameter. This study arbitrarily used the value of -0.001 for α, which is a value that makes the resulting accessibility vary pronouncedly for different scenario. This allows relative evaluation of the railway network scenario. However, absolute evaluation of the accessibility requires more rigorous calibration of α, which is beyond the scope of the present study.

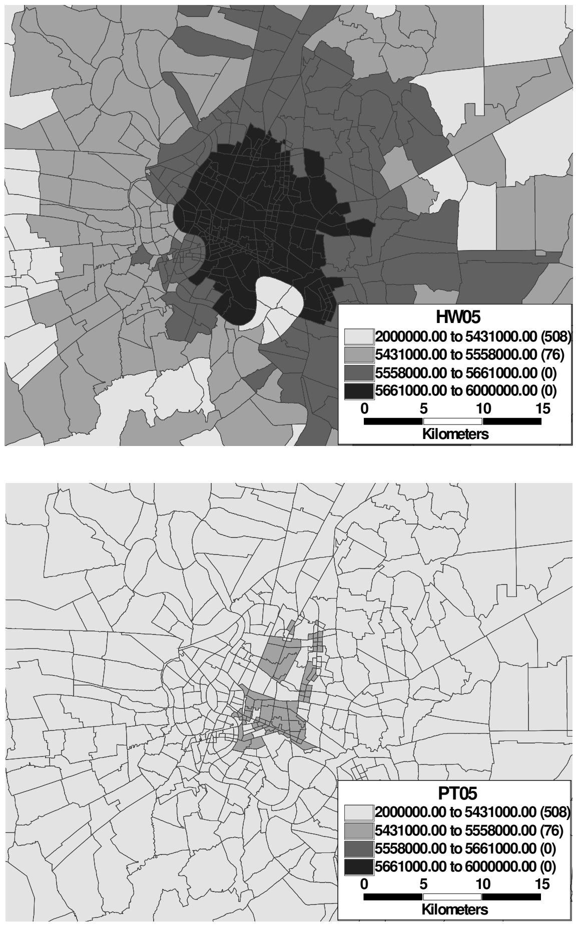


Figure 3 Job Accessibility in 2005: a) Private, b) Public

The employment accessibility on private and public transport are shown in Figure 3a and b respectively. With the same scale, it is obvious that employment accessibility on private transport is far larger than on public transport. This implies that public transport service is significantly inadequate, considering that people are living around the city and most of them are commuting to work in the city center. Again, the large numbers of people living outside with low job accessibility on public transport would have no choice other than using private modes of transport for their commuting trips. Noticeably, the areas along rail transit corridor, (dark areas in Figure 3b) have large employment accessibility and gain rapid increase in land value. This implies that transport has large influence on land value; transport development has largely influenced land development potential in those areas.

2.3 Polycentrism

It may be accepted that Bangkok is a rather mono-centric city where most of activities are concentrated in the large city core, it is continuously expanding and at the same time sprawling. However, some activities have relocated and agglomerated at some nodes. If these nodes are large enough and self-contained, they will be considered as sub-centers. This paper examines the residential location preferences of some employment nodes, represented by a so-called location-specific travel preference curve, which is based on the intervening opportunity model (Black et al. 1993; Vichiensan 2007). For an employment zone, the residential zones are ranked by the increasing distance or the increasing travel time either on private or public transport. The number of residential workers living in each zone is a proxy for housing opportunities. By plotting the cumulative distribution of residential workers reached, a “housing” opportunity surface around that employment zone can be visualized. The horizontal axis is the travel time to each employment zone; the vertical axis is the accumulated proportion of workforce within the corresponding travel time boundary. In the other word, the graph presents the capability that an employment area is able to capture its workforce from the surrounding residential places. In this paper, the location-specific travel preference curves at four employment nodes in Bangkok, namely, Wong Wian Yai, Chatu Chak, Hua Mak, and Asoke, are shown in Figure 4. Notice that a steep gradient implies a nearby choice of residential location; a shallow gradient around a sub-center implies a broader or metropolitan-wide spatial labor market.

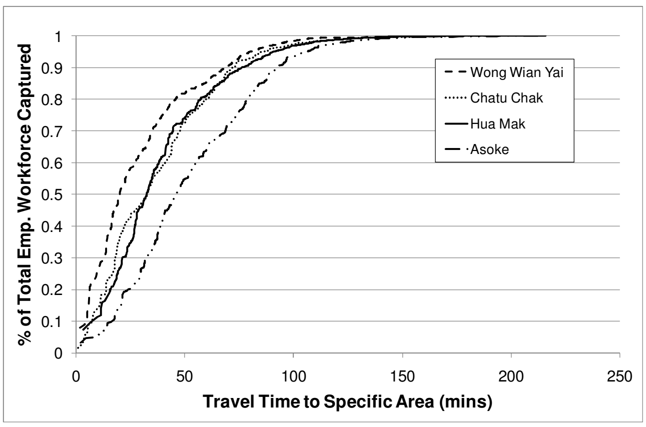


Figure 4 Location-Specific Travel Preference Curve

It is obvious that Asoke exhibits different shape than the other. This means that workers in Asoke, one of the busiest business districts, are coming from or living in various parts of Bangkok, as shown by relatively flat curve. On the contrary, workers of the outer nodes such as Chatu Chak or Hua Mak are coming to work for shorter distance, as shown by relatively steep curves. For instance, approximately 50 percent of workers in Asoke are coming from the area within 50 minutes travel time to Asoke; while almost 80 percent of workers in Wong Wian Yai are coming from the area within 50 minutes travel time. This implies that Wong Wian Yai has large potential to form an employment sub-center.

3 SCENARIO EVALUATION

Based on viewpoint of mobility, accessibility, and location preference, three railway network scenarios are evaluated. Firstly, the based network (called reference scenario), comprises of the existing 42-kilometer railway shown in Figure 5a. Secondly, the extended network comprises of the high priority lines (called priority scenario), shown in Figure 5b. Thirdly, the 291-kilometer railway network in the master plan is considered (called full scenario), as shown in Figure 5c. The base year is 2005; the future years are 2010 and 2025. The scenarios are summarized in Table 1.

Table 1 Scenario Summary

	2005	2010	2025
A - Reference	Base	10A	25A
B - Priority		10B	25B
C - Full		10C	25C

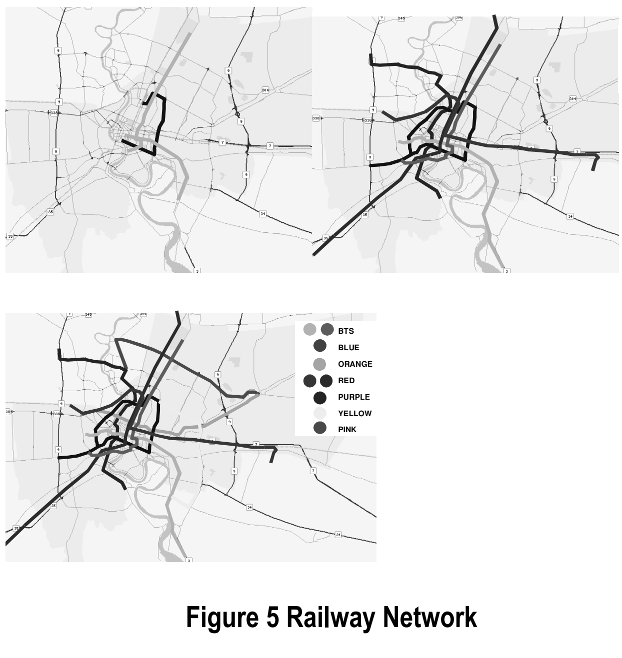


Figure 5 Railway Network

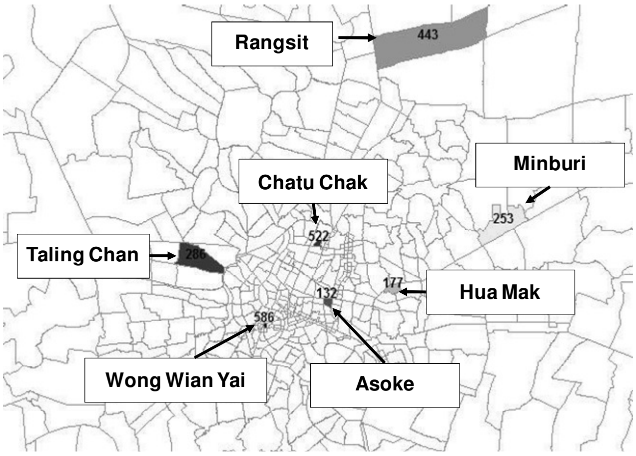


Figure 6 Six Selected Employment Areas

Based on the framework presented in the previous section, the travel hazard map and accessibility map are constructed in each scenario to examine its overall performance. Six specific areas are selected, as shown in Figure 6. The first three, Chatu Chak, Asoke, and Hua Mak, are the high-density areas with large employment opportunity. The next two, Taling Chan and Wong Wian Yai, are expected to be transit centers where railway lines cross. And the last two, Rangsit and Minburi, are sub-urban areas where they are expected to be self-contained.

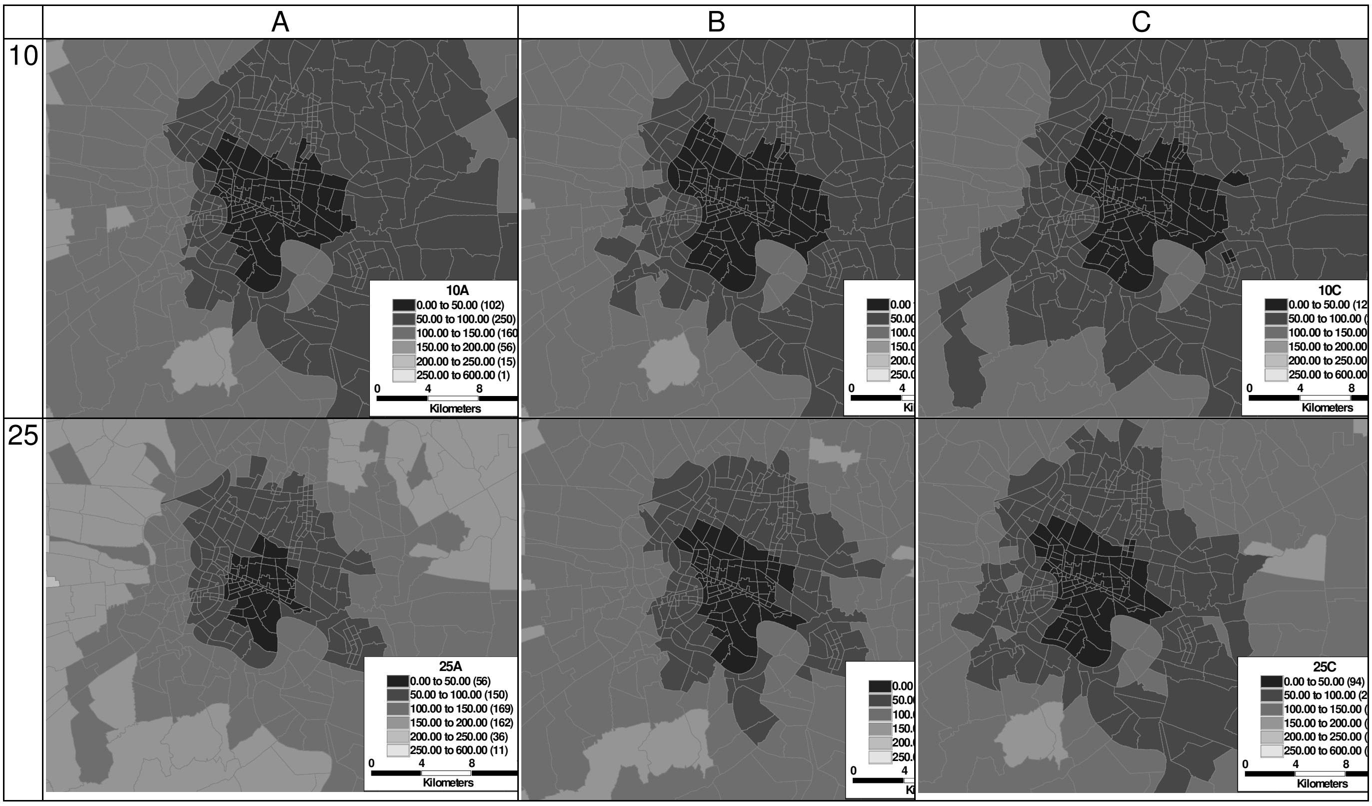


Figure 7 Impact on Mobility

3.1 Change of Mobility

The future-year travel hazard maps, representing mobility on private mode (mainly on road network) are shown in

Figure 7. It illustrates to what extent railway would help to ease the travel or relieve traffic congestion. It is obvious that the full network (Scenario C) has significantly changed the mobility and accessibility, comparing to the case with only the three lines of BTS & MRT (Case A). Unless the network is improved, the city will be severely congested, i.e., it will possibly take very long time to travel into the city center.

Further examining the six selected areas found that the extended network has improved the future mobility level in 2025 differently, as summarized in Figure 8. Those areas that presently have railway service such as Chatu Chak and Asoke will not get much additional benefit. But those potential sub-centers, i.e., Wong Wian Yai, Rangsit, Talingchan, and Hua Mak, will greatly gain benefit from the new railway lines in Scenario B. Likewise the expected sub-urban sub-center, i.e., Minburi, gain much mobility benefit from the completed railway network in Scenario C.

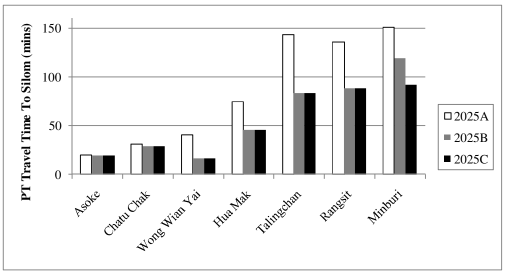


Figure 8 Mobility at Certain Nodes

3.2 Change of Accessibility

Maps of the future employment accessibility based on public transport travel time under different railway network scenario are shown in

Figure 9. It is again obvious that both Scenario B and C, with extended railway lines, provide more job opportunity compared to the reference network in Scenario A.

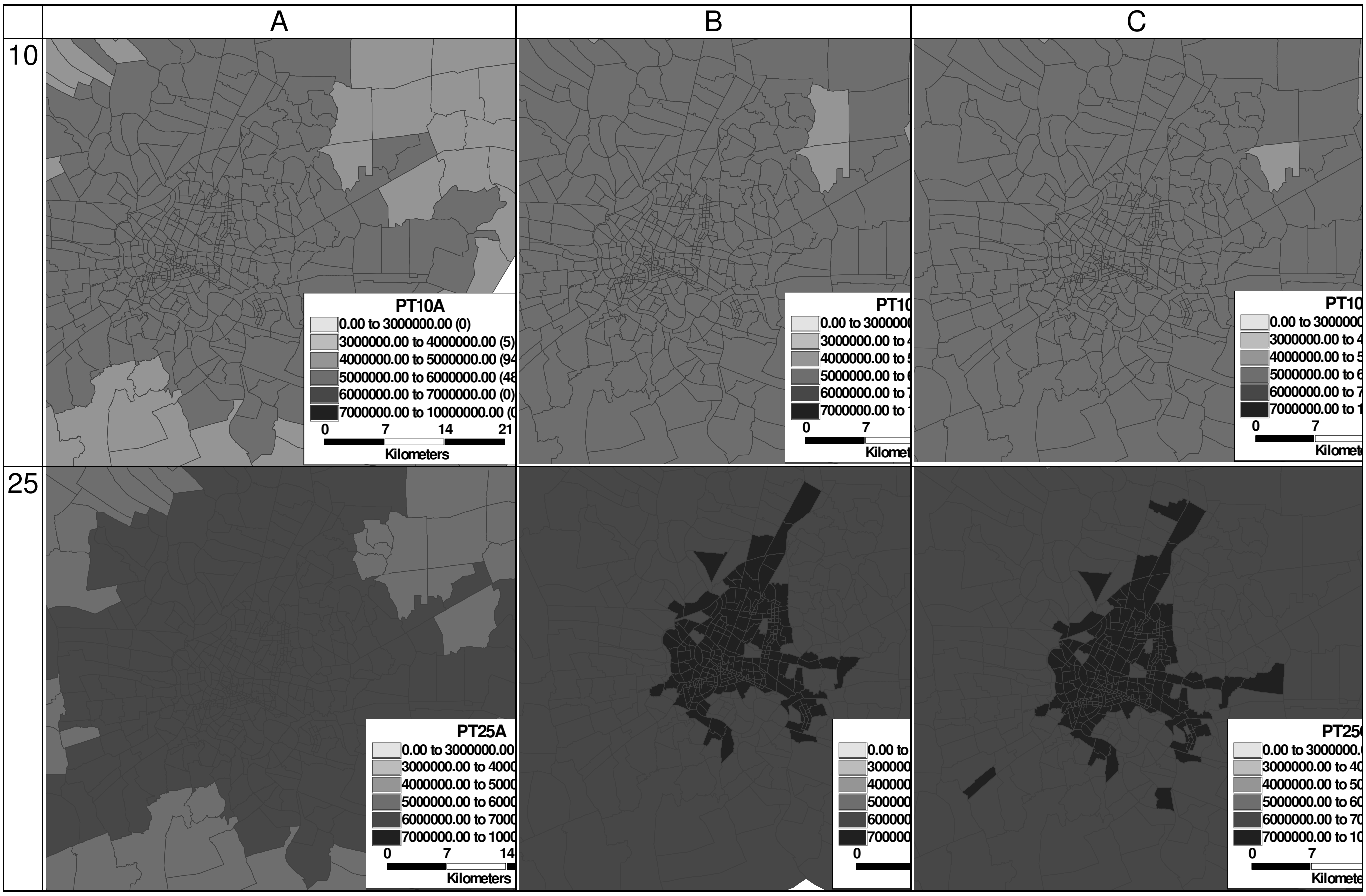


Figure 9 Impact on Accessibility

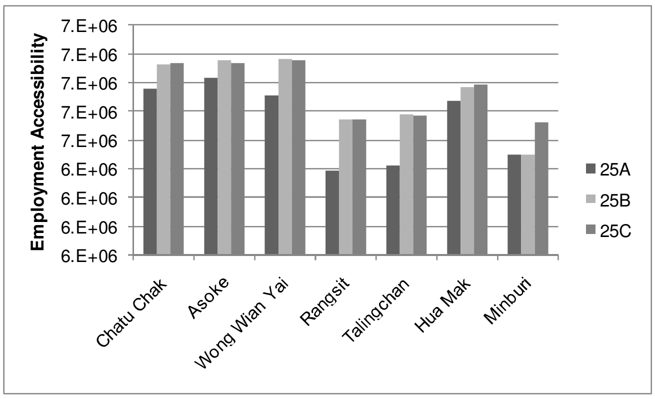
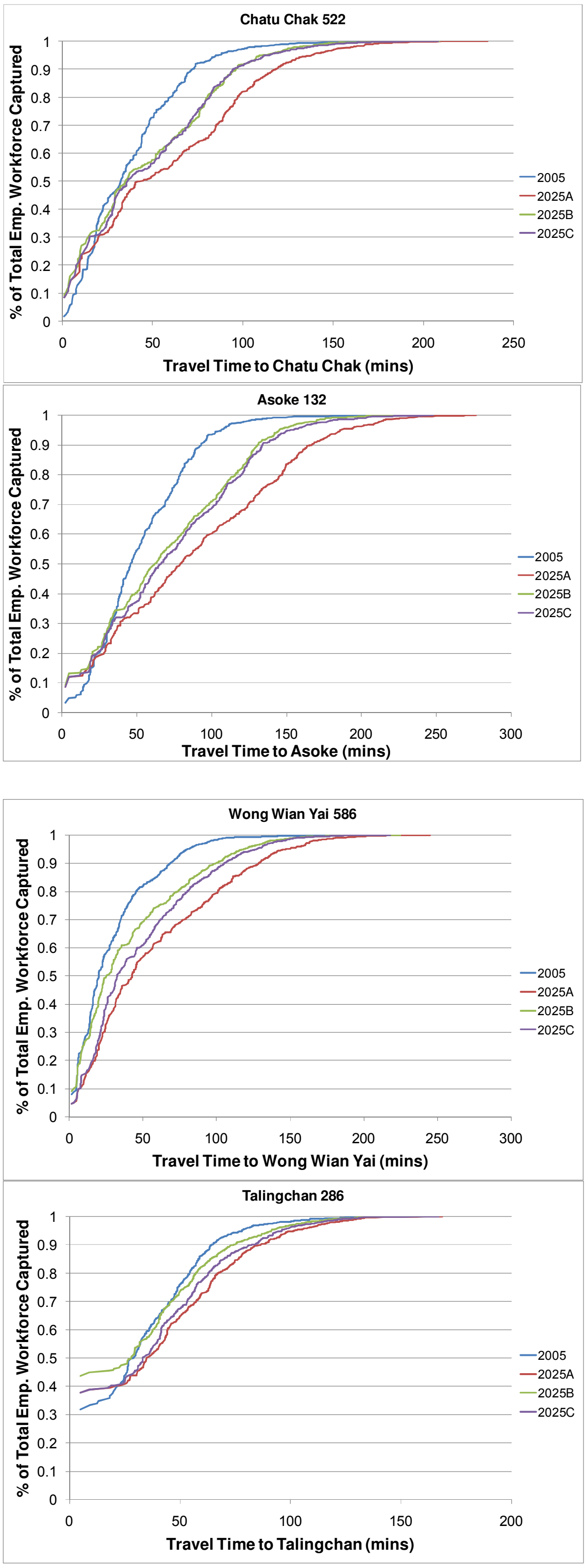


Figure 10 Accessibility at Certain Nodes

Considering the six selected areas, as summarized in Figure 10, they gain larger employment accessibility in 2025 as the railway network is extended but at slightly different extent. Clearly the priority-line network (Scenario B) provide greater employment accessibility in the other area than Minburi, which is the only one benefited from the complete network (Scenario C), which is due to the yellow line train.

3.3 Change of Location-Specific Travel Pattern

Examining the location-specific travel preference curves in Figure 11 let us know that different locations have different response to railway network configuration in terms of sub-center potential. Taken 2005 as reference, Asoke may be considered as city center comparing to the others, i.e., at 50-minute boundary it has received only 50% of its workers while Chatu Chak has got only 70%, Wong Wian Yai 80%, Talingchan 80%, Hua Mak 70%, and Min buri 50%.



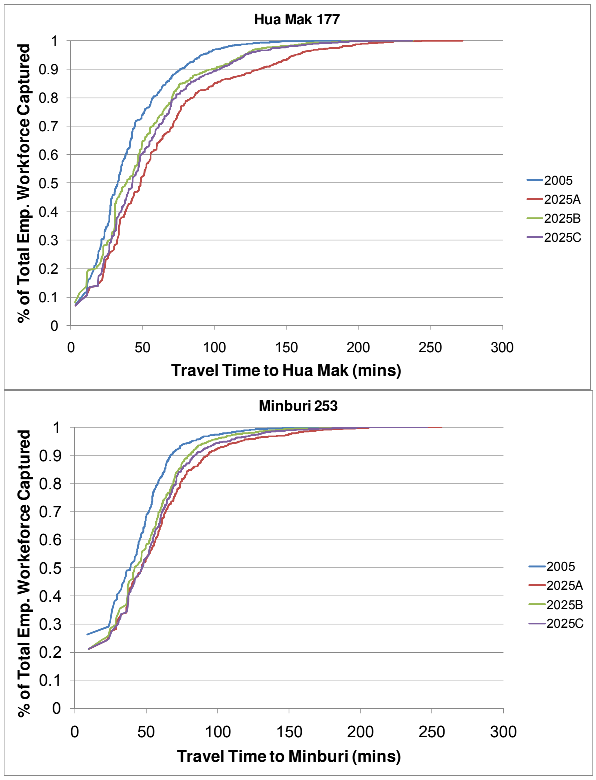


Figure 11 Location-Specific Travel Preferences

In the future year 2025, Scenario 25A indicates that it takes much longer for each area to capture the same proportion of workers as in 2005. When the network is improved by adding more railway lines to the network, it is intuitive that the time to attain the same proportion is reduced than in the reference case. However, the extent of improvement is different for each location. Locating in the inner core, Chatu Chak, Asoke, and Hua Mak gain substantial portion of workers when railway service is expanded. But adding the yellow and orange lines does not help much, as shown that the curves in Scenario 25B and 25C are coincide. In contrast, the railway development does not affect Minburi locating in the suburb. But it is interesting in Wong Wian Yai and Talingchan on the west side of Bangkok, see Figure 6, that Scenario 25B exhibit steeper curves than Scenario 25C, meaning that it would take longer to attain the same worker proportion although the network is improved. This implies that adding more service on the east may cause negative impact on the west side considering the potential to form sub-center or employment node. The framework illustrated here let us understand the impact of accessibility on the urban form based on travel pattern. It allows transport policy such as transit oriented development (TOD) be evaluated to what extent it has capability to capture or attract activity within certain travel range.

4 CONCLUSION

This paper has presented a framework to evaluate transport policy based on mobility, accessibility, and locational preference points of view. The present level of those indicators are evaluated, showing that each sub-area have attained different mobility, accessibility, and sub-center potential. Some representation tools are proposed; travel hazard map of travel time boundary is used to represent mobility; location-specific travel preference is used to represent the sub-center potential. In the later part, the railway network scenario evaluation provides insight on the network performance with respect to mobility, accessibility, and poly-centric urban development. Some areas are greatly benefited, e.g., the planned sub-urban sub-centers. These areas have great potential to effectively form a sub-center in the future. The proposed framework is important and indispensable in evaluating such transport policy as transit oriented development (TOD) to examine the capability to attract activity in the neighborhood by public transport. However, the indicators presented in this paper are the fundamental ones; further study on more complicated and appropriate expression of mobility and accessibility is recommended.

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A ROAD MAP FOR ROAD PRICING IMPLEMENTATION IN THAILAND

- Decision Making Context –

Sittha Jaensirisak
Assistant Professor
Department of Civil Engineering
Faculty of Engineering
Ubon Ratchathani University
Ubon Ratchathani, Thailand
Phone: 045-353 336 Fax: 045-353 333
E-mail: sittha.j@ubu.ac.th

Agachai Sumalee
Assistant Professor
Department of Civil and Structural Engineering
Faculty of Construction and Land Use
Hong Kong Polytechnic University
Hong Kong
E-mail: ceasumal@polyu.edu.hk

Sumet Ongkittikul
Research Fellow
Thailand Development Research Institute
Bangkok, Thailand
E-mail: sumet@tdri.or.th

Several previous studies provide useful lessons of both successful and failed experiences in planning and implementing road pricing schemes. This recollection of experiences helps revealing important issues to be considered during the design and implementation phases of a road pricing scheme. This paper reviews and summarizes these experiences from several cases including Singapore, London, Stockholm, Seoul, and Hong Kong. Based on these experiences, the paper draws the lessons learnt from the past development of road pricing schemes which help identifying the lifecycle and critical factors to be considered during the planning and implementation phases of a road pricing scheme. The paper then suggests some broad strategies to support the development and planning of a road pricing scheme in Bangkok. The paper finally identifies research challenges on planning and implementing road pricing schemes in Thailand. These would also be useful for cities in other developing countries.

Keywords: Road pricing, Public acceptability, Scheme design and integrated strategies, Legislation and organization structure

1 BACKGROUND

Most major cities around the world have been facing a growing traffic congestion problem whose impacts extend from delay in travel, economic loss, pollution problem, to degraded quality of life. The congestion problem is an outcome of an imbalance between available transport supply and travel demand. Transport engineers and planners have attempted to tackle the problem by increasing or providing more transport infrastructure (supply side strategies). The outcomes of such strategies from several cases were, however, not sustained in which the travel demand eventually overrode additional road capacities. This is due to the induced (or elastic) demand effect responding to lower travel cost. To this end, the idea of travel demand management (TDM) has been put forward to address the problem from the demand perspective.

Road pricing is one of the possible TDM policies. The policy has been widely accepted by transport economists and planners as an appropriate measure for tackling the congestion problem. Road pricing involves charging the motorists a fee for using their vehicles within charging zones or on tolled roads. The term road pricing covers any fiscal form of travel demand restraint which can be either direct or indirect charges of road users. Great interests in road pricing are caused by its effectiveness in curbing car uses and its revenues (which can be used to fund other transport projects). These potential benefits of road pricing put itself as a centerpiece of an integrated transport policy.

Many cities have been interested in introducing urban road pricing, but only few actually succeeded (including Singapore, Sweden, Norway, and UK). There was a long history of road pricing studies before the idea became widely known. In UK, the Smeed Report (Ministry of Transport, 1964) was probably the first full contribution of the theory and policy implementation of road pricing. This study catalyzed the interests in road pricing studies in UK and around the world. Subsequently, the first practical road pricing scheme was implemented in 1975: the Area Licensing Scheme (ALS) in Singapore. Norway is the other country who successfully implemented the policy during that period. Toll rings were installed to raise revenue for transport projects around Bergen in 1986, Oslo in 1990, and Trondheim in 1991. Following the success of the Singapore's ALS scheme, other cities started to pay attention to the possible implementation of road pricing. In 1985 an electronic road pricing was on trial in Hong Kong. In 1988 the Netherlands Government developed a proposal for a road pricing implementation in the region called

'Randstad'. In 1991 the Swedish Government developed a proposal for introducing tolls around Stockholm. In UK several local authorities, e.g. Bristol, Cambridge, Derby, Durham, Edinburgh, Leeds, and London, recently revived their interests in road pricing following a new legislation which allows the cities to implement road user charging and utilizes the revenues to fund other transport projects (DETR, 1998). The recent interesting implementations are London Congestion Charging scheme starting on 17 February 2003, and Stockholm Congestion Tax starting on 1 August 2007.

One of the main barriers to the implementation of road pricing is public acceptability (Jones, 1998, 2003; Jakobsson et al., 2000; Schade and Schlag, 2000, 2003; Jaensirisak et al., 2005). This is also interrelated with political acceptability. Two other important issues are institutional barriers (inappropriate legislation and organization structures, and contradictory policies elsewhere) and time dimension (the temporal development of policy from planning, decision-making, to implementation and operation) (Milne et al., 2001; Glazer et al., 2001). These issues are particularly important in developing countries whose political situations are less stable. Road pricing is likely be most easily implemented in a city in which the roles of transport planning and decisions are responsible by a single authority. An example is the experience of London. The creation of the Greater London Authority (GLA) and Transport for London (TfL) played a crucial role in overcoming these barriers by providing a single decision-making and implementation body. Nevertheless, the institutional and time dimension barriers should not pose a serious obstacle if the road pricing scheme is acceptable to the general public, and in turn to the politicians.

The other type of constraint is the complex interaction between transport and other economics sectors (market interaction constraints) (Verhoef, 2001). The decision makers have to take into account indirect effects of changes in transport prices on other markets, e.g. change in commodity price due to higher transportation costs. This interrelationship creates a constraint that should be considered seriously in setting transport prices. It is noteworthy that technology was a barrier to the implementation in the past. However, the Singapore electronic road pricing, London congestion charging, and Stockholm congestion tax have proven the practicality and readiness of the current electronic road pricing technology for the real-world implementation.

In section 2, we review and summarize experiences of road pricing planning and implementation in Singapore, London, Stockholm, Seoul, and Hong Kong. Section 3 presents the lessons learnt from the past development of road pricing schemes which help to identify the lifecycle and critical factors to be concerned in the planning and implementation phases of a road pricing scheme. Then, Section 4 presents development and possibility of road pricing in Bangkok. Section 5 suggests some broad strategies to allow Bangkok to realistically consider road pricing implementation. Finally, Section 6 identifies research challenges on road pricing planning and implementation process for Thailand.

2 SELECTED CASE STUDIES

The implementation of road pricing is complex and often involves not only economic aspect but also political one. In order to study the factors that contributed to the successful implementation of road pricing schemes at the international level, we need to look at the history of each successful or unsuccessful case, especially the process before, during, and after the implementation phase.

The selected case studies include: Singapore; London, UK; Stockholm, Sweden; Seoul, South Korea; and Hong Kong. There are several underlying reasons for the selection of these particular cases. In the nutshell, each of these cases represents different key aspects of success and failure during the planning and implementation phase of road pricing policy. In addition, in some cases the local environment and circumstance can be compared to the condition in Thailand to some extent.

2.1 Singapore

Singapore has been at the forefront of the development of the road pricing policy which was started by a low-tech scheme since 1970's. The case represents an ideal subject for studying the actual impact of different design or implementation aspects of road pricing. Particularly, three main points can be analyzed from this case including the impact and effect of different pricing structure (e.g. area covered and time of day), utilization of revenue in improving public transport services, and evolution process of the scheme from a simple one to a more complex system. Nevertheless, the political climate and social norm in Singapore is considerably different from the situation in Thailand. This point is fully considered in our analysis in which other cases are, thus, included in the study to supplement this part.

Singapore was the first country to introduce urban road user charging in 1975. Initially, the objective was to restrict traffic at peak periods into the Central Business District in order to alleviate congestion. The system applied was called Area-Licensing Scheme (ALS), covering most of the central area in peak morning hours. The system was paper-based, and enforcement was effected by observers posted at each of the 22 entrance-points to the Restricted Zone-RZ (over 5 kilometers square). Each vehicle entering this zone had to display an area license on windscreen.

The charge structure was simply a flat rate charge of S$3 for travelling inside the RZ in the AM peak period (7:30-9:30 a.m.) on Monday to Saturday. However, three weeks later the charging hours was extended until 10:15am in response to the substantial increase in traffic volume entering the RZ just after 9:30am (Chin, 2002). The charge was then increased to S$4 and S$5 in 1976 and 1980 respectively. Gradually, the structure of the charge and charging period was modified to increase the effectiveness of the scheme. In 1989, the charge period was extended into the PM peak (4:30pm – 7:00pm) with a charge level of S$3. The charge period was extended again to the whole day from Monday to Friday in 1994 with the same charge level of S$3. The ALS was considered successful and it was also claimed that there were no significant impact on businesses inside the RZ (Seik, 1998).

The original ALS also had unintended adverse effects such as congestion on feeder roads and expressways leading to the CBD (Goh, 2002). The government decided to introduce the Road Pricing Scheme (RPS) to regulate traffic on the expressways and feeder roads in 1995. The RPS (manually operated) was implemented on the three main expressways heading to the CBD with congestion tolls to pass defined points. About 16% of motorists stopped using the expressways during the RPS operation hours (between 7:30am and 9:30am). However, the ALS and RP schemes were claimed to cause under-utilisation of the roads within the CBD and not to be able to deter the congestion outside the RZ and RPS. In addition, the manual operation of both systems was too labour-intensive and not flexible enough to permit the future modification of the scheme.

In 1998 the ALS was replaced by Electronic Road Pricing (ERP) (Menon, 2000). The objective of the system was changed to improve travel speeds in the road network. Vehicles to pass through the area, during 7:30am and 7:00pm on weekdays and 7:30am and 2:00pm on Saturday, must have an electronic In-vehicle Unit in which a smartcard with positive cash balance has been inserted. The toll applying at the particular time when the vehicle passes under each of the 33 gantries is automatically deducted without the driver having to slow down. Prices applied under ERP do not fluctuate directly with actual traffic volumes, but they are subject to maintain traffic speeds of 45-65 km/h on expressways and 20-30 km/h on arterial roads. The tolls would be varied according to the average speed on the network.

It should be noted from the experiences of Singapore that the road pricing scheme is successful because the system is a part of a policy package, including e.g. substantial improvement of public transport, high parking charge and additional registration fee, and vehicle quota system. Singapore can easily implement the ‘stick’ policies because there is no political problem; the government is strong and people believe in the government’s policies. Moreover, surprisingly, the restraint policies have no major negative side effect on economic growth; on the contrary, they have generated substantial funds for the improvement of social welfare (Willoughby, 2001).

2.2 London, UK

The first proposal for London road pricing was during the 1970s by the Greater London Council (GLC). The charging system was ‘supplementary licensing’, in which every vehicle was required to purchase a daily license to drive in the Inner London area. These charges were expected to reduce traffic substantially and to increase speeds by about 40% during peak period (May, 1975). However, the proposal was rejected by the GLC in 1975.

In the 1980s the London Planning Advisor Committee (LPAC) commissioned research into a number of transport strategies. This work concluded that improvement of public transport by itself was not seen as sufficient; there was a need for direct measures to restraint road traffic and to obtain a better balance between the demand and supply of road space. Various possibilities were suggested. Congestion charging was seen as the most favourable.

During the early 1990s, ‘The London Congestion Charging Research Programme’ was sponsored by the Department of Transport in UK (MVA, 1995). The research studied various charging systems. The simplest scheme was a single cordon charge around central London. The most complex schemes involved three cordons and screen-lines. The levels of charges were different for each cordon and screen-line and time period. The study found that the charging schemes were relatively effective in reducing car use. For example, for a single cordon charge around central London at £8 per crossing, 22% reduction of total vehicle kilometers could be expected. Nevertheless, the schemes were very much likely to be opposed by the public. At the end the systems were postponed by the government.

In 1999, the Greater London Authority Act was passed by parliament. This act gives London a unique local government structure. It also provides full powers for the Mayor to introduce congestion charging schemes in Greater London. For London surveys in 1999, the results reported by the Government Office for London (GOL) show that a daily charge of £5 for driving within Central London and £2.50 for Inner London is supported by about a half of the respondents (53%). Also the survey by MORI (GOL, 2000) found that the scheme is supported by majority of the public, particularly when the revenue is proposed to be used for public transport improvement.

In May 2000, Mr. Livingstone was elected to be the Mayor of London on the basis of a manifesto which included a promise to introduce a congestion charging scheme in central London. Charging schemes suggested were based on the ‘Road Charging Options for London’ study, which was produced by an independent group of transport professionals (called Review of Charging Options for London (ROCOL) Working Group) and supported by Government Office for London (GOL, 2000).

The London congestion charging scheme was successfully introduced on 17 February 2003. The level of charge is £8 per vehicle per day (£5 before 4 June 2005). The scheme enforcement is based on the area license enforced by using digital cameras to check number plats against the database. The charge operates between 7am and 6.30pm on weekdays within central London (21 square kilometers). Some vehicles such as buses, minibuses (over a certain size), taxis, ambulances, fire engines and police vehicles, motorcycles, very small three-wheelers, alternative fuel vehicles and bicycles are exempt from the charge. Residents of the zone are eligible for a 90% discount.

There are three interesting issues for the UK case study in relation to this project. The first is the experiences from the planning and implementation of the area pricing scheme in London. This case illustrates the factors of political leadership and timing of the implementation. The political climate in London and UK in general is more similar to the condition in Thailand (as compared to Singapore). Thus, the scheme in London can provide us the details on how to handle public and political acceptability problems. For London case, there are several detailed documents and reports on the design, strategy, justification, and political discussion before, during, and post the implementation phase of the scheme. These are invaluable sources for understanding the factors for success and failure in delivering a pricing scheme. The last issue for the UK case is related to the government plan and action to promote and support the development of road pricing policy in different cities in the UK including the legislation process. On the formal side, prior to the implementation of the scheme in London, the government had to modify and approve several legislations to allow for the introduction of road pricing scheme and enable the local authority to utilize the revenues collected from the scheme in several ways. In addition, on the non-legislative part, several policies at the national level have been put forward by the government to encourage and support different cities to apply the pricing policy. For instance, the government offers an advance budget for developing major public transport infrastructures for the cities planning to implement the policy. On the technical side, a congestion charging partnership was set up to regularly promote the idea and provide information on the development and design process of the scheme.

2.3 Stockholm, Sweden

The road pricing system for Stockholm was proposed in 1991. The objective was primarily to reduce air pollution, traffic noise and congestion. The charging system was based on pre-purchased licenses. The charge would have operated on weekdays by using £30 monthly cards or £2.50 daily cards (May et al., 1991). These have been predicted to reduce traffic by 10% and 6-8%, respectively. However, in 1997 the proposal was suspended by the government because of political problems and opposition by the business community (Ahlstrand, 2001).

In 1999, a new study of road pricing for Stockholm was carried out by the Swedish Institute for Transport and Communications Analysis (SIKA), a governmental agency. It was claimed that road pricing would be able to reduce the number of private cars struck in the morning peak period by 90-95%, compared to the current situations, and to decrease car traffic in the Stockholm region between 1998 and 2010 by 9% in the morning peak time (Ahlstrand, 2001).

On 2 June 2003 the Stockholm City Council passed a decision to conduct a trial implementation of environmental charges in the Stockholm inner city zone, about 47 square kilometers. On 28 April 2004, the Swedish Government submitted the Congestion Tax Bill to Parliament. The bill was approved by Parliament in June 2004 and the Congestion Tax Act was issued on 17 June 2004. In an appendix to the Act it was stated that the trial implementation of a congestion tax in Stockholm would start on a date to be decided by the Government and continue until 31 July 2006. Thus, the full-scale trial in Stockholm began on 22 August 2005, when public transport services were expanded. The trial congestion tax applied for seven months, between 3 January and 31 July 2006.

A referendum was held in September 2006 (about two months after the end of the trial period). In the referendum the residents of Stockholm municipality voted “yes” (more than 50% of voters) and in 14 other municipalities voted “no” to implement it permanently. However, on October 1, 2006, the leaders of the winning parties in the 2006 general election, declared they would implement the Stockholm congestion tax permanently. The parliament approved this on 20 June 2007, and the congestion tax came into effect on 1 August 2007.

The primary purpose of the congestion tax is to reduce traffic congestion and improve the environmental situation in central Stockholm. The charge operates between 6.30am and 6.00pm on weekdays. The amount of charge is 10-20 SEK (about 1.5-3 USD) depending on time of the day. The charge is applied to every crossing the cordon (both enter and exit the area). However, the maximum amount of tax per vehicle per day is 60 SEK. The vehicles passing the control points are identified through automatic number plate recognition. The equipment, consisting of cameras, laser detectors, antennas, and information signs are mounted on a set of gantries at each control point.

The experience in Stockholm represents a unique case for understanding the benefit of illustrating the benefit of the scheme to the public. The swing of the votes to support the scheme after the trial of the road pricing scheme in Stockholm is a key lesson for any other cities who are interested in implementing the policy. The case illustrates the benefit of a clear illustration of the objective and benefit of the scheme and the significance of open political debates on the topic. This research benefits from this case by looking at the planning and development process of the trial scheme and the communication methods between the city and the public, as well as monitoring the progress of the development of the current scheme which was transformed from the trial one.

2.4 Seoul, South Korea

The case study in South Korea is primarily on the Namsan tunnel toll in Seoul. The similarity between Seoul and Bangkok makes this case study an ideal subject for analyzing the approach to overcome public opposition (or increase public acceptability) to the road pricing policy through different planning and public participation stages.

Seoul has experienced a rapid growth in car ownership and serious congestion problem since 1980’s. Several self-financed expressways were commissioned to relief the pressure on the existing road network. In particular, the

Namsan #1 and #3 tunnels were constructed to serve as the main corridors linking the southern part of the city to the Central Business District (CBD). The tolls of 100 won (around 0.1 USD) were collected for 20 years until 1996 to recover the construction costs. The concession of the tunnels came to an end in 1996. After that, the Seoul Metropolitan Government (SMG) started charging the tolls of 2000 won (around 2 USD) as a congestion charging toll for both tunnels. The tolls are applied to all private vehicles occupied by less than three persons (including the driver). The tolls are collected manually at the tollbooths in which the staffs can check the number of passengers in the vehicle before applying the tolls. The objectives of this implementation are three fold: reducing low occupancy vehicle, raising revenues for transport related projects, and assessing the effectiveness of the pricing technique.

In 1996, 90% of the traffic volume passing the two tunnels was made by private vehicles in which more than 78% of the private vehicles were one person occupied. This was the highest among all the major corridors linked to the CBD. After the congestion toll operation, the number of carpooling vehicles (occupied by three of more persons) has increased substantially (more than double of the original figure). Immediately after the toll implementation in 1996, the traffic volumes on these two tunnels decreased by around 25%. However, the total traffic volume has been increasing since and the total traffic volume in 2000 exceeded the level before the toll implementation (around 96,000 vehicles during 7am – 9pm period). Nevertheless, the greater proportion of this traffic volume consisted of toll-free vehicles such as taxies and high-occupancy privative vehicles. Furthermore, the traffic speed in the tunnels increases by 70% in 2000 compared to the speed before the toll implementation.

Based on the post-evaluation of the scheme mentioned earlier, it can be summarized that the Namsan tunnel tolls successfully achieved the set objective in encouraging the car-pooling and increasing the efficiency of the expressway system. In particular, the tolls cause the shift in travel mode (including the use of higher occupancy vehicle) which improves the travel condition on these two tunnels. This also benefit the rest of the network by improving the travel condition all other interconnected routes

Before the implementation, the SMG started a campaign to spread information in Seoul to raise the awareness of the congestion problem particularly in these two tunnels. The campaign also promoted participation and communication between the public and the authority to ensure the acceptance of the new policies. It was suggested later on that the key ingredient to the successful implementation of the congestion toll was mainly credited to public hearings, information campaigns, and efforts to win media support, as well as political leadership.

The Seoul case illustrates a different tactic of introducing the road pricing policy to the public through the introduction of toll onto existing tolled road but with different purposes. Also, the case demonstrates a great power of public understanding campaign and selection of the scheme. The justification of the scheme is clear which is due to the congestion problem on these major corridors to the Seoul CBD. It is also interesting to look at the approach taken to avoid the direct impact to many stakeholders in the same time. A form of exemption (high occupancy vehicle) is introduced to encourage shared rides and also the taxis are exempted from the toll. This form of road pricing development is particular of relevance for the development in Thailand especially in Bangkok since already having a large extensive network of tolled expressway in the city which is under different contractual agreements.

2.5 Hong Kong

In 1982, the Hong Kong government decided to adopt fiscal controls to contain traffic. Particular measures introduced were trebling the annual fee for private cars and doubling the fuel tax and the registration fee for new cars. As a result of the vehicle ownership restraint, private vehicle ownership decreased from 211,000 in 1981 to 170,000 in 1984. However, the level of congestion was only reduced in the least congested (low income) areas and in the same time rose in the most congested areas (Dawson and Brown, 1985). Private car and taxi use still remained high, particularly during peak periods (Lewis, 1993).

In response to this failure, the first Hong Kong pilot of Electronic Road Pricing System (RRP) was undertaken between 1983 and 1985. The Hong Kong chose not to adopt a low-tech option like the ALS in Singapore on the basis that it would be too liable to fraud and require a considerable amount of enforcement (Borins, 1988). The system was based on the automatic toll collection, billing and enforcement. Three schemes with different levels of charge, number of zones and geographical coverage were tested. Vehicles' owners would receive a bill with details of their use of the network at the end of each month (Catling and Harbord, 1985).

The effects of the schemes were predicted (by a traffic simulation model) to reduce total daily car trips by 9-13% and peak-period trips by 20-24% (Harrison, 1986). Economic evaluation found that net benefits of the schemes were satisfactory (Gomez-Ibanez and Small, 1994). Nevertheless, the schemes were not implemented. One of the main reasons was the public concern about the potential intrusion of privacy by 'big brother', in addition to political and economic problems (Hau, 1992).

After the failure of the attempt, in 1994, the Hong Kong government revived the idea of tackling traffic congestion by road pricing. The government commissioned a major feasibility study, which began in March 1997, with the objective of examining the practicality of implementing ERP in Hong Kong. Various technological alternatives were considered including the Dedicated Short Range Communications (DSRC) system as currently operated in Singapore and the Vehicle Positioning System (VPS) based on Global Positioning System (GPS). A cordon-based charging scheme was still the preferred alternative for the charging regime. Similarly to the scheme design in 1983, the charging zone would cover the most congested areas of Hong Kong and be operated on a directional and time period basis. The initial suggestion was that the peak period charge would be from 8:00am to 9:00am and from 5:30pm and 7:00pm. A slightly lower charge would be applied during the inter-peak hours. The charge rate would be set to maintain a target speed on 20km/hr. It was estimated that the implementation of this proposed ERP scheme would reduce car trips entering the charging zones by up to 50%, with 40% diverting to public transport and 10% changing travel time. In order to rectify the failure of the first proposal, there was a well-planned public consultation programme to allow public input into the development of the scheme.

Technology trials were conducted in late 1998 with both DSRC and VPS technologies. The results showed that both DSRC and VPS could be adopted in Hong Kong and the privacy issue could be overcome. However, in 2001 the government concluded that based on the feasibility study report in 1999 there were no transport and environmental grounds to justify electronic road pricing (Legislative Council, 2001). Therefore, the government decided not to pursue the implementation of the ERP scheme, despite the promising results of the technological trials. Although the technological barrier in relation to the privacy issue has been overcome, the question of the political and public acceptability of ERP still remains.

Most recently, after 2003 economic has been growing, so there is an increase in congestion and pollution, as well as an increase of public awareness in particularly air quality. To address the problem, the Council for Sustainable Development in Hong Kong offers a series of options and suggestions to tackle the problem in the "Clean Air and Blue Skies – the Choice is Our" report in 2006. One option suggested is road pricing. Currently, this option is under discussing in Hong Kong.

Although there has not been any successful implementation of a real urban road pricing scheme in Hong Kong, the city has been developing several plans and proposal since 1970s'. The main objective for studying this case is to look at the key obstacles that prevent Hong Kong to implement the schemes including technological and political issues. It is also the intention to look at the attempt of the government to develop the proposals over the years in order to handle these issues (there were already at least three major studies on the implementation of road pricing policy in Hong Kong). There are also several similarities between Bangkok and Hong Kong particularly on the social norm, public participation, and high volume of taxis in the traffic system which should enhance the transferability of the experiences to avoid the same problem.

3 CASUAL RELATIONSHIP OF ROAD PRICING DEVELOPMENT

The lessons learnt from the past development of road pricing schemes help identifying the lifecycle and critical factors during the planning and implementation phases of a road pricing scheme.

Figure 1 shows the life-cycle of road pricing policy development. Before the implementation phase, there are two prior phases: initial phase and design phase. The initial phase is to raise the awareness of the public on road pricing. The design phase is mainly to study the detail of the system design.

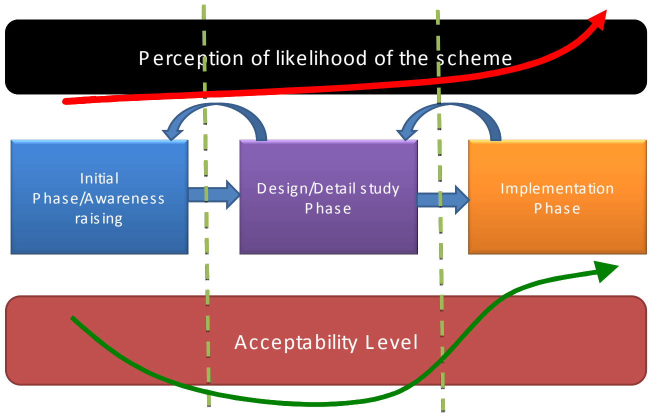

Figure 1 Life-cycle of Road Pricing Policy Development

Once a city council or the government suggests or raises road pricing as a possible solution for the city, the lifecycle of the policy moves from the initial phase to design phase which also gradually increases the perception of the likelihood and inevitability of the scheme. During the initial phase the public may not really pay a close attention to the on-going discussion since they may perceive this as an idea which is far from reality. Thus, the opposition level and acceptability problem may not be so high (but also no strong support). When the process moves to the design phase, if the outcome or impact of the scheme is still uncertain, many oppositions or stakeholders will eventually come out to strongly criticise and oppose the policy. Consequently, the acceptability level will decrease rapidly. Many cities in the previous cases abandoned the scheme at the initial or design phases to avoid the public confrontation and political damage. London and Stockholm had been back and forth between in these two phases a few times before the successful implementations.

Based on the previous experiences, interactions among the critical factors can be illustrated by relationship diagrams for the initial process (Figure 2), and the design phase (Figure 3).

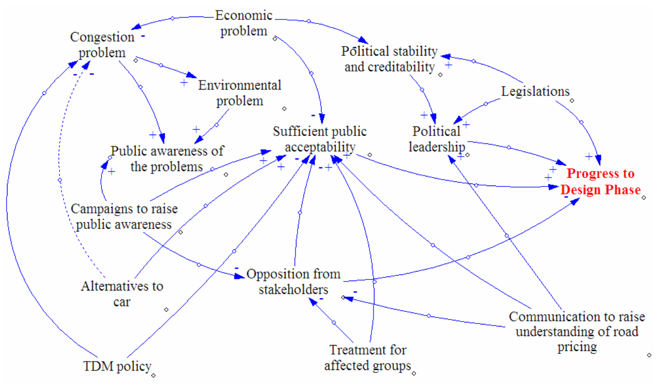

Figure 2 The Relationship of Initial Phase of Road Pricing Development

Figure 2 illustrates the relationship of initial phase of road pricing development. From the initial phase prior to the design phase, there are four key factors: **public acceptability**, **opposition from stakeholders**, **political leadership**, and **legislations**. Public acceptability of road pricing relates to several conditions. If there is an economic problem (e.g. high inflation rate), the public is likely to disagree with road pricing (e.g. the case in Hong Kong). Acceptability also relates to the public awareness of congestion and pollution, which can be influenced by campaigns through the media (i.e. the cases in London and Stockholm). Furthermore, acceptability of road pricing relates to whether alternatives to car are available, and how many other "stick" measures to control car use have been in place (i.e. the cases in Singapore and Seoul). If some "stick" demand management measures exist, road pricing would be unlikely to be accepted.

The opposition from the stakeholders depends on their level of the impacts and benefits they perceived during the development process. The authority should engage them in the negotiation and discussion as early as possible to ensure their supports and to provide them appropriate exemptions of the scheme and other impact alleviation measures. Communication with all stakeholders, particularly business community and the media, should be done continuously to provide sufficient knowledge about potential advantage of road pricing. More importantly the policy should be presented to the public and media as a part of the policy package which involves other measures to provide alternative to case uses. The involvement of the public is essential to understand the concerns of the public, pressure groups, politicians and the media (CURACAO project, 2008).

Obviously, the progression to the design phase can occur with a strong political stability and government creditability (e.g. Singapore and Seoul). In the case of political instability (e.g. Stockholm and London), modification of or new legislations can provide power to support political champions to facilitate the design process.

Figure 3 illustrates the relationship of design phase of road pricing development. The general factors in the design phase to progress to the implementation phase are rather similar to the factors in the initial phase. They are (i) **acceptability of the scheme**, (ii) **political leadership**, and (iii) **opposition from stakeholders**. An additional factor is the **perception of inevitability**. However, the factors affecting the acceptability in this stage are different from the factors in the initial phase.

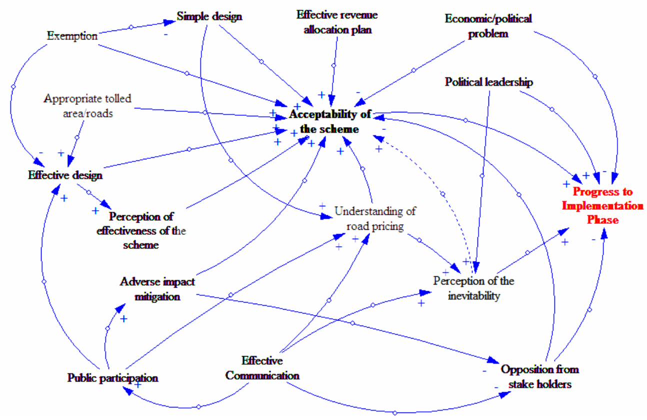

Figure 3 The Relationship of Design Phase of Road Pricing Development

The acceptability of the scheme in this stage mainly relates to system design. The scheme needs to be simple and effective in an appropriate area. Importantly, it is perceived by the public as effective to achieve its objectives. Exemptions and discounts can increase the acceptability but may also make the scheme to be more complicated, more costly (e.g. the scheme in Stockholm), and less effective if the majority is exempted (e.g. if the Hong Kong scheme provides an exemption for taxis).

The acceptability is also influenced by the revenue allocation plan, adverse impact mitigation, and understanding of road pricing. These issues can be managed through the public participation and effective communication.

During the design phase the public may pay attention to the scheme. The perception of likelihood and inevitability of the scheme gradually builds up. Consequently we may face strong oppositions or even campaigns against the scheme from different stakeholders. Thus, under this circumstance, we really need effective communication strategies to deal with all stakeholders, particularly business community and the media.

Finally, as in the initial phase, strong political leadership is one of the key success factors. This is depended on the economic and political situations. However, it does not mean that without political leadership the scheme will always be abandoned. The progress to implementation phase can also be success if an effective scheme, designed by an independent expert study groups, is perceived as effective to solve the transport problems, and is acceptable by the public. In the instability political situation, the designed scheme can be put in a referendum process (e.g. in Stockholm).

4 ROAD PRICING IN THAILAND AND ITS POSSIBILITY

Road pricing was first mentioned in Thailand more than three decades ago. In 1971, the German Agency conducted the first comprehensive transport study in Bangkok, called "Bangkok Transportation Study (BTS)" (Kocks, 1975). Major recommendations were the development of mass transit and expressways with the restriction of car use (road user charging), as well as polycentric developments around the city. Unfortunately, only the recommendation on the expressway development has been fully pursued and implemented. On the other hand, the mass transit system has been improved slowly, while road pricing or any TDM measure has been rarely mentioned. In 2001 the study of Traffic and Transportation Development Master Plan for the 9th National Economic and Social Development Plan 2002-2006, carried out by the Thailand Development Research Institute (TDRI), suggested that road pricing should be used in Bangkok for managing the demand of car use (TDRI, 2001).

The study on Urban Rail Transportation Masterplan (OCMLT, 2001) proposed a rail transit network in Bangkok for the Office of the Commission for the Management of Land Traffic (OCMLT), Minister of Transport of Thailand. It also recommended that road pricing and a new taxation scheme should be combined to support this rail development. However, currently the government is only considering approval of the rail network as an independent measure, i.e. decoupling it from the pricing scheme.

Although there are a few suggestions on road pricing in Bangkok, the politicians have never seriously showed their interests (in the public) in the policy. Recently, in May 2007 many mayors including Bangkok Governor Mr. Apirak Kosayodhin attended the "Large Cities Climate Summit" in New York. In the session of "Beating the Congestion and Surviving Your Next Election", London Mayor Mr. Ken Livingstone acknowledged the success of London Congestion Charging. The Bangkok Governor mentioned that he wanted to introduce the charge as well, but Bangkok does not have a proper mass transit system. He also asked whether Bangkok needs to have the mass transit system in place first or road pricing could start now in the inner city. Livingstone's advice was to improve the bus system because subways take a long time to construct. He added that in the case of London, the number of buses increased from 6,000 to 8,000 along with the introduction of new routes, and the private sector played a key role in helping with the expansion finance (The Nation, 2007).

In the early 2008, Mr. Apirak Kosayodhin mentioned to the public in Bangkok that the idea of road pricing should be plausible in Bangkok because of the rise of the fuel price. The governor said the idea follows primarily from the success in London and Singapore, where congestion pricing is already in place on urban roads; however, adjustments will be made to ensure its suitability for Bangkok. However, his idea received a strong criticism by the public who are afraid that the policy would make their living harder in times of economic difficulty (Bangkokpost, 2008).

Concerning the issue of public acceptability of road pricing in Bangkok, a study on travelers' attitude on introducing area licensing scheme (Pruttiphong et al., 2006) found that more than half of public responses revealed a positive attitude towards a concept of limiting automobile use in the business area; this is because the public perceive that air pollution is the major problem in the area. However, it also found that two third of automobile users perceived some difficulty in reducing their car trips, this is because of lack of alternatives.

Lately, although the economic has been slow down and fuel price has rapidly increased during a couple of years, congestion and pollution problems in Bangkok are still very serious. In addition, the political situation in Thailand is extremely unstable and abnormal. Under such a circumstance it may not be a good time to discuss about road pricing. Nevertheless, this does not necessarily imply that the planning process of road pricing should be on hold.

On the public related issue, the public awareness of congestion and pollution problems is high. However, road pricing is still not considered as a solution by the public mainly due to the fear of change in cost of living, lack of alternative travel modes, and lack of understanding of the potential benefit of the scheme. Opposition to road pricing from stakeholders is still high, particularly car user groups and business communities. The current communication and dialogue among the politicians, the decision makers, the media and the public mainly focuses on the mass rapid transit provision (supply-side policy) due to its popularity to the public. Travel demand management (demand-side policy), particularly road pricing, is rarely mentioned in the public, so the public understanding of road pricing is relatively low. Most people probably understand that road pricing is simply an implementation of road tolls like the expressway system on public roads. The key stakeholders, particularly business community and the media, have not been clearly informed. These are the reasons that public and political acceptability of road pricing is not sufficient.

Moreover, once a politician who has political leadership keens on introducing the scheme, but the current political situation is rather unstable (both at local and national levels) and the trust of the government (creditability) by the public is not so high, any approval of related legislation and implementation by the parliament and local council is, therefore, unlikely.

Therefore, based on the initial evaluations, it is likely that the road pricing development in Bangkok at its current standing cannot progress to the design phase.

5 SUGGESTION FOR BANGKOK

From the road pricing experiences and local circumstances in Bangkok presented in previous sections, some broad strategies can be suggested as follows, in order to help Bangkok moving from the initial phase to the design phase of road pricing.

5.1 The National Government has a Responsibility to Develop a Clear Transport Strategy and Legislation to Support the Local Government

Without the legislation and support from the central government road pricing scheme would never have been realised. The legislation should provide powers to the Mayor to introduce congestion charging schemes and also enables the local authority to utilize the revenue. The national government should also provide advance budget for developing alternative modes.

5.2 Road Pricing should be Considered as a Part of an Effective Transport Strategy

Road pricing should not be considered and mentioned independently. The development of road pricing scheme should be determined as a part of strategy formulation, in which the overall strategy is determined first. This will help to demonstrate whether road pricing is needed, and also help to identify those complementary policy instruments which are needed to integrate with road pricing scheme.

5.3 An Independent Expert Study Group should be Set to Formulate the Effective Strategy

An independent expert study group which is supported by the government should work independently from the politics. They will be allowed a great continuity and in-depth formulation on the most appropriate plan. This plan also allows great inputs from other stakeholders without political biases and influences. This process can help to avoid political instability and distrust of the public on the government.

5.4 Effective Communication should be Done Continuously Through a Two-Way Dialogue to Raise Public Awareness and Knowledge (mainly done by the expert study group)

Effective strategy to communicate with the public in general and all stakeholders, particularly business community and the media, should be done continuously through a two-way dialogue. This should be a responsibility of the expert study group (who generally has higher creditability than the politicians). This process is to raise public awareness on transport related problems, and to provide knowledge about potential advantage of road pricing. The involvement of the public is essential to understand the concerns of the public, pressure groups, politicians and the media (CURACAO, 2008).

5.5 Road Pricing Revenue Allocation Plan is a Critical Issue

Road pricing revenue allocation plan is critical to determining the acceptability and effectiveness of the scheme. Revenue use should be committed to the development and improvement of the mass transit, other public transport systems, and other alternative modes, e.g. walking and cycling. The revenue can also be used to compensate the losers.

5.6 Implementation Plan of Improvement of Alternative Transport Modes needs to be Clear and Convincible to the Public in the Early Stage of Planning Process

Lack of alternative transport modes is the key factors of the scheme opposition. The public usually claim that there is no appropriate alternative to cars. Thus an implementation plan of improvement of alternative modes needs to be clear and convincible to the public.

5.7 Political Will and Leadership to Commit the Scheme is a Key Success of the Scheme

It was found that a lack of strong political commitment acts as a benchmark for other stakeholders, their attitudes may become more negative as well (CURACAO, 2008). This contributes to a slower or even stopped introduction of the scheme. Thus, a political champion, who takes ownership of road pricing scheme, clearly facilitates the implementation process. However, politicians may fear of losing elections by promoting road user charging. One way of divorcing the road pricing issue from elections is to hold a referendum on the strategy formulated in (ii) and (iii), rather than on only the road pricing scheme.

6 RESEARCH CHALLENGE

The suggestions presented in the previous sections request for further research, in order to support planning and implementation process. This research challenges are not only for Bangkok, but also for other developing countries that are facing similar political situations. The research challenges can be divided into three groups, as follows.

Public acceptability, as mentioned earlier, is the main barrier for road pricing implementation in every country. Those can deal with this issue will be successful in the implementation, e.g. London and Stockholm.

From the international experiences, acceptability has been found to be influenced by many factors (Jaensirisak et al., 2005), including:

(a) attitudes to transport problems and the perceived effectiveness of the scheme (PATS Consortium, 2001), attitudes relating to the environment and towards the hazards of car traffic, as well as perceptions of freedom and fairness (Jones, 1998; PATS Consortium, 2001);

(b) personal characteristics and constraints (Schade and Schlag, 2000), e.g. income, age, education, transport mode used, frequency of car use, the availability ands quality of alternative modes, location of household and workplace, household type, and life style;

(c) importantly, system features (e.g. Bonsall and Cho, 1999; Schlag and Schade, 2000) particularly level of charge and revenue used. This shows that there is an interaction between acceptance level and system design. So in every city, it is very importance to find out how to design a system that is acceptable to the public and still effective to manage car use.

Furthermore, equity is another important issue that relates to acceptability (Giuliano, 1992; Langmyhr, 1997). The equity issue in road pricing must consider both the distribution of benefits associated with reduced congestion (including side-benefit such as pollution reduction gain and improved public transport service) and the distribution of costs needed to achieve the congestion benefits) (Giuliano, 1994). Jones (2002) proposed a simple approach to address equity concerns through scheme design, exemption, and discount. However, it is not simple to include equity aspects in the design of road pricing systems. Some research has been looking at this issue. Meng and Yang (2002) developed a framework for calculating optimal road toll (to maximise social welfare) with constraints on the spatial equity impact. Recently, Sumalee (2003) proposed an analytical method to identify an optimal location of charging cordon with spatial equity constraint. Maruyama and Sumalee (2007) demonstrate different design of road pricing by comparing performances of cordon- and area-road pricing regimes on their social welfare benefit and equity impact.

Scheme design and integrated strategies. Different road pricing scheme design leads to different impacts on network performance. Also different integration with other policies has very different impacts on both network system and public acceptability. Road pricing is being seen as part of an integrated strategy, particularly in European cities. Integration can be achieved by reinforcing the benefits, reducing political and financial barriers, and compensating losers (May et al., 2005).

A survey of the policies adopted by UK city planners indicated that they typically preferred a very simple approach, focusing on the city centre and any major traffic generators on its fringes. The single cordon would be placed just inside the inner ring road around the centre, with crossing points minimised where possible, a uniform charge to cross at all points, and that charge kept low enough to be publicly acceptable (Sumalee, 2001). The question is where best to locate a single cordon, or a given number of charging points. It is even more challenging if we try to determine optimal locations and charge levels for different patterns of charging points. This has been addressed by some researchers (Hearn and Ramana, 1998; Verhoef, 2002; Zhang and Yang, 2004; Sumalee et al., 2005).

Legislation and organisation structure is another major barrier for its implementation. It is so called institutional barriers (inappropriate legislation and organisation structures). This can be distinguished between two key issues: (i) laws required to support specific pricing measures; and (ii) laws governing the structures of organisations and the relationships among them (Milne et al., 2001). For example, for the case of London, some legislations were adopts to provide powers for the Mayor to introduce congestion charging schemes and also enables the local authority to utilize the revenue. Prior to the implementation, they also allowed the national government provided advance budget for developing alternative modes.

7 CONCLUSION

From the experiences of many countries, it is clear that road pricing is the most efficient and environmentally beneficial available for congested cities. However, the success of the implementation of this viable policy is rather limited due to a number of barriers in social, political, and constitutional contexts which obstruct its implementation. Road pricing has been suggested in Thailand over the past three decades by transport planners. Politicians and decision makers recently show their interest of the implementation. When the economic situation is normal, public tend to agree with the scheme because their perceptions of congestion and pollution are very serious. However, when the economic is slow down and fuel price rapidly increases, road pricing is not acceptable by many stakeholders. Although, it is likely that the road pricing development in Bangkok at its current standing cannot progress to the implementation phase, it does not mean that the planning process of road pricing, as well as communication to raise public awareness and knowledge, should be on hold.

Road pricing should not be considered and mentioned independently. The development of road pricing scheme should be determined as a part of strategy formulation, in which the overall strategy is determined first. This will help to demonstrate whether road pricing is needed, and also help to identify those complementary policy instruments which are needed to integrate with road pricing scheme. An independent expert study group should be set to formulate an effective strategy. The group should be allowed to work continually and independently from any political influence in order to investigate and formulate the most appropriate plan/strategy. This plan should also allow inputs from other stakeholders (who should be involved in a public participation process from an early stage) without political biases and influences. This process can help to avoid political instability and distrust of the public to the government.

Moreover, the effective strategy to communicate with the public in general and all stakeholders, particularly business community and the media, should be done continuously through a two-way dialogue. This should be a responsibility of the expert study group (who generally has higher creditability than the politicians). This process is to raise public awareness on transport related problems, and to provide knowledge about potential advantage of road pricing.

Finally, this paper has suggested some research challenges, not only for Bangkok, but also for other developing countries that are facing similar political situations. These include public acceptability, scheme design and integrated strategies, and Legislation and organisation structures.

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CRITICAL MODELING ISSUES IN TRANSPORTATION SAFETY PROGRAMMING

- Comprehensive View from Academia and Practitioners –

Sittipan Sittikariya
Project Manager/Senior Transportation Engineer and Planner DKS Associates
Seattle, *USA*
Phone: +1-206-382-9800
Fax: +1-206-587-0692
Email: sxs@dksassociates.com

Venkataraman N. Shankar
Associate Professor
Department of Civil and Environment Engineering
Pennsylvania State University
Pennsylvania State, USA
Phone: +1-814-865-9434
Fax: +1-814-863-7304
Email: shankarv@engr.psu.edu

This paper addresses critical econometric issues related to overdispersion of data in transportation safety programming. The problem of overdispersion is a result of various sources and has to be treated appropriately. In general, overdispersion is partially embedded in the accident database through correlation and heterogeneity or unobserved effects. Also, under-reporting, simultaneity (i.e. endogeneity), omitted/irrelevant measurement, and scale of measurement could potentially lead to overdispersed data. Improper treatment of overdispersion leads to several opportunities for erroneous coefficient estimates and erroneous inference in the estimation of crash model. From a programming standpoint, this could lead to the inefficiency and inconsistency of highway safety prioritization. The purpose of this essay is to provide insight into causes of critical modeling issues, symptoms and necessary treatments to develop robust accident model. In addition, consequences of using untreated model in transportation safety programming are discussed.

Keywords: Critical econometric issues, Overdispersion, Transportation safety programming

1 INTRODUCTION

In transportation safety programming, econometric models serve the policy makers as a crucial tool to define high accident location (**HAL**) and high accident corridor (**HAC**), to identify the contributing factors to accidents and to perform accident predictions. Furthermore, related policy that could mitigate the impacts of accident can be implemented from the robust econometric models. In the estimation of accident count models, one greatest concern that modelers usually face while developing the models is overdispersion issue. It is well known, base on many previous research (Shankar et al., 1995), that accident frequency data tend to be overdispersed, with the variance being significant greater than mean of accident frequency. However, conventional count models such as a Poisson model do not incorporate this critical issue. The risk of not recognizing this issue can result in erroneous coefficient estimates and erroneous inference. To overcome this issue, the modelers need to fully understand causes of overdispersion and treatments when overdispersion exists in the data. This paper addresses key sources of overdispersion in transportation safety programming along with symptoms of infected model with overdispersion. Additionally, consequent impacts of erroneous parameter estimation and inference on policy makers will be discussed. Last but not least, necessary treatments are provided to modelers.

The overdispersion conceptual framework in transportation safety presented here delves directly into the statistical and econometric treatment of crucial modeling issues. The material presented is in a form designed to delineate for the reader the logic of thought and sequence of research inquiries that occurred before this paper.

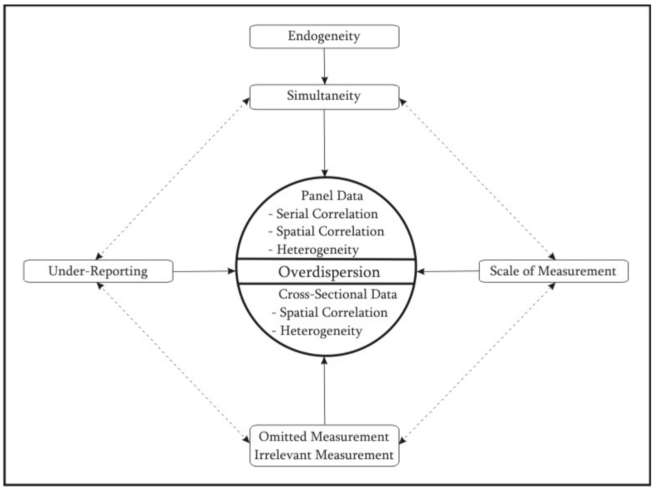

Figure 1 Conceptual Framework of Overdispersion in Transportation Safety Programming

In general, as shown in figure 1, overdispersion is partially embedded in the accident database through correlation and heterogeneity or unobserved effects. In addition, under-reporting, simultaneity (i.e. endogeneity), omitted/irrelevant measurement, and scale of measurement can potentially lead to overdispersed data. Following a discussion of this conceptual framework, crucial modeling issues such as unobserved effects, correlation, under-reporting issue and so on together with symptoms and treatments will be described in the following sections of this paper.

2 NATURE OF DATA

In crash count models, unobserved heterogeneity is a common theme in accident occurrence, leading to well-known overdispersion problem (Shankar et al., 1995). Overdispersion in reported crashes can result from two sources: high-valued crash counts or excess zeros in reported crashes due to under-reporting and environmental effects. Shankar et al. (1997) provide a detailed description of design situations where both forms of overdispersion occur. A simple Poisson model applied to this case to model the accident frequency per year would result in biased coefficients. The Poisson model would overlook the fact that the highway's limited accident history may provide spurious indication of its safety characteristic over its lifetime and ignore overdispersion phenomena that arise from unobserved effects or heterogeneity. As shown in several prior works (see for example Poch and Mannering, 1996; Milton and Mannering, 1996), the negative binomial (**NB**) distribution is suitable for overdispersed accident frequencies occurred from unobserved effects.

Another common issue that arises in accident data contexts is the issue of correlation among accident counts. Multiple years of cross-sectional data on highway accident occurrences are often available from public domains, including time series information on traffic volumes, accident counts and roadway geometrics as well as roadside characteristics. In addition, weather information is also available from national databases (see for example Shankar et al., 2004). It is noted here that correlation among accident counts and unobserved heterogeneity can be viewed as a simultaneity problem. That is, due to explicit correlation among dependent variables, or implicit correlation among the error structures, a simultaneity issue that argues for joint density functions arises. Complicating the decomposition of this simultaneity issue is the "mathematical overlap" between correlation and heterogeneity. From an empirical standpoint, it is highly possible that serial correlation may be spuriously captured as heterogeneity; the converse is also true. Fundamentally however, heterogeneity and serial correlation can be classified broadly as violations of the "independently and identically distributed" (**IID**) assumption. In the context of count models, as is the case in this dissertation, the empirical question relates to the proportion of the heterogeneity component of the **IID** violation problem. Some empirical examples follow to illustrate why treating the **IID** problem in count contexts as primarily a heterogeneity issue is useful.

In the presence of accident count correlation in multiple years of cross-sectional accident count data, the efficiency of parameter estimates comes into question. Similar to the classical linear regression model, one can expect parameter estimates to be inefficient in the presence of correlation in count models (Guo, 1996). A method to adjust for repeated observation effects on parameter estimates is necessary to adjust for heterogeneity in the form of correlation. One such method relates to the use of the cluster heterogeneity model or negative multinomial (**NM**) model (Ulfarsson and Shankar, 2003). In that model, a joint likelihood based on repeated observations is constructed to modify the traditional negative binomial likelihood. As a result, parameter estimates reflect an adjustment in their standard errors, with much of the adjustment resulting from proximate years. This type of correlation between the accident counts for a single section over many time periods (years, usually) causes the coefficient estimates to be inefficient and the estimated standard errors to be biased. In case of median crossover accident, median accident distributions occur in much lower numbers compared to other accident types (i.e. most of the observed accident counts are zeros) and likely in a more sporadic fashion, a longitudinal history of median accident counts is used to examine fundamental propensities in the long-term for median crossovers.

The second type of adjustment for correlation involves the development of random effects, where segment-specific heterogeneity is accounted for. In the traffic accident context, the random effects Poisson (**REP**) approach has been shown to be reasonable (See for example, Sittikariya, 2006 and Shankar et al., 1998). The empirical evidence in the above-mentioned literature points heavily to the usefulness of characterizing parameter estimation in longitudinal accident datasets as fundamentally heterogeneity problems.

In comparison with **NB** model, the coefficient values of **REP** model and **NM** model are similar to those of **NB** model but not identical (Sittikariya, 2006). Compared to the **REP** and **NM** models, the **NB** distribution underestimated the standard errors of the parameter estimates, therefore overestimating the t-statistic. Overestimating the t-statistic potentially results in the identification of irrelevant variables as significant effects. From a policy standpoint, extra variables, which should not exist in the model if t-statistic is not overestimated, imply unnecessary data collection needs required for safety programming and prioritization.

This is not to say serial correlation is irrelevant. Rather, one has to argue the case for serial correlation in count data contexts related to traffic accidents as primarily an error lag problem (Cameron and Trivedi, 1998). The reason for this argument is that the exogenous regressors in longitudinal accident datasets seldom vary. With the exception of traffic volumes and weather effects, roadway geometrics and other design related variables are practically constant. Much of the dynamics in longitudinal accident datasets arises from overlapping heterogeneity effects captured by the error term as a "group of omitted variables" effect. Akin to the linear context, if the omitted variables are correlated with the exogenous regressors, parameter bias is highly likely. Hence, at the very least, short of rigorous mathematical treatment through alternative estimators, treating the omitted variables problem as a heterogeneity effect as group specific effects over time or segment mitigates the potential for parameter bias.

3 UNDER-REPORTING

A common modeling issue that arises in the estimation of traffic accident contexts is one that pertains to partial observability. Partial observability relates to under-reporting of less severe accidents. As a result, some roadway segments appear to have perfect safety histories in the form of zero counts. However, this problem of zero counts may be a deceptive one. For example, especially in events of potentially high severity such median crossover crashes, the problem of excess zeros is a significant one. A highway segment with historically excess zeros may appear to be a safe location, but there is no guarantee that no median crossover accidents will occur in the future. As interactions between traffic volumes and geometrics increase, and geometrics and weather conditions exacerbate accident "proneness," one would expect that over time, with increase in traffic volumes and adverse weather conditions, non-zero count probabilities would be expected to rise. Limited history of observation may not adequately capture the "accident proneness" of the highway segment, as interactions increase over time.

For simplicity, we can consider two states, including a zero crossover state and a non-zero crossover state. Depending on how interactions vary over time, the segment may switch to a non-zero state. In such a case, a process that adequately captures the probability of the two states is necessary. The traditional count models, such as the Poisson or negative binomial, address only the non-zero state, thus ignoring the potential shift of excess zeros into non-zero counts. The classical zero-inflated Poisson (**ZIP**) structure and classical zero-inflated negative binomial (**ZINB**) variant decision rules seem to be reasonably reliable in examining the potential for alternate mixing distribution in estimation of traffic crash count models, as shown in several prior work (Sittikariya, 2005; Shankar el al., 2004; Kumara and Chin, 2003; Lee and Mannering, 2002; Shankar et al., 1997). Shankar et al., 1997 suggested that negative binomial distribution can spuriously indicate overdisperison when the underlying process actually consists of a zero-altered splitting mechanism.

Median crossover accidents are rare events when viewed at the annual level. Compared to the commonly occurring accident types such as rear-end or sideswipe accidents, the frequency distribution of median crossover accidents contains zeros in excess of what conventional Poisson and negative binomial model can incorporate. A zero-altered probability process model is promising due to its ability to add "zero density" through a splitting regime. Furthermore, it has great flexibility in uncovering the heterogeneity affecting median crossover frequencies and therefore zero-inflated processes provide significant improvement in frequency predictions. The fundamental advantage of the zero-inflated model would be in its ability to offer better predictions in terms of "safe" versus "unsafe" median crossover roadway sections.

In median crossover accident contexts, it is important to keep in mind that there are the possibilities of near-crossover cases in the roadway section. For example, as median width increases, the probability that a potential crossover will occur decreases, but may be enhanced with increasing volumes and interactions with adverse weather conditions over time. A near-crossover roadside encroachment usually takes the form of a rollover, fixed object or other similar types of roadside accidents that do not result in the vehicle crossing the median and entering opposing traffic. The segment hence may be characterized as operating in multiple states.

4 SIMULTANEITY AND ENDOGENEITY

Simultaneity in traffic crash contexts are special meaning from a safety programming standpoint. In a search space of over 7,000 centerline miles of Washington state highways for example, one is confronted with the question of where to start the evaluation process of identifying crash locations of high social cost. From a programmatic standpoint, viewing the network as a joint-investment problem is useful. For example, if location "**i**" has a high-risk of both roadway and roadside counts, it would serve the purpose of cost efficiency to investigate similar locations first and then address locations with either high-risk roadway characteristics or high-risk roadside characteristiscs alone. In the situation where roadside crash risk exceeds acceptable probability thresholds (Hauer et al., 2002), it may also indicate high roadway crash risks due to simultaneities between the roadway and roadside crash contexts. The sources of simultaneity between the roadway and the roadside are numerous. One can speculate what these sources are, primarily due to human factors interactions with the driving context and unmeasured factors relating to traffic, geometric and weather effects. In this paper, the term "simultaneity" here includes both implicit and explicit simultaneity. An example of implicit simultaneity is one where shared unobserved effects are the main source. Explicit simultaneity is one where a direct dependence between the dependent variables for the roadway and the roadside exists. This can occur in the form of causal relationship or recursive relationship where one dependent variable drives the other uni-directionally. The motivation for investigating simultaneity is the prospect of simultaneous equations bias which would occur if simultaneity is ignored. For example, if roadway and roadside crashes are explicitly related in a bi-directional manner or endogeneity issue, then, ignoring that simultaneity and employing single-equation approaches such as a **NB** structure would result in bias and inconsistency in parameters. On the other hand, if simultaneity is implicit, through unobserved effects, then ignoring that characteristic would lead to inefficient parameter estimates. So the net effect, at the very least, of ignoring simultaneity, is inefficiency of parameters and at the worst, inconsistent parameters, which even a large sample of crash observations cannot overcome. Inefficiency in parameters can results in inefficient safety programming and prioritization that overestimate roadway and roadside crash propensities, while inconsistent parameters can potentially provide biased policy inferences.

Systems of equations models are intuitively useful for capturing shared unobserved effects or explicit simultaneity between the dependent variables (endogeneity as an example). In the traffic crash context, the issue of identification is not a major one. For sure, a systems-of-equations model will be observationally identifiable, considering the vast amount data available in public domains. It has also been shown that both the order and rank conditions for identifications are usually met in systems-of-equations models. The downside of systems-of-equations models, especially in the count context is the accommodation of heterogeneity. Existing methods typically assume identical heterogeneity effects for both the roadway and roadside contexts.

Nebergall (2001) and Chayanan (2005) explored alternate models to address implicit and explicit simultaneity respectively through a system standpoint. Nebergall, 2001 used a linear seemingly unrelated regression estimation (**SURE**) model with the assumption that there is an implicit linkage between disturbances of roadway and roadside crash rate while roadway and roadside crashes themselves were driven by different sets of exogenous attributes. Existence of endogeneity and contemporaneous correlation are not entirely ruled out in the case of roadway and roadside equations. Endogeneity alone can be tested using the Hausman test (Greene, 2003). Presence of endogeneity alone will have to be accounted for by the use of an asymptotically best instrumental variables estimator that can also account for contemporaneous correlation of error. Chayanan (2005), however, explored the relationship between roadway and roadside crash rate as (i.e. explicit simultaneity) a system of crash rate models though three-stage least squares (**3SLS**) estimator. Furthermore, Ouyang et al., 2002 uncovered three systems of equations of crash counts. Three different types of models including the seemingly unrelated Poisson regression model (**SUPREME**), the seemingly unrelated negative binomial model (**SUNBREME**) and the bivariate negative binomial structural (**BIVARNB**) were employed. Main finding from three research were a system of equations is considered to account for bias and inconsistency in parameters and inefficient parameter estimates if bi-directional relationship is dominate (explicit simultaneity) and if shared unobserved effects are significant (implicit simultaneity) respectively.

Finally, it is also worth noting that data plays a major role in the inference process. In thinking about logical data inclusions in a simultaneous-versus-independent models approach, it is possible that different factors affect roadway and roadside crashes respectively. In this sense, it is important to gather as comprehensive data as necessary prior to exploring issues relating to simultaneity, since omitted variable effects can spuriously indicate simultaneity. Traffic crash data have been shown to be correlated with roadway geometrics (Mulinazzi and Michael, 1969), as well as traffic volume and weather data (Shankar et al., 1995). The limitation in collecting three different types of data, namely, traffic volumes, roadway geometrics and weather data arises primarily from the standpoint of spatial coverage and consistency in collection over time. When sufficient data is available however, for the three main data types, a system of equations approach lends itself well to modeling simultaneity in roadway and roadside crash risks.

5 OMITTED MEASUREMENT AND INCLUSION OF IRRELEVANT MEASUREMENT

In safety programming and prioritization, omitted measurement or omitted variable is one of fatal modeling issues. Omitted significant variables in the model could lead to biasness and inaccuracy in model forecasting, which supports the inefficient programming decision from the policy makers. In a structural model of roadway or roadside crash rate as an example, average annual daily traffic (**AADT**) and geometric variable as well as weather effects usually serves as independent variables to explain roadway or roadside crash rate in section "**i**" at time "**t**". An independent variable like "free-flow speed" is omitted from the model because either the data is not available from the public domain or the modeler excludes it from the model. Obviously, this "free-flow speed" variable is correlated with explanatory like **AADT** (non-orthogonal matrix structure). Conversely, the **AADT** variable is correlated with "free-flow speed" variable which is missed from the model and is incorporated into an error term of the model and therefore the **AADT** variable is correlated with that error term. In case of ordinary least square estimate (**OLS**), Greene (2003) showed that the correlating parameter will be biased for the small sample case. In addition, the correlation between **AADT** and "free-flow speed" does not disappear in the large sample; leading to inconsistent estimates. The magnitude of biasness depends upon the degree of correlation between included variable in the model and omitted variable as shown in Greene, 2003. The efficient treatment for this modeling issue is to include all necessary explanatory in the estimation. In case omitted variable is beyond the effort to observe in the field or spending more resource in terms of time and budget is required, the modeler need to include available variable that is highly correlated with that omitted variables in the model to minimize the effects from biasness and inconsistency. For example, "posted speed or legal speed limit" which requires less effect to collect in the field and positively correlated with "free-flow speed" is used to substitute for "free-flow speed".

On the other hand, if one tries to overfit the model by including irrelevant variables, the model will be suffered from inefficiency issue (i.e. the reduced precision of estimates). From a theoretical standpoint, the difficulty with this view is that the failure to use correct information is always costly. A shortcut to observe whether additional variable is irrelevant variable is to observe how coefficient of determination ($\mathbf{R^2}$) or log-likelihood function behaves. If those two indicators do not change significantly when additional variable is included in the model, extra variable can be suspected.

6 SCALE OF MEASUREMENT

Scale of measurement plays dominant role in robustness of accident models. It can change a structure of model for time to time. Variables or information differ in how well they can be measured, i.e., in how much measurable information their measurement scale can provide. There is obviously some measurement error (i.e. under-reporting and heterogeneity or unobserved effects) involved in every measurement, which determines the amount of information that we can obtain. For example, with time series data, if one develops median crossover crash frequency model using a few years of data, the possible model for this dataset will be zero-inflated model because "zero" median crossover accident are majority in the database. However, as interactions between traffic volumes and geometrics increase, and geometrics and weather conditions exacerbate accident "proneness," one would expect that over time, with increase in traffic volumes and adverse weather conditions, non-zero count probabilities would be expected to rise. As a result, a structure of negative binomial distribution might be used to model median crossover accident with multiple years of observations. It seems optimistic to apply a model structure to one year of data while expecting the underlying structure to be unchanging through the entire period.

Another classic example of scale of measurement in the accident model is how to define roadway section into manageable sections. As described by Shankar et al., 1995 there are two popular alternatives for determining roadway section lengths. The first alternative is the use of "fixed-length" section or homogeneous sections (i.e. sections with homogeneous geometric characteristics. The disadvantage of this method is that the roadways with numerous horizontal curves and grades tend to produce sections that are less than 1 km in length. This can result in bias resulting from accident-reporting locational error. Another way to define roadway section length is to use the "unequal -length" section approach. The unequal length of section that will result from the homogeneity requirement may exacerbate potential heteroskedasticity problem and lead to loss of efficiency. The increasing in standard error leads to lower t-statistic and therefore some critical variables may be ignored to explain the accident frequency in the equation.

7 INTERACTION OF MODELING ISSUES

In the estimation of accident count models, model developers sometimes experience the interaction modeling issues. For example, if one needs to estimate median crossover frequency in the roadway section "**i**" and time "**t**", the first concern regarding modeling issue will be under-reporting issue. The "zero" median crossover accident frequency in the database could be higher than 80 percent of median crossover accident dataset. Additionally, multiple years (time "**t**") of cross-sectional data at section "**i**" are often available from public domain, including time series information on traffic volumes, accident counts and roadway geometrics as well as roadside characteristics. The classical issue that often arises in time series data is serial correlation. In this case, it is a combination of the under-reporting issue and correlation problem, namely, excess zero and serial correlation. Sittikariya et al., 2005 presents an empirical technique to adjust for serial correlation effects on standard errors in median crossover accident models. Sittikariya employed **ZIP** model of median crossover accident counts to address the presence of excess zeros in the dataset. This excess zero is unique to median crossover accidents, especially due to the fact that only five years of observation are available. It is important to keep in mind that the estimated parameters from the **ZIP** model would be efficient if serial correlation did not exist. Such is not the case in median crossover contexts where multiple years of observations are available. In fact, as in the classical linear regression model, one would expect standard errors to be downward biased if serial correlation is not accounted for. To correct the variances in a dual-state distribution (such as the **ZIP** model) with temporal correlation, the **NM** offers an intuitive approach. Sittikariya, 2005 showed that the **NM** captures serial correlation across years without biasing the parameters of the **NB** distribution. He then developed a technique for adjusting standard error in the **ZIP** model using the ratio of standard errors from the **NM** model to the naïve **NB** model. It is noted here that there is no exact solution to account for all interaction modeling issues. It is depends upon the nature of data and what model developers try to explore. Also, it should be keep in mind that before model developers look for the interaction modeling issues, the modelers need to profoundly understand individual modeling issue and treatments to ensure that the accurate treatment of interaction modeling issues is applied.

8 CONCLUSION

Overdispersed data is a fundamental issue in the estimation of accident model which is critical component of accurate and efficient transportation safety prioritization. The possible issues that could lead to overdipersion of data are illustrated in through figure 1. The problem of overdispersion is a result of various sources and has to be treated appropriately. Overdispersion leads to several opportunities for erroneous coefficient estimates and erroneous inference in estimation of crash model. From a programming standpoint, this could lead to the inefficiency and inconsistency of highway safety prioritization. The purpose of this essay is to provide insight into causes of critical modeling issues, symptoms and necessary treatments to develop robust model. In addition, consequences of using untreated model in transportation safety programming are discussed.

In general, overdispersion is partially embedded in the accident database through correlation and heterogeneity or unobserved effects. Also, under-reporting, simultaneity (i.e. endogeneity), omitted/irrelevant measurement, and scale of measurement could potentially lead to overdispersed data. In conclusion, biased parameters are the results of heterogeneity, under-reporting, explicit simultaneity and omitted/irrelevant measurement. However, correlation and implicit simultaneity are potential causes of inefficiency issue. From a theoretical standpoint, biased coefficient costs more than inefficiency issue. Biased estimates could provide wrong information to the policy maker; leading to biased policy inferences. Although inefficient estimates cost less, this issue should not be overlooked. Inefficient estimates could possibly point to accurate policy but need to spend more resources in terms of time and budget to implement. In other words, inefficiency in parameters can results in inefficient safety programming and prioritization that overestimate roadway and roadside crash propensities.

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IN PURSUIT OF TRANSPORTATION RESEARCH CHALLENGES IN THAILAND

Wiroj Rujopakarn
Professor
Department of Civil Engineering
Faculty of Engineering
Kasetsart University
Bangkok, Thailand
Phone: +66-2-942-8555,
Fax: +66-2-579-4575
E-mail: fengwir@ku.ac.th

Varameth Vichiensan
Assistant Professor
Department of Civil Engineering
Faculty of Engineering
Kasetsart University
Bangkok, Thailand
Phone: +66-2-942-8555,
Fax: +66-2-579-4575
E-mail: fengvmv@ku.ac.th

Sorawit Narupiti
Associate Professor
Department of Civil Engineering
Faculty of Engineering
Chulalongkorn University
Bangkok, Thailand
Fax: +66-2-251-7304
E-mail: kong@chula.ac.th

Pichai Taneerananon
Professor
Department of Civil Engineering
Faculty of Engineering
Prince of Songkla University
Songkhla, Thailand
Phone: +66-74-212499
E-mail: breathislife@yahoo.com

Viroat Srisurapanon
Associate Professor
Department of Civil Engineering
Faculty of Engineering
King Mongkut's University of Technology Thonburi
Bangkok, Thailand
Phone: +66-2-470-9147
Fax: +66-2-427-9063
E-mail: viroat.sri@kmutt.ac.th

The challenge to meet the mobility, environment, energy and logistics objectives under the ongoing adverse economic and energy situations places widespread demands on transport research. It has spurred a group of researchers under the auspices of Asian Transportation Research Society (ATRANS) to carry out a joint research project with the aim of presenting the status of the transport research activities in Thailand. The outcomes of the research including key recommendations and future research challenges are expected to be useful to the concerned authorities. This research comprises four separate transport related topics. It focuses on Thailand/Bangkok mobility and accessibility, energy and environment issues, road safety and logistics cost.

Keywords: Urban mobility & accessibility, Urban transport energy & environment, Road safety and Logistics cost

THE CHALLENGES

Urban Mobility and Employment Accessibility

The first research topic attempts to examine present and future mobility and accessibility situations in Bangkok. The scenarios tested cover present traffic and network conditions and those as per the recently committed mass transit line(s). The evaluation is made possible by the transport planning model and data developed by the Office of Transport and Traffic Policy and Planning, (OTP).

This topic explores the Bangkok city spreading activities by constructing the location- associated travel preference curves. For each specific employment center, the curve explains the cumulative number of employments that could be reached under certain travel time. The study also produces a so-called travel hazard map to show how easy a traveler can move to their travel destinations. Finally, it presents the gravity-type accessibility for employment opportunity in Bangkok.

The study on mobility and accessibility reveals that private mode is still far superior to public transport. The impact of railway development is examined by scenario analysis. It is found that mobility and accessibility of the whole study area are improved with the railway network development. Certain locations are greatly benefited such as the planned sub-urban/sub-centers except for those already well-serviced.

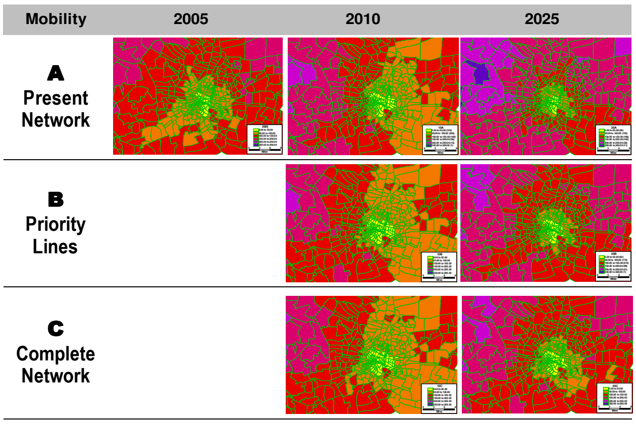

Figure 1 Mass Transit Development Impact on Bangkok Mobility

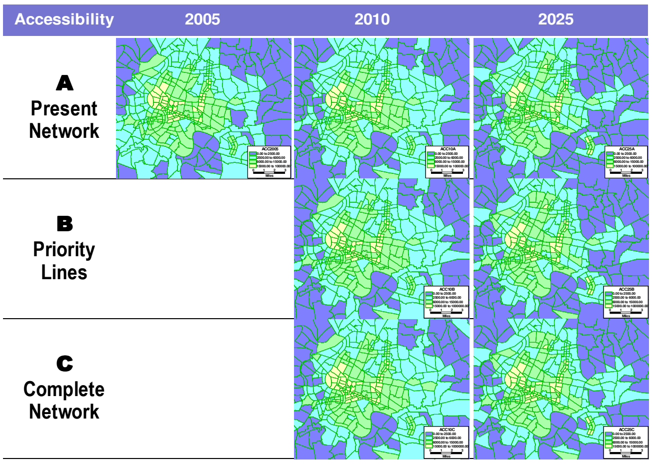

Figure 2 Mass Transit Development Impact on Bangkok Accessibility

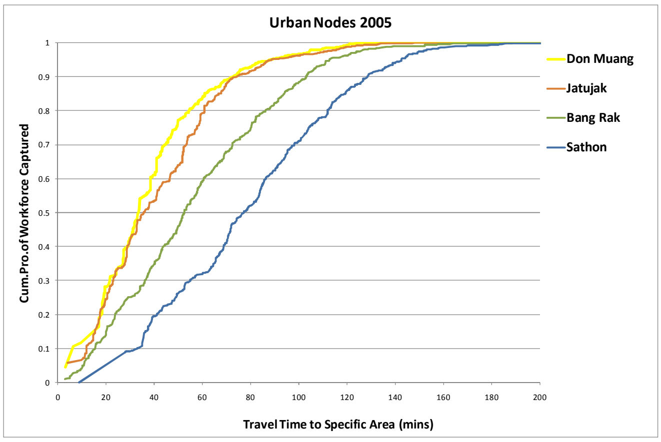

Figure 3 Location-Associated Travel Preference Curves

The location-associated travel preference curves reveal that railway network improvement may produce adverse effects to some locations from the viewpoint of sub-center formation potential and attractiveness.

The findings provide useful guidelines and could recommend some challenging research topics such as mobility and accessibility definitions, property value impact of transport development, integrated land-use/transport analysis, and sustainability planning and evaluation.

For example, it will be greatly useful to define a set of mobility measures that is possible in terms of data availability, other than in the form of travel time to city center as applied in this study. However, some primary raw data from household interview or roadside survey need to be collected and should be conducted periodically.

Moreover, the accessibility expression employed in this study is among several ways of expressing the opportunity to reach the activities in a city. It should be more appropriate to develop an accessibility measure capable of characterizing, in a meaningful way, the overall system represented by the interaction between land use and transportation facilities.

Having shown that mobility and accessibility would be dramatically improved as a result of transport development, its impact to nearby property value is yet to be explored. It is recommended that land development impact be studied in more elaborated ways.

The analysis under this topic has an inherent assumption that the future land use is predetermined and not sensitive to the changes in transport conditions. This definitely limits the policy discussion and contradicts the long-recognized land use/transport interaction. Researches on land use/transport interaction where the mobility and accessibility affects the future land use is recommended.

Sustainability of a city may be achieved through fully understanding the interaction between the several developed activities and their impacts to the environment, society and the urban economy. Transportation system plays an important role to preserve the resident's well-being by providing mobility and accessibility within the city but needs to minimize its impact to the environment. It is worthwhile to proper define sustainability within a developing country context.

Urban Transport Energy and Environment for Bangkok

The second research topic in this series is considered to be a gigantic challenge. Since transport sector, road traffic in particular, is the fastest growing energy consumer and major contributor of adverse environments, nonetheless relatively new in Thailand, this section aims to present an overview of the present transport energy consumption and related environmental situation in Bangkok, Thailand. It attempts to find the facts and some directions on how the transport energy and environmental considerations are being proceed. The study interest is to synthesize the available data and information to yield the directions for future researches. The study is made possible by exploring current researches with certain interviews where necessary.

It is found that relevant data/researches in this area are very limited. It is highly requested that data be collected. However, some of the retrievable data and analyses are summarized in the following sections.

For Thailand, it is found that the total amount of energy use will increase by 5.5% per annum. Transport sector consumes 37% of the total energy, the highest over industry, residential, and business sectors. However, Thailand can save a lot of energy and reduce the growth from 5.5% (Business as Usual, BAU) to 4.1%. via several measures. Transport sector can contribute to the largest saving, accounting for 12% and 16.2% in 2021 and 2026 respectively. The highest saving comes from Travel demand management, TDM (Joint Graduate School of Energy and Environment (2007) "Draft: Final Report of the First Phase of the Thailand Energy Policy Research Project").

Bangkok consumed 2,842 ktoe of gasoline and 6,247 ktoe of diesel in 2003. The trend of fuel consumption is at the rate of 5% during 2000-2003.

From 1986–2003, Bangkok's gasoline consumption grew at an annual rate of 7.2%, while diesel consumption grew at a robust rate of 7.8% p.a. Because of the economic crisis, diesel consumption declined at an annual rate of 1.2% during 1995-2000. Nevertheless, it bounced back to 15.5% growth during 2000-2003.

quantity in 2030 can be doubled the figure in 2010 if nothing has been done. BMA responds to this problem by inaugurating the Bangkok protocol to reduce GHG in May 2007. This was announced during C40 Large Cities Climate Summit. The target is set that CO_2 be decreased by 20% in 2012 (from year 2007).

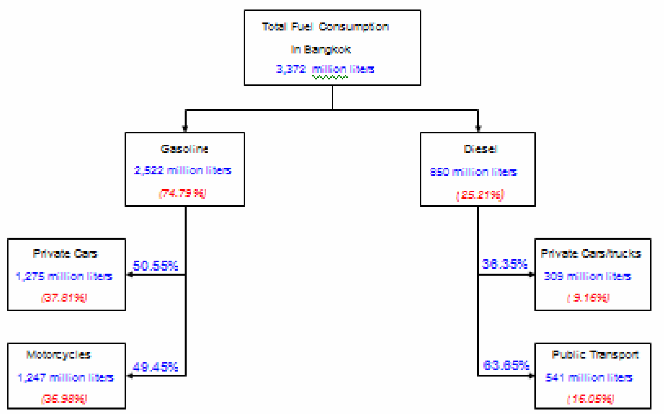

Figure 4 Estimated Bangkok Transport Fuel Consumption 2003

Source: Faculty of Engineering, Chulalongkorn University (2006) "Transport Energy Saving and Efficiency Evaluation"

In 2007, transport in Bangkok contributes approximately 20 million tons of CO_2. The improvement of public transport

Table 1 Gasoline and Diesel Consumption in Bangkok

	Absolute Level (ktoe)					Annual Growth Rate (%)				
	1986	1990	1995	2000	2003	1986-1990	1990-1995	1995-2000	2000-2003	1986-2003
Gasoline	868	1,399	2,271	2,475	2,842	12.7	10.2	1.7	4.7	7.2
Diesel	1,732	3,131	4,313	4,054	6,247	16.0	6.6	-1.2	15.5	7.8

Source: APERC (2007)"Urban Transport Energy Use in the APEC Region"

Another source of data indicates that the amount of gasoline and diesel used for transport in 2003 should be 2,522 and 850 million ktoe respectively.

Due to strict regulation and actions, the Bangkok air quality has been improved since 1990s. Although, some substances may exceed the standard, they are in the minimal proportion.

The amount of pollution generated by road transport can also be estimated from Road Transport Model. The results are presented in the following tables.

For CO_2, the Asia Pacific Energy Research Centre: Energy Supply and Demand Outlook (2006) estimated that its

and traffic system can curb 5.33 million tons in 2012 (Business as Usual, BAU 25 million tons). Measures to reach this target include the expansion of rail transit, integration of public transport, ease of traffic congestion, auto restriction, and promotion of non-motorized transport (i.e., walking, bicycling).

The promotion of alternative fuel can also lessen CO_2 emission. If Gasohol and Bio-diesel can replace the gasoline and diesel by 100 million liters per year, 0.61 million CO_2 can be saved in 2012. The promotion of alternative fuel includes the production of quality alternative fuel and gain acceptance by public.

Table 2 Air Quality in Bangkok in 2007

Pollutants	Ambient Air Quality in Bangkok in 2007				
	Range	95 Percentile	Annual Average	Standards	Exceeding Standards %
TSP (24-hr) mg/m3	0.02 - 0.41	0.17	0.09	0.33	0.43 (2/460)
CO (1-hr) ppm	0.00 - 6.4	1.70	0.7	30	0/79,818
CO (8-hr) ppm	0.00 - 4.9	1.60	0.7	9	0/82,712
Pb (monthly) ug/m3	0.10 - 0.28	0.17	0.07	1.5	0/119
PM_{10}(24-hr) mg/m3	10.8 - 188.9	90.6	46.6	120	1.1 (22/1,957)
O_3(1-hr) ppb	0.0 - 186.0	56.0	17.2	100	0.2 (133/58,411)
SO_2(1-hr) ppb	0.0 - 43.0	10.0	4.1	300	0/75,757
SO_2(24-hr) ppb	0.0 - 16.2	8.7	4.1	120	0/2,995
NO_2(1-hr) ppb	0.0 - 148.0	52.0	21.7	170	0/77,014
Pollutants	Roadside Air Quality in Bangkok in 2007				
	Range	95 Percentile	Annual Average	Standards	Exceeding Standards %
TSP (24-hr) mg/m3	0.03 - 0.76	0.31	0.15	0.33	4.33 (26/600)
CO (1-hr) ppm	0.00 - 16.30	3.40	1.4	30	0/62,091
CO (8-hr) ppm	0.00 - 9.40	3.00	1.4	9	0.01 (9/62,364)
Pb (monthly) ug/m3	0.02 - 0.19	0.13	0.07	1.5	0/103
PM_{10}(24-hr) mg/m3	9.8 - 242.7	118.1	60.9	120	4.7 (92/1,970)
O_3(1-hr) ppb	0.0 - 102.0	39.0	11.6	100	0.004 (1/24,561)
SO_2(1-hr) ppb	0.0 - 42.0	12.0	5.3	300	0/23,523
SO_2(24-hr) ppb	0.4 - 19.0	9.6	5.3	120	0/11,014
NO_2(1-hr) ppb	0.0 - 150.0	68.0	32.5	170	0/24,586

Table 3 Daily Vehicle Emissions in Bangkok

Base Year	PCU-Km per day	Speed Km/hr	NO_2 g/km	CO g/km	PM_{10} g/km
2005	6,544,860	17.2	15,707,664	3,861,467	458,140
2010	7,688,940	16.4	19,222,350	4,920,922	692,005
2025	9,959,460	13.5	27,886,488	7,668,784	1,195,135

Table 4 AM Peak Vehicle Emissions in Bangkok (Business as usual (BAU) Case)

Base Year	PCU-Km per day	Speed Km/hr	NO_2 g/km	CO g/km	PM_{10} g/km
2005	458,140	15.4	1,099,536	250,995	34,361
2010	522,848	17.3	1,326,342	344,465	47,748
2025	717,081	15.6	2,091,487	529,146	95,611

The thorough investigation under this topic reveals that Thailand lacks the comprehensive study in this subject. Related available data are far from perfect. The number of strategic analyses is limited. The solid policies and right attainment can not be ensured. A lot of research works should be done in this field.

With limited data, it is not possible to fully incorporate energy and environment for transport considerations. The existing data can not provide clear understanding of the present status, thus it is difficult to find the accurate impact of any alteration to the transport system or any results of the policy development/direction.

This section thus proposes possible researches to improve this area of study as follows: research on impact and implication of road transport development on energy and environment conditions; research on the data collection and update techniques; research towards basic understanding of transport-energy efficiency improvement measures (vehicle fuel economy, traffic operations, taxation and regulation, promotion of public transport and non-motorized transport mode); research on how to raise public awareness.

Moreover, an accurate method or model to estimate emissions and the diffusion of the pollution for Bangkok is needed. Researches to identify proper measures to reduce adverse environmental effect due to transportation in Bangkok are also indispensable.

Thailand Road Safety Research Challenge

The third topic addresses Thailand road safety research challenge. The 2007 study on the costs of traffic accidents to the nation reveals a staggering sum of USD7.0 billion, equivalent to almost 3.0% of the country GDP in 2007. This topic describes international good practices on road safety (Japan, and the SUN countries) and Thailand's past efforts in managing road accidents, results of interviews of experts, and key recommendations. Table 5 shows the cost of a fatality in ASEAN countries . Figure 5 compares the fatality rate per 100000 population for a number of countries in Asia, Europe and USA.

Table 5 Cost of a Road Fatality in ASEAN

Country	National Costs ($ million)	National Costs (฿ million)	Fatal Costs ($ million)	Fatal Costs (฿ million)	Approach
Brunei	99	4,146	1,419,639	**59,454,481**	HC.
Cambodia	116	4,792	18,864	779,272	HC.
Indonesia	6,032	**249,182**	47,698	1,970,404	HC.
Loa	47	1,984	7,203	301,662	HC.
Malaysia	2,400	100,512	323,021	13,528,119	WTP.
Myanmar	200	8,376	43,614	1,826,561	HC.
Philippines	1,900	79,572	41,330	1,730,900	HC.
Singapore	457	20,894	921,271	42,120,510	HC.
Thailand	3,000	123,930	69,061	2,852,924	HC.
Viet Nam	885	36,559	11,463	473,526	HC.

From: Asean Regional Road Safety Strategy and Action Plan (2005-2010)

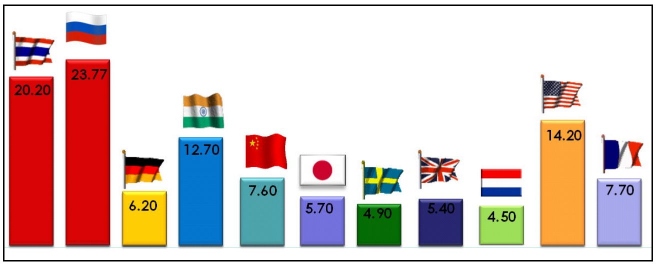

Figure 5 Road Traffic Fatality Rate in 2006 of Thailand, Russia, Germany, Hungary, China, Japan, Sweden, UK, Netherlands, USA, and France

Source: IRTAD(2008) and Royal Thai Police (2008)

The review of international practices can broadly be classified into four categories, namely human factor related, vehicle safety related, road environment related and those related to road crashes including management, enforcement and costs. The interviews of road safety experts focusing on the field of medicine, police, and engineering were conducted to obtain their views about the problems and remedial measures related to road safety.

The goal of this road safety research is to help reduce the nation's loss by saving some 5,000 lives of Thai people in five years and reduce the number of crashes and injuries through the recommendation of strategic research topics. The specific objective is to produce a RED BOOK on road safety and strategic research topics for Thailand. Benchmarking with the international good practices countries indicates the magnitude of the challenge Thailand is facing.

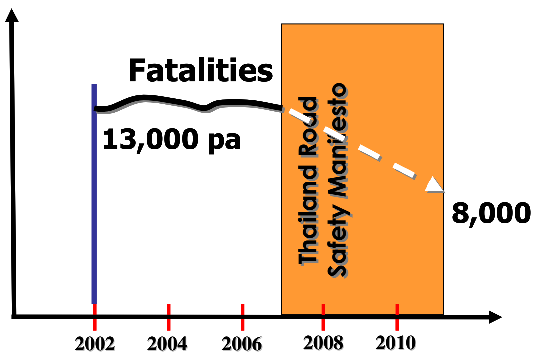

Figure 6 The Challenge of Road Safety Research

The study recommends that the strategic research direction in Thailand should be based on the principle that "**the loss of human life in traffic is unacceptable**" and the country needs to leapfrog into saving the life of its citizens from road crashes. Also, the SUN countries' guiding principle: "**adaptation of road infrastructure, and vehicle to human capacity and tolerance**" should be adopted in the design and construction of the same for Thailand.

Since some of the problems related to road safety are specific to Thailand, special care should be taken to deal with such problem. For example, motorcycle use is rampant in Thailand. Motorcycle crashes and the ensuing casualties are the most significant component of all the road crashes and casualties in Thailand.

The strategic research in future should be focused on ameliorate the safety of the motorcycle users. Crash investigations and analysis can be taken as a lead in the future researches relating to the design of motorcycles, its safety features, exclusive motorcycle lanes and its road-side elements, use of low speed electric motorcycles etc.

Figure 7 A Pilot Motorcycle Lane in Thailand

Figure 8 Misuse of Front Basket

Moreover, researches of practical significance like improvement of vehicle safety features based on the some standard practices like EuroNCAP may be introduced. Use of ITS techniques to enhance safety of vehicles by simplifying and assisting drivers and also providing information for all road users is taken as an area for future researches in road safety. Researches related towards improvement of safety for pedestrians and cyclists and the facilities related to them are other strategic research areas.

Enforcement measures and its efficacy including modernization of surveillance, revision of driver licensing system are some other areas for the future researches. The economic issues related to road safety including the economic losses of road accidents, design and provision of safer road infrastructures and the cost benefit analysis are also key strategic issues for future researches. The identification of barriers to and opportunity for introduction of a road safety bill to mandate the setting and implementation of road safety strategies for dealing with the short and long term challenges must also be a key research area.

Thailand's Logistics Cost

The last research topic deals with the logistics cost. It represents the competitiveness of the country. In this study, the macro logistics cost is analyzed in two ways: logistics activity base and demand group base. The analysis on logistics activity classifies the logistics cost into four categories: transportation cost, inventory carrying cost, administration cost and infrastructure cost. The analysis on demand group classifies the logistics cost into three groups: business, household and government sectors.

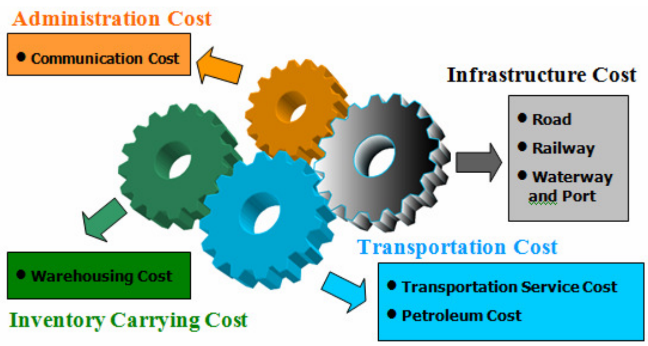

Figure 9 Logistics Cost Components

The study assembles existing data namely, input-output table, GDP, energy consumption in transportation sector, freight transport statistics and business data (i.e., revenue, expenditure, employee, stock value, etc.) available from various Thai authorities and past related researches. The logistics cost can be calculated via the input-output table, gross domestic product and energy consumption in transportation sector.

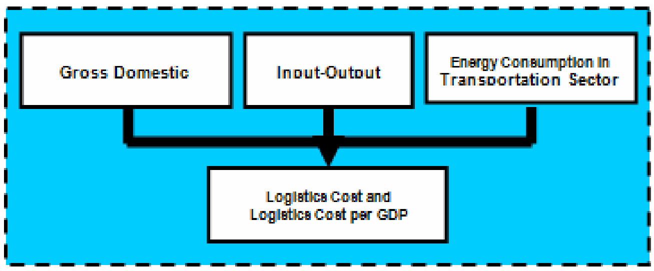

Figure 10 Logistics Cost Calculation Process

Transportation cost comprises transportation service cost, petroleum cost, vehicle cost and maintenance cost. It constitutes the largest part, approx. 60% of total logistics cost. Inventory carrying cost comprises warehousing cost and financial costs. Administration cost includes compensation of employees in business logistics operation and communication cost. The last component is infrastructure cost expensed by government sector.

Comparing the logistics cost with the GDP, it increases rapidly from 17.43% to 18.69% during 2000-2005 and remains approximately constant until 2010. After 2010, it gradually increases to 19.09% in 2020.

Transportation cost increases every year. In 2005, highway cost was 684 billion baht, accounting for 80% of total amount of transportation cost, while railway cost was only 4 billion baht, less than 0.5% of total amount of transportation cost. From this relevant information, shifting road to rail transport is the challenging strategy which is worth investigating.

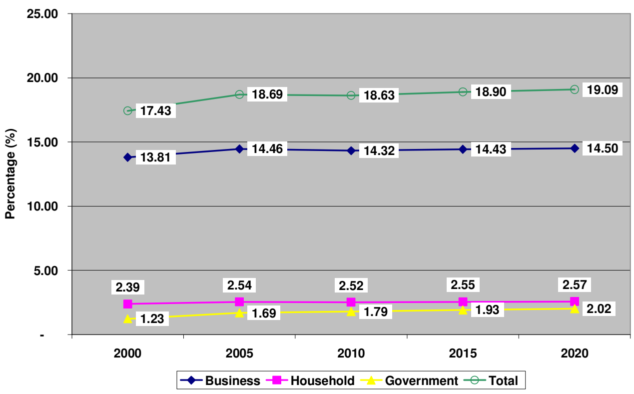

Figure 11 Logistics Cost per GDP by Demand Group

Considering the percentage of logistics cost per total output for each business sector, the highest percentage is in transportation sector, 19.51% followed by the construction sector, 13.81% for the year 2000.

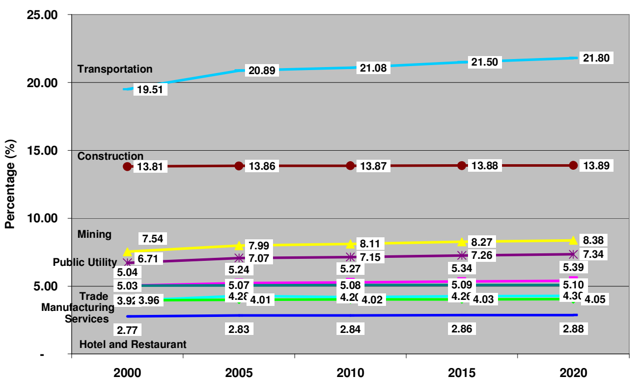

Figure 12 Logistics Cost per Total Output by Business Sector

This research section also performs a policy test: mode-shift strategy, by shifting 5% of total freights from road to rail transportation. The result is shown as follows:

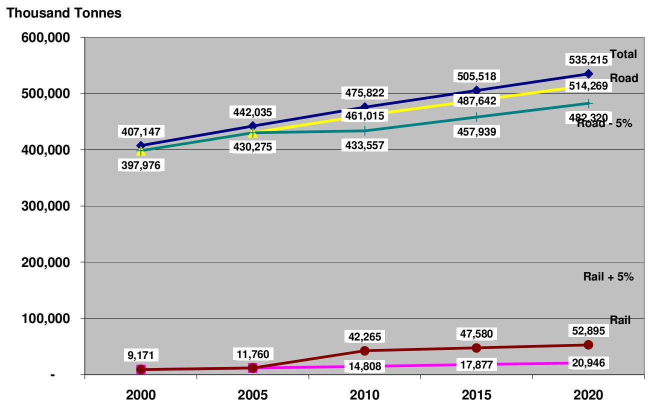

Figure 13 Comparison of Freight Volume

The measurement of the impact of the transport policy is presented in terms of the reduction in macro logistics cost and saving in transport service cost as presented in the following figures.

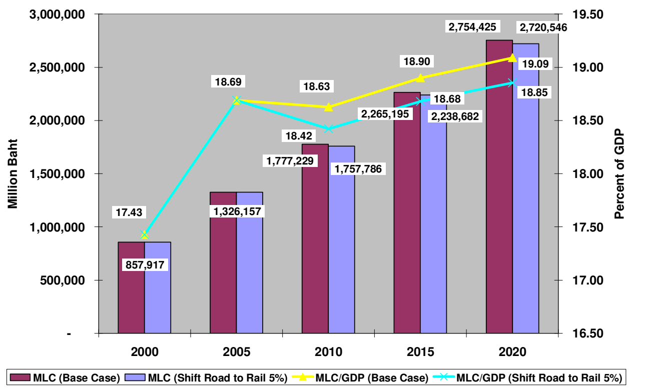

Figure 14 Comparison of Logistics Cost and Logistics Cost per GDP

Table 6 Logistics Cost by Activity (Unit: Million Baht)

Year	2000	2005	2010	2015	2020
Transportation Cost	518,361 (60.42%)	806,510 (60.82%)	1,075,027 (60.49%)	1,369,563 (60.46%)	1,664,987 (60.45%)
Inventory Carrying Cost	210,437 (24.53%)	299,810 (22.61%)	398,313 (22.41%)	497,544 (21.96%)	596,848 (21.67%)
Administration Cost	72,985 (8.51%)	107,321 (8.09%)	142,878 (8.04%)	179,672 (7.93%)	216,571 (7.86%)
Logistics Cost	801,784 (93.46%)	1,213,641 (91.52%)	1,616,218 (90.94%)	2,046,779 (90.36%)	2,478,406 (89.98%)
Infrastructure Cost	56,134 (6.54%)	112,516 (8.48%)	161,011 (9.06%)	218,416 (9.64%)	276,019 (10.02%)
Macro Logistics Cost	857,917 (100%)	1,326,157 (100%)	1,777,229 (100%)	2,265,195 (100%)	2,754,425 (100%)

Table 7 Percentage of Logistics Cost per GDP

Year	2000	2005	2010	2015	2020
Transportation Cost	10.53	11.37	11.27	11.43	11.54
Inventory Carrying Cost	4.27	4.23	4.17	4.16	4.14
Administration Cost	1.48	1.51	1.50	1.50	1.50
Logistics Cost	16.29	17.10	16.94	17.08	17.18
Infrastructure Cost	1.14	1.59	1.69	1.82	1.91
Macro Logistics Cost	17.43	18.69	18.63	18.90	19.09

Table 8 Transportation Cost by Mode (Unit: Million Baht)

Year	2000	2005	2010	2015	2020
Transportation Cost	518,361 (100%)	806,510 (100%)	1,075,027 (100%)	1,369,563 (100%)	1,664,987 (100%)
Railway	2,677 (0.52%)	3,782 (0.47%)	4,932 (0.46%)	5,942 (0.43%)	6,830 (0.41%)
Highway	420,303 (81.08%)	684,197 (80.37%)	852,448 (79.30%)	1,078,402 (78.74%)	1,305,045 (78.38%)
Waterway	79,120 (15.26%)	131,301 (16.28%)	186,835 (17.38%)	246,881 (18.03%)	307,213 (18.45%)
Airway	10,077 (1.94%)	14,630 (1.81%)	19,587 (1.82%)	24,517 (1.79%)	29,484 (1.77%)
Others	6,184 (1.19%)	8,600 (1.07%)	11,226 (1.04%)	13,821 (1.01%)	16,417 (0.99%)

Table 9 Logistics Cost by Demand Group (Unit: Million Baht)

Demand Group	2000	2005	2010	2015	2020
Business	679,759 (79.23%)	1,026,062 (77.37%)	1,365,947 (76.86%)	1,728,910 (76.32%)	2,092,736 (75.98%)
Household	117,478 (13.69%)	180,414 (13.60%)	240,598 (13.54%)	305,379 (13.48%)	370,349 (13.45%)
Government	60,681 (7.07%)	119,681 (9.02%)	170,684 (9.60%)	230,906 (10.19%)	291,339 (10.58%)
Total	857,917 (100%)	1,326,157 (100%)	1,777,229 (100%)	2,265,195 (100%)	2,754,425 (100%)

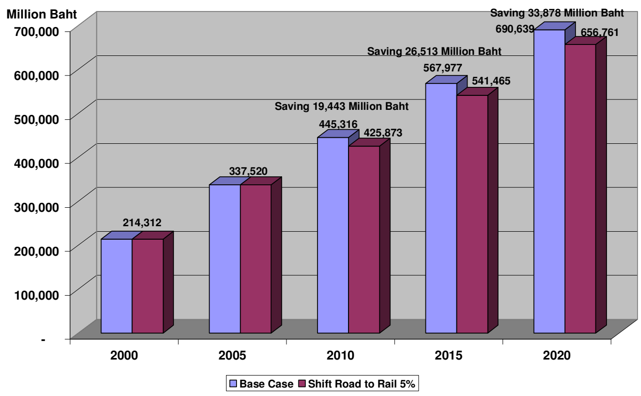

Figure 15 Comparison of Freight Transport Services Cost

Moreover, the study presents benefits resulting from the proposed mode shifting strategy: reduction in transportation energy consumption and reduction in air pollutant emissions, e.g., CO_2, CO and NO_X. They are presented as follows:

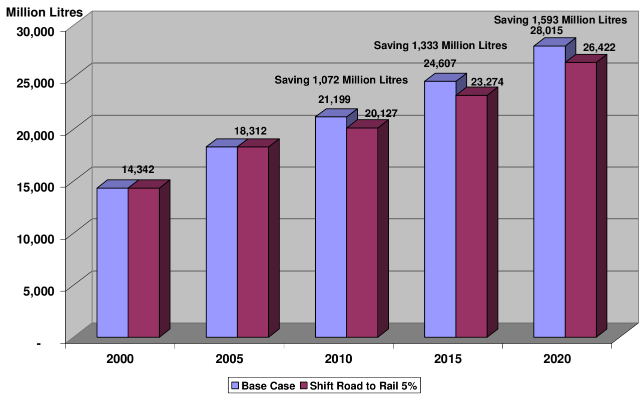

Figure 16 Comparison of Energy Consumption

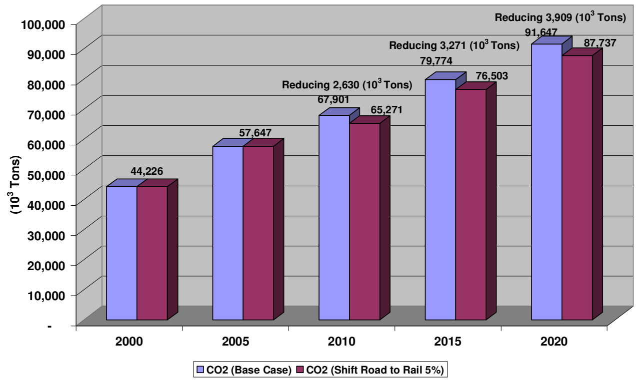

Figure 17 Comparison of CO_2 emission

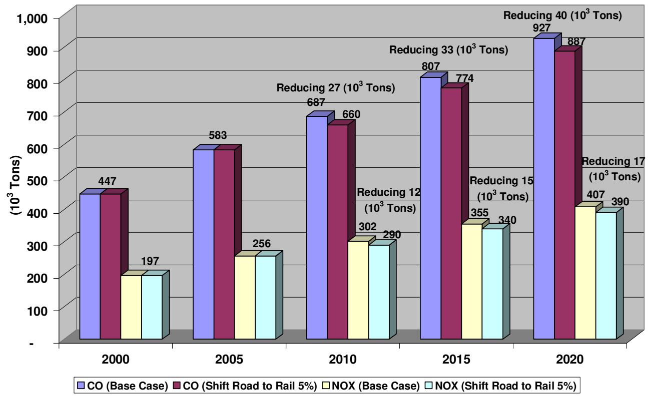

Figure 18 Comparison of CO and NO_X emissions

In summary, macro logistics cost could be estimated from the input-out table. Thailand's logistics cost was 858 and 1326 billion Baht in 2000 and 2005 respectively. It would reach 1777, 2265, and 2754 billion Baht in 2010, 2015 and 2020 respectively. It rapidly rises from 17.43% in 2000 to 18.69% of GDP in 2005. It would increase to 19.09% in 2020. Thailand's logistics cost is high comparing to the developed countries, e.g., Japan, US, UK, that varied between 10 to 11% of GDP.

No one area of logistics operates independently. As a case study of the mode-shift strategy, it does not work in transportation area only. All components of logistics activity, i.e., transportation, inventory, warehousing, are interrelated. The decisions made in the transportation system have an impact on the cost of inventory and warehousing. The total logistics cost must be considered. This challenge requires further close consideration.

FINALE

This entire research work concentrates mainly on analyzing the "*cost*" the public has to bear. It appears in various forms of resources consumption: travel time and logistics costs, energy usage, fatalities and injuries from road accidents and environmental degradation. Nonetheless, the research group assures that the study results, alias the "*benefit*", will lead to more cautious resources consumption, i.e. sustainable development.

Bangkok has long suffered from the transportation syndromes, even before the introduction of the first modern transport planning process in 1972. All the accumulating problems can not be solved overnight. It requires *strong, serious and sincere* wills to work together to overcome the obstacles.

The transportation research in Thailand is still in its infancy. Both the concerned agencies and the researchers need to put more efforts to boost the Thai research realm to international level and develop Thailand's own research based "*transport standards*." The standards, the country badly need. This study is a good example of the much needed efforts to mark an "*origin*." The "origin" that is crucial for the long journey to the final "*destination.*" However, since our major goal is to construct a "*foundation*" for future researches, it appears the challenges have already been challenged and yet still needs to pave a proper pathway for sustainable transport development to suit with our dynamic society.

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2. Highlight transportation research that addresses policy implication, modeling, technological application, social and cultural aspects, energy and environmental problems.

3. Discuss on the human aspect when considering traffic safety problems.

4. Further strengthen academic exchange with different countries and to examine transferability between countries of various policies and countermeasures for traffic safety and transportation-related problems.

5. Create opportunities to stimulate practical policy change.

6. Encourage students, faculty members, researchers, engineers, scientists, administrators, policy-makers and others to conduct comparative research and related activities.

ATRANS RESEARCH provided opportunities to exchange informative, innovative and critical ideas on a wide range of multidisciplinary issues in Asia and beyond. The issues are addressed in four major areas as follows:

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2. Traffic safety aspects including investigation of human behavior, accident analysis, ergonomics, social and cultural analysis, medical and health impact, traffic education, community and school based approach.
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   The abstract should contain approximately 1000 words in length.

   - The abstract should include title of paper, author's name, affiliation, mailing address, telephone and fax numbers, e-mail address.
   - Three to five keywords must be indicated after the abstract.
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1. Language: The abstract or manuscript to be submitted to ATRANS RESEARCH must be written in English Language.

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3. Submission format: Authors should submit papers in MS-Word by e-mail attachment.

4. Abstract and keywords: All papers should start with an abstract of 300-350 words and 3-5 keywords.

5. Tables, figures & photographs: Tables, figures and photographs must be ordinal numbered as they appear in the paper/manuscript, and must be accompanied by a self-explanatory caption and its source(s) if applicable. Please note that final output will be in black and white color only so makes sure that those figures are simply identifiable or readable in black and white.

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   1. Book:
      Jaensirisak, S. Model choice behavior in Bangkok. In May, A. (Eds.) Travel Behavior in City. Wiley, London. pp.10-30. (1998).

   2. Journal:
      Fukuda, T. Road traffic safety in Japan. “IATSS Research” Volume 27, No. 50, pp. 57-72. (2002)

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

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902/1, 9th Floor, Glas Haus Building, Soi Sukhumvit 25 (Daeng Prasert),
Sukhumvit Road, Klongtoey-Nua, Wattana, Bangkok 10110, Thailand
Tel. (66) 02-661-6248 FAX (66) 02-661-6249
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