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An Analysis of Vehicle Kilometers of Travel of Major Cities in Thailand

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CHAPTER I INTRODUCTION

1. Introduction

Vehicle kilometer of travel (VKT) is one of the most meaningful indicators to represent travel demand in a particular area (Chin et al, 1999) or on highway systems (Wang and Teng, 2004). In the countries that such estimates are available, VKT are often used for setting goals and objectives in transportation planning (Lie et al, 2006) and used in various important decision making processes, such as the compliance with the air quality, and funding allocation for roadway improvements (Wang and Teng, 2004). Furthermore, the travel demand in the form of VKT is often used to indicate the exposure to traffic in an area, thus is commonly used for normalizing various traffic parameters that enable us to make a fair comparison of ratios across regions/countries (Cardoso, 2005), for example, the number of accidents per 100 million vehicle kilometers of travel. However, in countries that government agencies do not collect the actual odometer readings of the registered vehicles on a regular basis, like Thailand, it is easy to obtain the exact number of kilometers traveled, and it is required to use an estimate instead.

1.1 Rationale

There are a few approaches that are commonly used to estimate VKT in a particular area. The first approach is the estimation from a developed transport model, normally the conventional four-step method. Once the model is developed for the area, it can be used to estimate and forecast trip generation, trip distribution, mode choice, traffic assignment, then vehicular kilometers of travel as a by-product. An example is the project that is performed by Fort Collins LUTRAQ team in USA. Second, VKT can be estimated indirectly from the amount of gasoline consumption or the transport expenditures of the citizens in the area (e.g., Cardoso, 2005). Such data can be converted to the amount of travel, when modes of travel and the gasoline consumption rates by travel modes are known. Finally, the VKT can also be estimated from the odometer readings that are regular recorded by various government agencies or private enterprises (e.g., Stopher and Swann, 2008). With this method, we are able to estimate the average vehicle kilometers of travel for each vehicle type and size, and apply the numbers to the vehicle fleets in the area.

1.2 Objectives

The ultimate goal of this study is to estimate the travel demand of Bangkok Metropolis and majors provinces in Thailand, in terms of vehicle kilometers of travel (VKT), by using records of odometer readings. The researchers aim to analyze distance traveled with vehicle characteristics, end-user's socio-economics, and household characteristics, to investigate degree of influencing of such factors on vehicle distance travel.

1.3 Scope of Work

The study is focusing in two study areas: Bangkok Metropolis and Nakorn Ratchasrima province. The Bangkok Metropolis is the most highly urbanized city in Thailand, whereas Nakorn Ratchasrima is one of the major regional provinces in North Eastern of Thailand. It is one of three major cities in this regional. These two areas are different in socio-economic characteristic and transport characteristics. We expect that the analysis of these areas will be presented the different characteristics of VKT in the highly urbanized area as Bangkok and the major province of regional area in Thailand.

1.4 Benefit from the study

Despite the numerous benefits of the parameters VKT, there exist very few efforts to estimate VKT in Thailand. Currently, the Energy Planning and Policy Office (EPPO) and Department of Highways (DOH) are the only two agencies that have attempted to estimate such parameters. The EPPO estimates and forecasts the VKT using an indirect method from gasoline consumption and transport expenditure data. However, the estimations by EPPO have been conducted sporadically, and it uses simple assumptions, thus there is likelihood that the results will not be satisfactory. Moreover, such estimates have never been cross-checked with the estimates from other methods, so it is difficult to know the accuracy of the estimation. For the DOH's method, it simply uses traffic volume data which collected on the major highways and multiplies by the segment lengths to approximate the amount of VKT. However, the volume data are only available for the major highways, thus the results from this method will not include the travel demand on minor highways, rural highways nor local streets. Thus, the estimated VKT tends to be underestimated.

Consequently, the ultimate goal of this study is to estimate the travel demand of Greater Bangkok area and majors provinces in Thailand, in terms of vehicle kilometers of travel (VKT), by using the available records of odometer readings. In addition, the researchers expect to get better understandings of the pattern of distance traveled of various vehicle types and sizes, which are yet not well documented in Thailand.

CHAPTER 2 Literature Review

This chapter presents the literature review in the area of the VKT estimation using the odometer readings.

2.2.1 Review of VKT model

Azevedo et al (2007) has estimated the vehicle kilometers of travel in Portugal using a model that developed from the odometer reading records. The study collected information from 5 million vehicles or 67 percent of the total vehicle fleet in Year 2006.

The annual VKT estimation was estimated using the following formula:

$$ADTD_j^i = \frac{1}{J^{TOT}} \times \sum_{k=1}^{K-1} \left(\frac{R_i^{k+1}}{\Delta T^{k+1;k}} \times J^{k+1;k} \right)$$

where

$ADTD_j^i$ =Annual Daily Travelled Distance of the vehicle i in the year j (km/day).

J^{TOT} =Total number of days in the year j.

K =Set of of odometer reading of interest for the calculation of the AADT of year j(readings in the year j ,the last reading before year j ,and the first reading after the year j)

R_i^k =Odometer reading k of the vehicle i(kilometer)

$\Delta T^{k+1;k}$ =Number of day between the two consecutive odometer reading k and k+1.

$J^{k+1;k}$ =Number of days within year j between the two consecutive reading k and k+1.

The forecasting results of VKT for 2004 found that the total travel distance of the light vehicles was approximate 91.4 percent, while the distance travel by heavy vehicles account for only 8.6 percent.

The estimated VKT in 2005 showed that the total travel distance on national road network was approximately 50.7 percent of the total nation VKT. The heavy vehicles tend to travel on the national road network 65.4 percent, while the light vehicles travel on the national road network by 50.5 percent.

Bureau of Automotive Repair (2000) proposed a methodology for estimating VKT in 1999 for all registered vehicles in California. The objective of the study is to utilize the estimated VKT to evaluate the efficiency of the I/M program. The VMT data was collected from the odometer readings, simply the difference of the two odometer readings divided by the number of days in between. Table 1 below shows the analysis results from the 6.2 million vehicles included in this study.

Table 1 Annual VMT by Vehicle Type and Program Area

Vehicle Type	Enhanced	Basic or Change of Ownership	Statewide
Passenger CAR	11,936	11,489	11,794
Light Duty Truck	12,717	12,272	12,556
Medium Duty Vehicle	12,511	12,312	12,425
Heavy Duty Truck	11,150	10,618	10,971
All Vehicle Types	12,132	11,720	11,995

2.2.2 VKT model development

Corpuz et al (2006) developed a household VKT model for Sydney, Australia using a regression analysis. The modeled developed based on the household travel data collected between 1997 – 2004 for a total number of 16,000 households. The independent variables include the distance from the residence to the central business district (CBD), accessibility to public transit, employee density, household density, land use, type of residency, household vehicle ownership, the number of household members, the number of household members with driver licenses, and household income. The model is a multiple linear regression model with a general form of:

Y = a+b1x1 +b2x2+...+ b2x2

The study found that the independent variables that are significant to the model with a 95% confidence interval include household vehicle ownership, the distance from the residence to the CBD, land use, employment, household density and accessibility to public transit. The model's coefficient of correlation (r2) is 0.731.

Cervero and Hansen(2000) studied the relationship between the road serviceability and the travel demand. The road serviceability was measured in vehicle miles of travel (VMT) and the width of the road. In this study, a variety factors representing politics, environment, and population were used as independent variables of the models.
The model was developed based on the 22-year data of 34 cities in California using a regression model. It was found that the key variables for determining VMT include the number of lanes, the total length of the roadways in the area, gasoline price, the number of population, per capita income, and land use density.

Cameron et al (2004) studied the trend of VKT in various cities in the world from 1960 – 1990 by focusing on the changing trends to policies and drivers. The increasing trends of VKT in the city was found to be a result from the growth in population, the growth of the city, the growth in the private vehicles, and the growth in automobile ownership.

CHAPTER 3 Methodology

This chapter describes the methodology used in this study. Section 3.1 summarizes the study areas under investigation. Section 3.2 lists the classifications of vehicles of this study. The data collection procedure and the estimation of the sample size are described in Sections 3.3 and 3.4, respectively. Section 3.5 explains the methodology used for the data analysis.

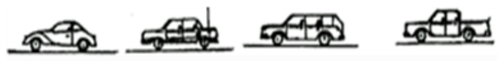
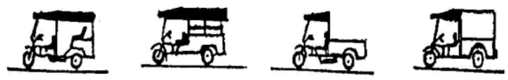
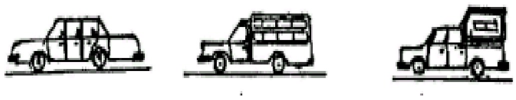
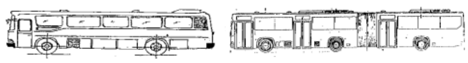
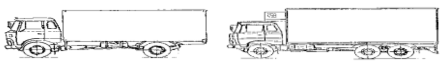
3.1 Study Area

This study focuses on the two provinces of Thailand: Bangkok and Nakhon Ratchasima. Bangkok is the capital city of Thailand with a population of 5,702,595(2009). It is the most highly urbanized city in Thailand, and houses many government agencies, important central business districts, high-rise building, offices, shopping malls. Approximately 25 percent of the gross domestic product of Thailand occurred in Bangkok. As of 2009, there are a total of 600,901 vehicles registered in Bangkok; approximately 54 percent are motorcycles, 0.61 percent are passenger vehicles, and 11 percent are pick-up trucks. The median income of Bangkokians is approximately 334,053 Baht per head(2008). Bangkok is, perhaps, the city that has the most decent public transit system in Thailand with numerous organized buses and public vans, skytrains, subways, commuter trains, taxis and motorcycle taxis. Other than private vehicle (like, passenger cars or motorcycles), Bangkok people has a variety of transport options to travel in the city. The other province, Nakhon Ratchasrima is one of the major regional provinces in North Eastern of Thailand with a population of 2,571,292(2009). It encompassed the area of 20,494 square kilometers, becoming the 1st largest city in Bangkok in terms of area. The Gross Provincial Product of Nakhon Ratchasima accounts for 1.74 percent of the nation GDP. In 2009, there are a total of 73,790 vehicles registered in Nakhon Ratchasima, approximately 71 percent is motorcycles, 9 percent is pick-up trucks, and 0.69 percent is passenger vehicles. The median income of Nakhon Ratchasima residents is approximately 56,872 Baht per head(2008). As typical regional cities, the public transit system of Nakhon Ratchasima is not in its best quality. There are a few bus routes available, but its service is far from convenience since the conditions of the vehicles are usually, old, rotten and lack of safety. Besides, it operates with slow speed, unreliable timetables, unsafe driving behavior. Thus, residents of Nakhon Ratchasima would travel with private vehicles if they have choice. Bangkok and Nakhon Ratchasima possess different socio-economic characteristic and transport characteristics. We expect that the analysis of these areas will show the different characteristics of VKT in the highly urbanized area as Bangkok and the major province of regional area in Thailand.

3.2 Classifications of Vehicles

This study will classify the vehicles in accordance to the vehicle classification of the Department of Land Transport due to the convenience of total VKT estimation in the last step. The classifications of the vehicles are summarized in Table 3.2-1. They include Sedan (not more than 7 passengers), Vans/pick-ups, motorcycles, urban Taxis, motortricycle/Motortricycle taxi/tuk tuk, motorcycle taxi, microbus and passenger pick-ups, fixed route buses and non-fixed route truck.

Table 3.2-1 Type of vehicle

No.	Type of Vehicle	Illustration.
1	Sedan Not more than 7 pass.	
2	Van & Pick up	
3	Motorcycle	
4	Urban Taxi	
5	Motortricycle &Motortricycle taxi,tuk tuk	
6	Motorcycle Taxi	
7	Microbus&Passenger Pick Up	
8	Fixed Route Bus	
9	Non Fixed Route Truck	

3.3 Data Collection

Both primary and secondary data are collected and utilized in this study, as summarized in Table 3.3-1. The primary data of basic socio-economic of drivers, vehicle characteristics and travel demand characteristics will be collected from a direct interview. In addition, the secondary data, such as, the number of registered vehicles, the detailed characteristics of vehicles will be also collected from the official data sources, such as Department of Land Transport (DLT), and National Statistical Office (NSO), etc.

Table 3.3-1 Source of Data

DATA DESCRIPTION	VEHICLE TYPE	TYPE OF DATA	DATA SOURCES
1.The number of registered vehicles	All	Secondary	www.dlt.co.th
2. Record of registeration	All	Secondary	www.dlt.co.th
2. Vehicle Characteristics -Age Of Vehicle -License Plate -Odometer Reading	-Urban Taxi -Microbus &Passenger Pick Up -Fixed Route Bus -Truck	Primary	-Bus Terminal -Shopping Mall
3. Questionnaire. 3.1.Socio-Economic Of End-User -Gender, Position ,Age -Education Level -Carreer, Income Etc 3.2 Vehicle Characteristics -License Plate -Size Of The Engine -Model Of Vehicle -Vehicle Age -Fuel Type -Odometer Reading 3.3 Household Characteristic -Number Of Member -Status In Home -Number Of Vehicle	-Sedan Not More Than 7 Pass -Van & Pick Up -Motorcycle -Motortricycle& Motortricycle Taxi Tuk Tuk -Motorcycle Taxi	Primary Primary Secondary Secondary Secondary Secondary	-Shopping Mall -Bus Terminal -DLT DLT DLT DLT DLT

3.4 sample size

In this study, we determine the minimum sample size for each of the vehicle category using a formulation of Taro Yamane

$$n = N/(1 + Ne^2)$$

Where

n = Sample size

N = Population size

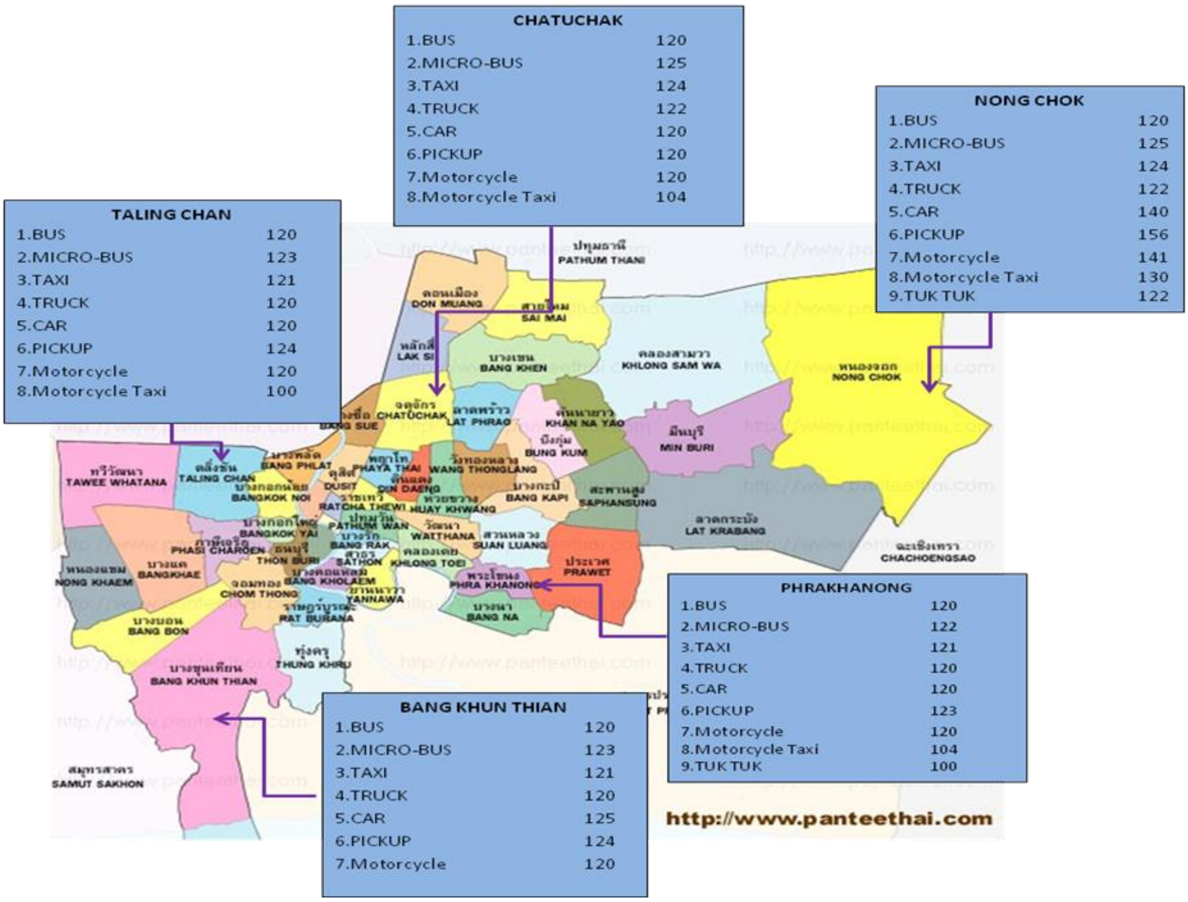
e = Error of random sample size (0.05)

The total number of vehicle registration for each vehicle class is collected from the Department of Land Transport. Based on the statistics coupled with the Yamane's equation, we can estimate an approximate number of the sample for both Bangkok and Nakhon Ratchasima sites as summarized in Table 3.4-1

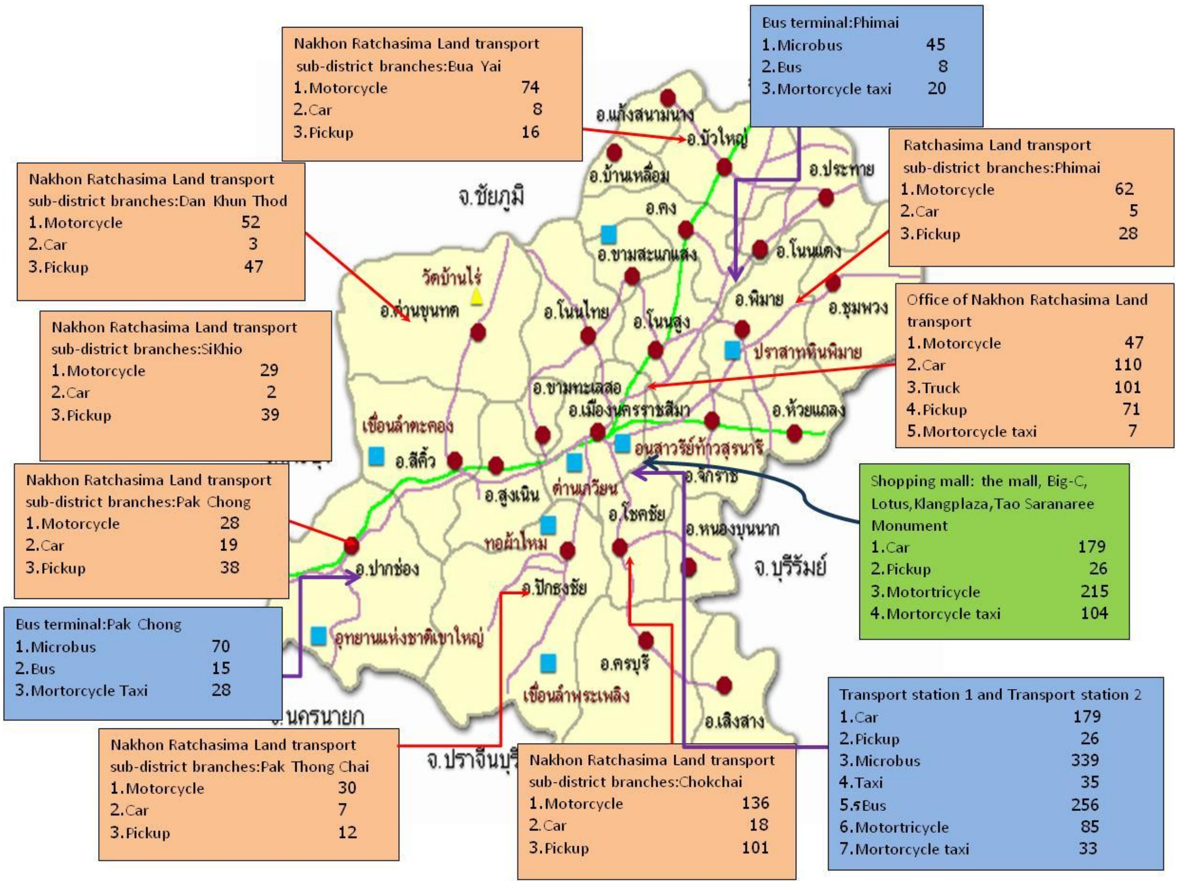
Table 3.4-1 Estimated sample size for each location

No.	Type of Vehicle	Vehicle Register*		Sample size		Acquired	
		Bangkok	Korat	Bangkok	Korat	Bangkok	Korat
1	Sedan Not more than 7 pass.	2,074,491	79,546	400	400	581	409
2	Van & Pick up	947,204	154,934	400	400	628	442
3	Motorcycle	2,339,308	57,359	400	400	569	463
4	Urban Taxi	83,857	34	400.	32	611	36
5	Motortricycle &Motortricycle taxi,tuk tuk	9,645	802	385	270	509	300
6	Motorcycle Taxi	73,301	2,197	400	340	493	192
7	Microbus& Passenger Pick Up	192,675	7,645	400	385	618	468
8	Fixed Route Bus	21,390	3,643	395	365	600	279
9	Non Fixed Route Bus	49,203	3,586	400	360	604	71

In this study, we conducted a survey at different key locations, including the local offices of Department of Land Transport throughout the province, the shopping malls in different areas The summary of survey locations in Bangkok and Nakhon Ratchasima are provided in Figures 3.4-1 and 3.4-2, respectively. It should be noted that we try to cover the entire province area as much as possible, in order for the collected numbers truly representing the overall vehicle usage of the province.



Figures 3.4-1.The summary of survey locations in Bangkok



3.4-2 . The summary of survey locations in Nakhon Ratchasima

3.5 Data Analysis

Generally, the VKT is influenced by many factors, such as age of vehicle, socio-economics of vehicle’s owner, household characteristics, fuel price, transport infrastructure, (Button et al, 1993; Kenworthy and Laube, 1996). Previous research papers, for instance, indicate that the age of the vehicle will play roles on the VKT as well, that is, as the vehicles get older, it will be driven less distance, as presented in Fig. 1. In this study, the relationship between the VKT of each vehicle type and its influencing factors will be analyzed.

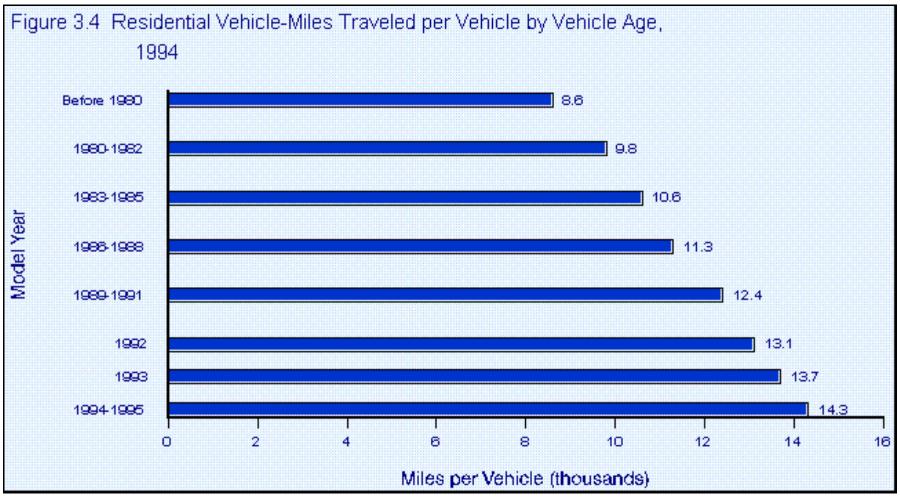


Figure 1 Residential Vehicle-Miles Traveled (VMT) per Vehicles by Vehicle Age
Source: http://www.eia.doe.gov/emeu/rtecs/chapter3.html

In this study, the researchers will employ descriptive statistical methods to analyze and model VKT from the odometer reading data. The VKT statistics will, later, be applied to the entire vehicle fleet of the Greater Bangkok Area and Nakhon Ratchasima in order to estimate the overall VKT in these two provinces. The VKT estimates will then be compared with the results from other estimation methods. As well, a comparison will be made to compare the amount of travel in other countries/cities.

CHAPTER 4 Results

This chapter presents the data collected from the odometer reading surveys and the initial results of data analysis per vehicle types. It covers the descriptive statistics of the collected data, as well as the initial findings of the statistical analysis. This chapter includes the collected data in Nakhon Ratchasima province and Bangkok province, as described in Sections 4.1 -4.4, respectively. .

4.1 Odometer reading data in Nakhon Ratchasima

From the odometer reading surveyed conducted in Nakhon Ratchasima, the research team summarize the cumulative VKT data by vehicle types as described below.

4.1.1 Sedans (not more than 7 passengers)

The total number of sample of this vehicle group was 297 vehicles, which had been collected from various locations in Nakhon Ratchasima, as described in Chapter 3. Figure 4.1.1 shows the collected cumulative VKT data versus the vehicle age of sedans (not more than 7 passengers). The average cumulative VKT and the number of samples per the vehicle age group are summarized in Table 4.11. As shown, the number of samples in each vehicle age group varies since it is a randomly selected surveyed. In order to make the analysis meaningful, the research team selected the data of the vehicle age groups that contain 10 or more samples for further analysis. (We assumed that the number of samples less than 10 vehicles would not be sufficiently represented the population of that group.) Table 4.1.2 lists those vehicle age groups that have more than 10 samples.

Figure 4.1.1 the distribution of the collected cumulative VKT Vs vehicle age of Sedans (not more than 7 passengers)

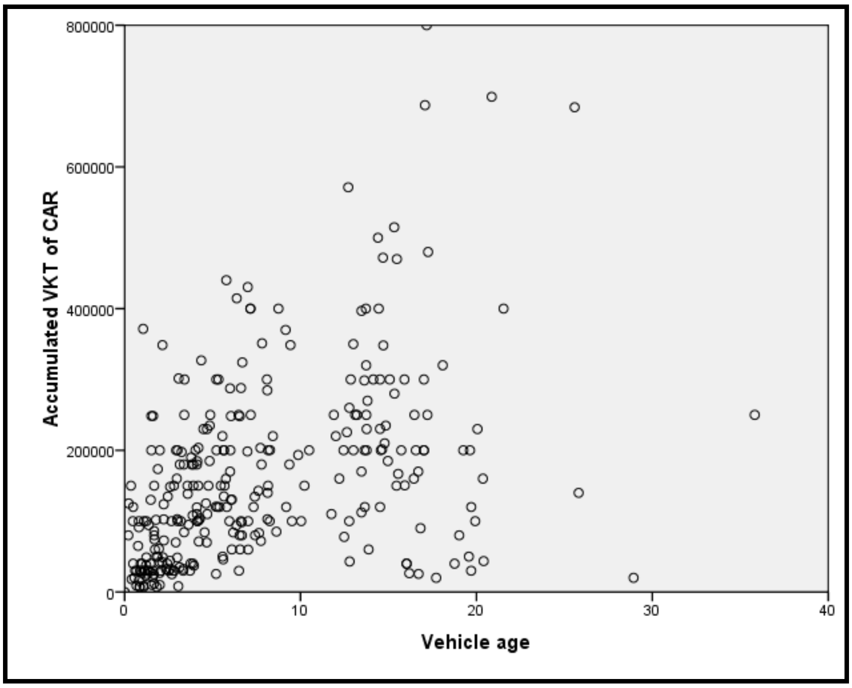


Table 4.1.1 Average cumulative VKT per vehicle age of Sedans (not more than 7 passengers)

Vehicle Age	Accumulated VKT of Car	N	Vehicle Age	Accumulated VKT of Car	N
1	53421	22	14	239873	17
2	77578	40	15	284728	13
3	89441	24	16	281351	9
4	128377	26	17	111337	9
5	157391	23	18	367150	8
6	172103	21	19	180000	2
7	177436	20	20	111429	7
8	184056	14	21	283139	4
9	198459	12	22	400000	1
10	218663	6	26	412157	2
11	150000	3	29	20000	1
12	180000	2	36	250000	1
13	215766	10			
Total			297		

N – sample size, in vehicle

Table 4.1.2 Average cumulative VKT per vehicle age of Sedans (not more than 7 passengers), only for the vehicle age groups with more than 10 samples.

Vehicle Age	Accumulated VKT CAR	N
1	53421	22
2	77578	40
3	89441	24
4	128377	26
5	157391	23
6	172103	21
7	177436	20
8	184056	14
9	198459	12
13	215766	10
14	239873	17
15	284728	13
Total		242

N – sample size, in vehicles

4.1.2 Vans and Pick-ups

The total number of sample of this vehicle category was 218 vehicles, which had been collected from various locations in Nakhon Ratchasima. Figure 4.1.2 shows the collected cumulative VKT data versus the vehicle age of vans and pick-ups. The average cumulative VKT and the number of samples per the vehicle age group are summarized in Table 4.1.3. As shown, the number of samples in each vehicle age group varies since it is a randomly selected surveyed. In order to make the analysis meaningful, the research team selected the data of the vehicle age groups that contain 10 ore more samples for further analysis. (We assumed that the number of samples less than 10 vehicles would not be sufficiently represented the population of that group.) Table 4.1.4 lists those vehicle age groups that have more than 10 samples.

Figure 4.1.2 the distribution of the collected cumulative VKT Vs vehicle age of Vans/Pick-ups

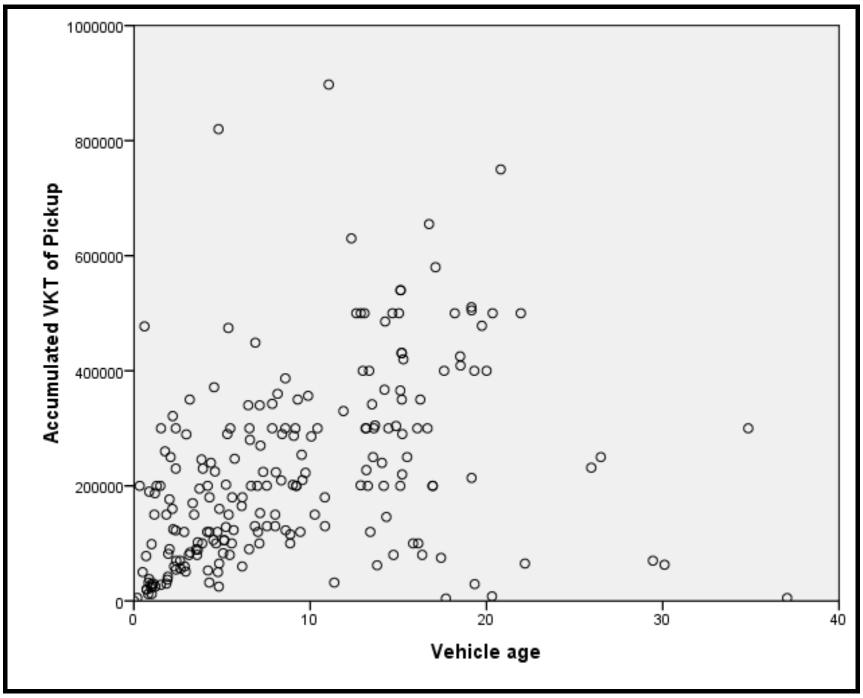


Table 4.1.3 Average cumulative VKT per vehicle age of Vans/Pick-ups

Vehicle age	Accumulated VKT	N	Vehicle age	Accumulated VKT	N
1	69,017	19	16	344,782	12
2	124,231	16	17	273,123	8
3	146,196	16	18	264,803	4
4	151,227	13	19	444,667	3
5	175,729	17	20	362,389	7
6	183,518	14	21	419,333	3
7	209,490	12	22	500,000	1
8	212,708	11	23	65,000	1
9	231,009	10	26	231,572	1
10	250,015	10	27	250,000	1
11	209,170	5	30	70,000	1
12	419,807	3	31	63,000	1
13	446,200	5	35	300,000	1
14	275,505	12	38	5,100	1
15	312,275	10			
Total			218		

N – sample size, in vehicles

Table 4.1.4 Average cumulative VKT per vehicle age of Vans/Pick-ups, only for the vehicle age groups with more than 10 samples.

Vehicle age	Accumulated VKT	N	Vehicle age	Accumulated VKT	N
1	69,017	19	8	212,708	11
2	124,231	16	9	231,009	10
3	146,196	16	10	250,015	10
4	151,227	13	14	275,505	12
5	175,729	17	15	312,275	10
6	183,518	14	16	344,782	12
7	209,490	12			
Total			160		

N – sample size, in vehicles

4.1.3 Motorcycles

The total number of sample of this vehicle category was 191 vehicles, which had been collected from various locations in Nakhon Ratchasima. Figure 4.1.3 shows the collected cumulative VKT data versus the vehicle age of motorcycles. The average cumulative VKT and the number of samples per the vehicle age group are summarized in Table 4.1.5, while Table 4.1.6 lists those vehicle age groups that have more than 10 samples.

Figure 4.1.3 the distribution of the collected cumulative VKT Vs vehicle age of Motorcycles

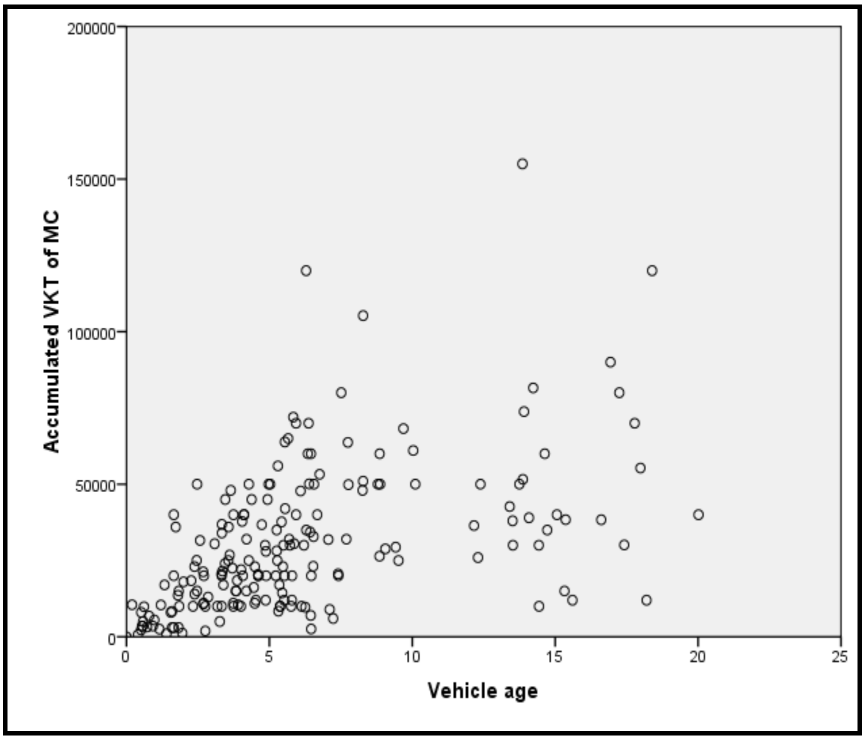


Table 4.1.5 Average cumulative VKT per vehicle age of Motorcycles

Vehicle age	Accumulated VKT	N	Vehicle age	Accumulated VKT	N
1	5,191	12	11	50,000	1
2	12,357	17	13	37,469	3
3	17,187	15	14	63,009	7
4	23,053	27	15	42,594	6
5	28,752	23	16	26,343	4
6	30,888	27	17	64,180	2
7	39,773	19	18	58,852	4
8	34,784	9	19	66,000	2
9	55,808	7	20	40,000	1
10	42,499	5			
Total			191		

N – sample size, in vehicles

Table 4.1.6 Average cumulative VKT per vehicle age of Motorcycles, only for the vehicle age groups with more than 10 samples.

Vehicle age	Accumulated VKT	N	Vehicle age	Accumulated VKT	N
1	5,191	12	5	28,752	23
2	12,357	17	6	30,888	27
3	17,187	15	7	39,773	19
4	23,053	27			
Total			140		

N – sample size, in vehicles

4.1.4 Urban Taxis

Urban taxi is the vehicle group that is relatively new in Nakhon Ratchasima. It was first introduced to Nakhon Ratchasima in Year 2008. As of now, there are a total of 35 urban taxis registered in Nakhon Ratchasima; all of them were surveyed in this study. Figure 4.1.4 shows the collected cumulative VKT data versus the vehicle age of urban taxis. The average cumulative VKT and the number of samples per the vehicle age group are summarized in Table 4.1.7, while Table 4.1.8 lists those vehicle age groups that have more than 10 samples.

Figure 4.1.4 the distribution of the collected cumulative VKT Vs vehicle age of Urban taxis

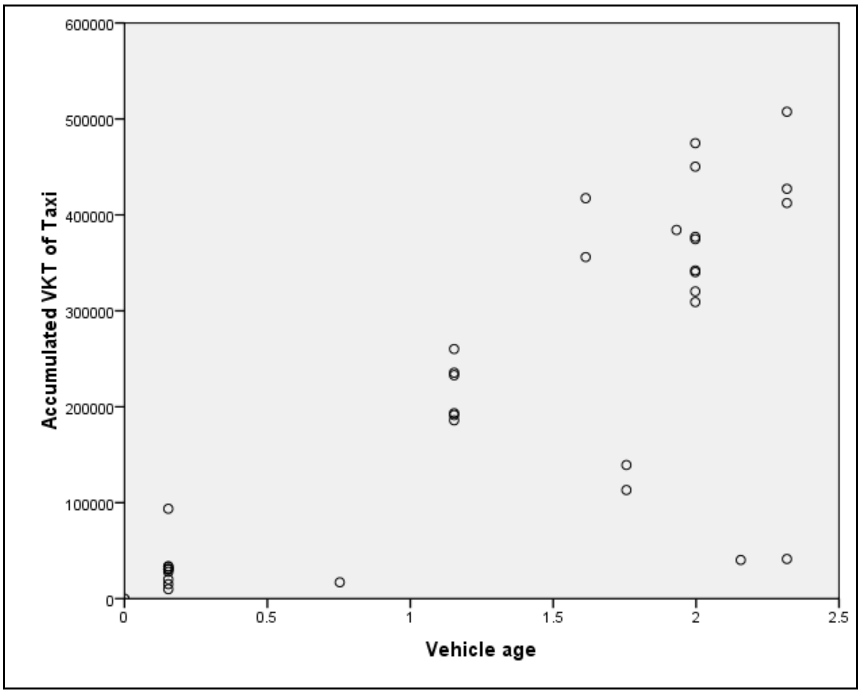


Table 4.1.7 Average cumulative VKT per vehicle age of Urban Taxis

Vehicle age	Accumulated VKT	N	Vehicle age	Accumulated VKT	N
0.5	32,603	10	2.5	305,483	12
1.5	188,032	7	3	347,127	4
2	386,729	2			
Total			35		

N – sample size, in vehicles

Table 4.1.8 Average cumulative VKT per vehicle age of Urban taxis, only for the vehicle age groups with more than 7 samples.

Vehicle age	Accumulated VKT	N	Vehicle age	Accumulated VKT	N
0.5	32,603	10	2.5	305,483	12
1.5	188.032	7			
Total			29		

N – sample size, in vehicles

4.1.5 Tuk-Tuks

Tuk-tuk is the vehicle type that has been presented in Nakhon Ratchasima for a few decades. It is rather difficult to collect the odometer readings of Tuk-tuks, since such vehicles do not have a odometer guage. In this study, the surveyor then requested supplementary information from the drivers, such as the average daily VKT, or the average daily amount of energy consumed. The information was then translated into the annual vehicle kilometers of travel of Tuk-tuks. The total number of sample of this vehicle category was 256 vehicles, which had been collected from various locations in Nakhon Ratchasima. Figure 4.1.5 shows the collected cumulative VKT data versus the vehicle age of tuk-tuks. The average cumulative VKT and the number of samples per the vehicle age group are summarized in Table 4.1.9, while Table 4.1.10 lists those vehicle age groups that have more than 10 samples.

Figure 4.1.5 the distribution of the collected cumulative VKT Vs vehicle age of Tuk-tuks

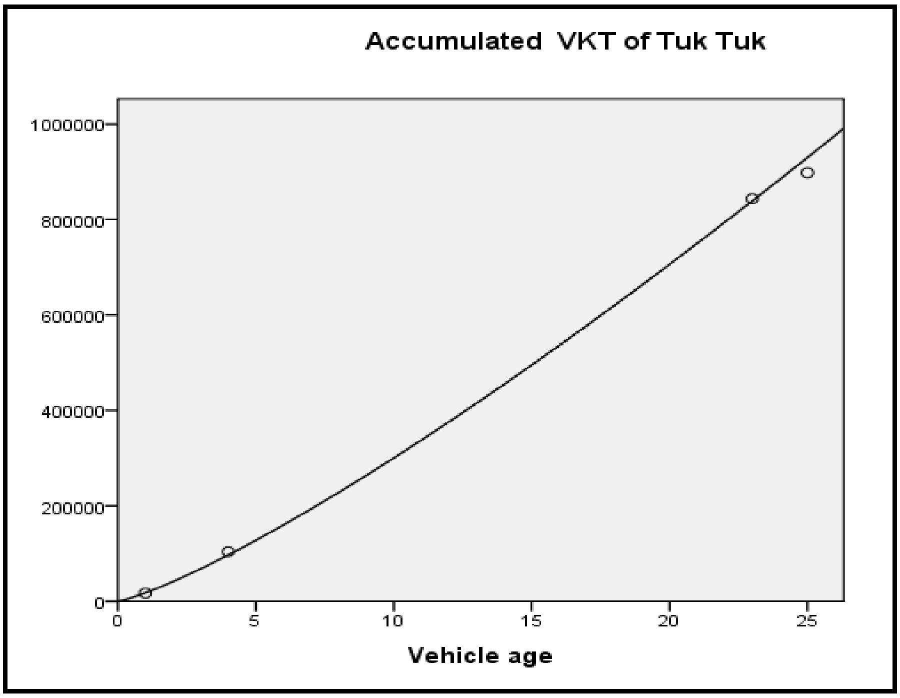


Table 4.1.9 Average cumulative VKT per vehicle age of Tuk-tuks

Vehicle age	Accumulated VKT	N	Vehicle age	Accumulated VKT	N
1	16,805	6	27	851,160	3
2	47,500	1	28	882,324	5
3	68,240	1	43	1,248,740	3
4	103,574	7	45	1,294,900	2
23	843,617	241	47	1,710,100	1
24	678,960	1	50	2,717,600	2
25	897,892	6	51	1,465,200	1
26	329,525	1			
Total			281		

N – sample size, in vehicles

Table 4.1.10 Average cumulative VKT per vehicle age of Tuk-tuks, only for the vehicle age groups with more than 10 samples.

Vehicle age	Accumulated VKT	N	Vehicle age	Accumulated VKT	N
1	16,805	6	23	843,617	241
4	103,574	7	25	897,892	6
Total			260		

N – sample size, in vehicles

4.1.6 Public motorcycles

The total number of sample of this vehicle category was 141 vehicles, which had been collected from various locations in Nakhon Ratchasima. Figure 4.1.6 shows the collected cumulative VKT data versus the vehicle age of public motorcycles. The average cumulative VKT and the number of samples per the vehicle age group are summarized in Table 4.1.11, while Table 4.1.12 lists those vehicle age groups that have more than 10 samples.

Figure 4.1.6 the distribution of the collected cumulative VKT Vs vehicle age of Public motorcycles

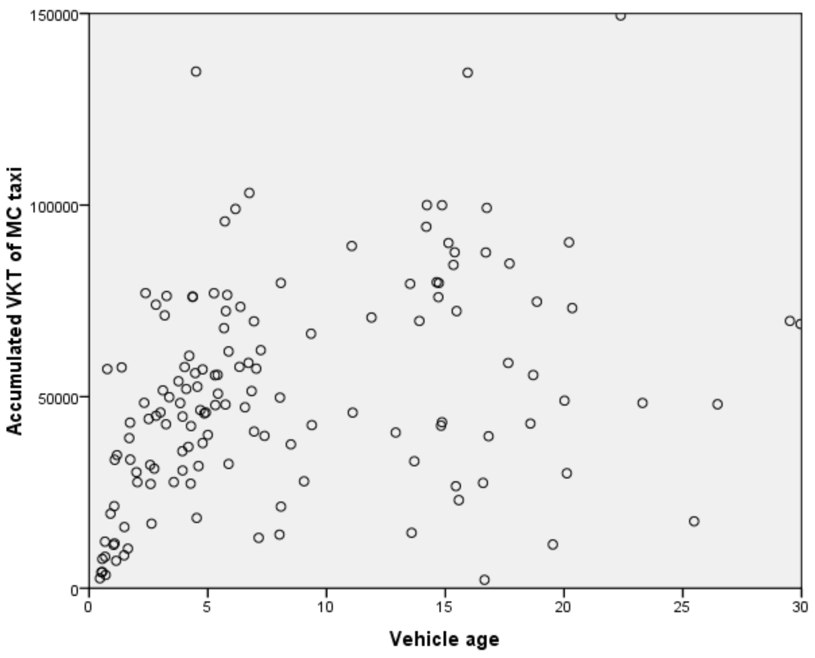


Table 4.1.11 Average cumulative VKT per vehicle age of Public motorcycles

Vehicle age	Accumulated VKT	N	Vehicle age	Accumulated VKT	N
1	13,044	10	15	76,947	8
2	26,792	14	16	74,110	7
3	44,199	10	17	51,248	5
4	49,246	12	18	71,765	2
5	52,124	18	19	57,805	3
6	61,799	12	20	30,190	2
7	65,876	10	21	64,472	3
8	35,766	5	23	149,506	1
9	41,607	4	24	48,362	1
10	54,501	2	26	17,482	1
12	68,608	3	27	48,027	1
13	40,634	1	30	69,360	2
14	49,206	4			
Total			141		

N – sample size, in vehicles

Table 4.1.12 Average cumulative VKT per vehicle age of Public motorcycles, only for the vehicle age groups with more than 10 samples.

Vehicle age	Accumulated VKT	N	Vehicle age	Accumulated VKT	N
1	13,044	10	5	52,124	18
2	26,793	14	6	61,800	12
3	44,199	10	7	65,876	10
4	49,246	12			
Total			86		

N – sample size, in vehicles

4.1.7 Fixed-route vans (Song-taews)

The total number of sample of this vehicle category was 281 vehicles, which had been collected from various locations in Nakhon Ratchasima. Figure 4.1.7 shows the collected cumulative VKT data versus the vehicle age of Song-taews. The average cumulative VKT and the number of samples per the vehicle age group are summarized in Table 4.1.13, while Table 4.1.14 lists those vehicle age groups that have more than 10 samples.

Figure 4.1.7 the distribution of the collected cumulative VKT Vs vehicle age of Song-taews

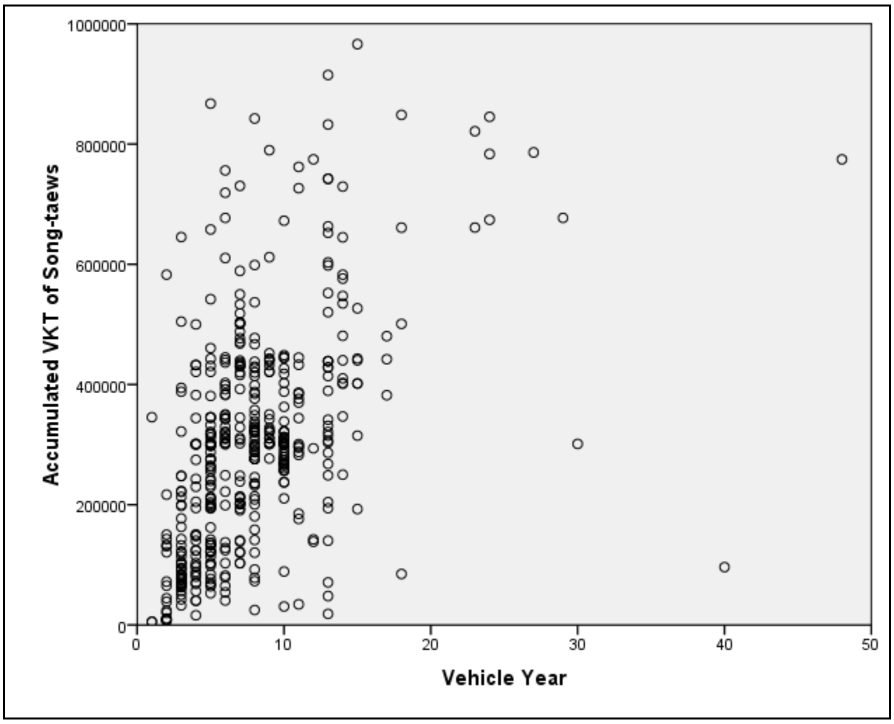


Table 4.1.13 Average cumulative VKT per vehicle age of Song-taews

Vehicle age	Accumulated VKT	N	Vehicle age	Accumulated VKT	N
1	84,503	35	15	355,283	4
2	177,333	34	16	478,680	6
3	216,094	20	17	486,122	5
4	278,936	43	18	303,984	1
5	316,664	25	19	442,853	9
6	364,091	19	20	287,856	1
7	405,627	18	22	761,995	1
8	463,926	9	25	131,878	2
9	432,683	10	26	308,114	1
10	357,927	9	29	677,149	1
11	348,910	7	30	301,287	1
12	218,834	8	40	96,340	1
13	228,403	4	48	774,593	1
14	404,951	6			
Total			281		

N – sample size, in vehicles

Table 4.1.14 Average cumulative VKT per vehicle age of Song-taews, only for the vehicle age groups with more than 10 samples.

Vehicle age	Accumulated VKT	N	Vehicle age	Accumulated VKT	N
1	84,503	35	5	316,664	25
2	177,333	34	6	364,091	19
3	216,094	20	7	405,627	18
4	278,936	43	9	432,683	10
Total			204		

N – sample size, in vehicles

4.1.8 Fixed-route buses

The total number of sample of this vehicle category was 196 vehicles, which had been collected from various locations in Nakhon Ratchasima. Figure 4.1.8 shows the collected cumulative VKT data versus the vehicle age of Fixed-rout buses. The average cumulative VKT and the number of samples per the vehicle age group are summarized in Table 4.1.15, while Table 4.1.16 lists those vehicle age groups that have more than 10 samples.

Figure 4.1.8 the distribution of the collected cumulative VKT Vs vehicle age of Fixed-route buses

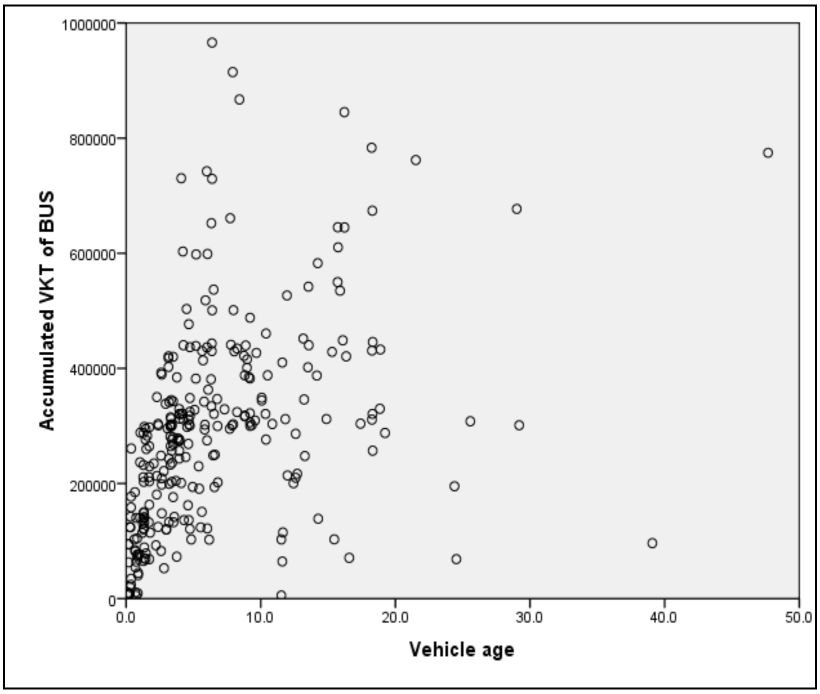


Table 4.1.15 Average cumulative VKT per vehicle age of Fixed-route buses

Vehicle age	Accumulated VKT	N	Vehicle age	Accumulated VKT	N
1	312,682	13	18	649538.75	4
2	398,902	10	19	471266.40	5
3	442,297	9	20	490489.00	3
4	449,771	10	21	605616.64	7
5	413,131	8	24	782418.00	1
6	453,279	10	25	556808.25	4
7	420,234	7	27	394813.50	2
8	473,569	11	28	329396.00	2
9	468,636	7	32	592556.00	2
10	431,971	3	35	300411.00	1
11	796,617	3	36	753874.00	1
12	611,804	16	37	456059.25	4
13	665,485	12	38	329396.00	2
14	700,387	9	39	88727.50	2
15	692,759	15	40	739958.00	1
16	659,123	7	43	1608067.50	2
17	541,511	3			
Total			196		

N – sample size, in vehicles

Table 4.1.16 Average cumulative VKT per vehicle age of Fixed-route buses, only for the vehicle age groups with more than 10 samples.

Vehicle age	Accumulated VKT	N	Vehicle age	Accumulated VKT	N
1	312682.08	13	8	473569.23	11
2	398902.20	10	12	611803.50	16
4	449771.20	10	13	665484.89	12
6	453279.20	10	15	692759.27	15
Total			97		

N – sample size, in vehicles

4.1.9 Trucks

The total number of sample of this vehicle category was 70 vehicles, which had been collected from various locations in Nakhon Ratchasima. Figure 4.1.9 shows the collected cumulative VKT data versus the vehicle age of trucks. The average cumulative VKT and the number of samples per the vehicle age group are summarized in Table 4.1.17. The number of collected data was limited due to the difficulties to get cooperation from truck drivers; thus, the researcher team decides to use the available data for further analysis.

Figure 4.1.9 the distribution of the collected cumulative VKT Vs vehicle age of Trucks

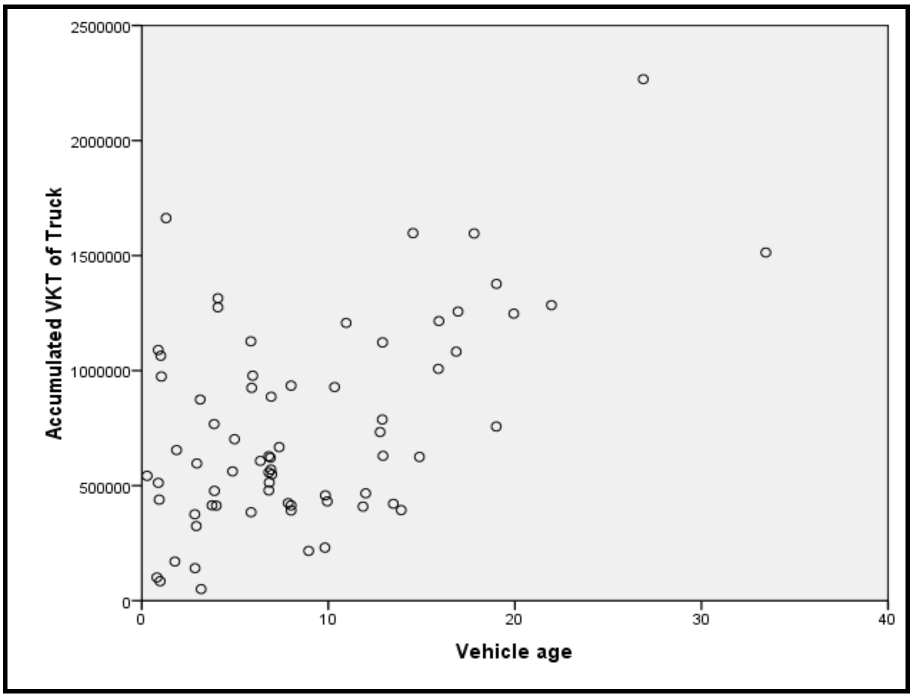


Table 4.1.17 Average cumulative VKT per vehicle age of Trucks

Vehicle age	Accumulated VKT	N	Vehicle age	Accumulated VKT	N
1	601,048	8	13	818,085	4
2	829,355	3	14	407,447	2
3	359,415	4	15	1,111,208	2
4	499,581	6	16	1,111,564	2
5	963,559	4	17	1,169,570	2
6	853,734	4	18	1,596,089	1
7	601,427	9	19	1,066,944	2
8	566,488	5	20	1,247,667	1
9	216,369	1	22	1,284,549	1
10	373,265	3	27	2,266,794	1
11	1,067,924	2	34	1,513,319	1
12	437,759	2			
Total			70		

N – sample size, in vehicles

4.2 Data Analysis in Nakhon Ratchasima

In this section, we utilized a statistical approach to find the relationship between the cumulative VKT and the vehicle age. The cumulative VKT is the dependent variable of the model, while the vehicle age is the independent variable of the model. For each vehicle category, the model development follows the steps below:

1. Select the vehicle age groups that have more than 10 samples
2. Estimate the average cumulative VKT for each vehicle age group
3. Identify a statistical model that best fit the data in 2)

To identify the best fitted model, we have tried a few variations of regression models, including a power model and for some vehicle group, a cubic model. The model with the highest r^2 was selected to represent the relationship of the model. All of the models were developed using the commercial software SPSS.

4.2.1 Sedans (not more than 7 passengers)

The power models were developed to explicit the relationship between the cumulative VKT and the vehicle age. Table 4.2.1 summarizes the relevant statistics as well as the estimated coefficients for the models. Figure 4.2.1 shows the trends of the estimated cumulative VKT from the developed models in comparison with the observed data. As shown, use the power model to be the final model for Sedans (not more than 7 passengers). Figure 4.2.2 illustrates the final estimated cumulative VKT as well as annual VKT per vehicle age for Sedans (not more than 7 passengers) using the power model. As shown, it was found that the annual VKT decreases as the vehicle age increases. A plausible explanation is the owner excitement with a new vehicle, thus, they tend to drive a new vehicle more often and for a longer distance. In addition, it is highly probable that aged vehicles tend to be broken and thus spent more days in the mechanic shops; thus, it limits the number of days for the owner usage. In addition, aged vehicles tend to consume more gasoline and are likely to be broken, thus, the owners might decide to go with other travel options that are more convenient and safer for them, especially for the long-distance trips.

Table 4.2.1 Summary of the statistics and the estimated coefficients of the developed models for Sedans (not more than 7 passengers)

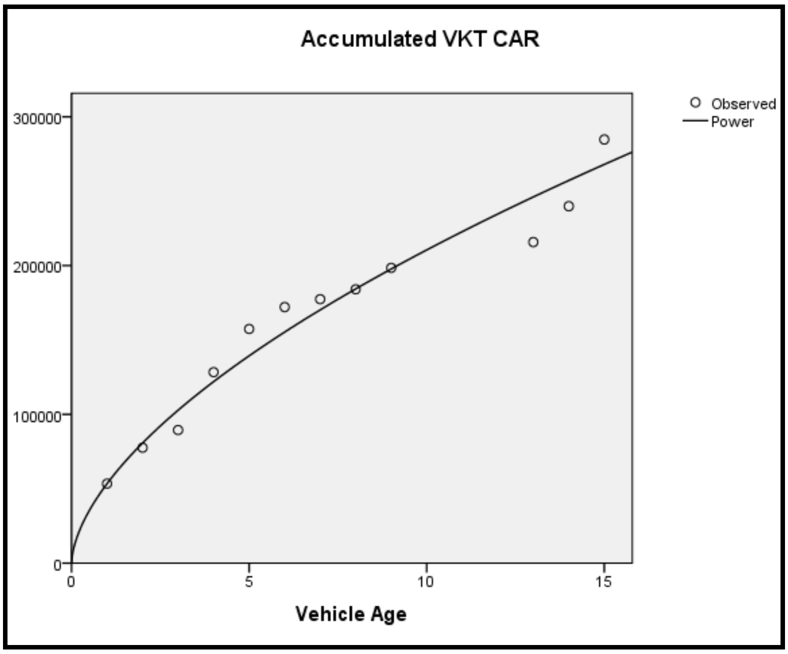
Model Summary and Parameter Estimates

Dependent Variable :Cumulated VKT

Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Power	.972	346.043	1	10	.000	5.343E4	.595

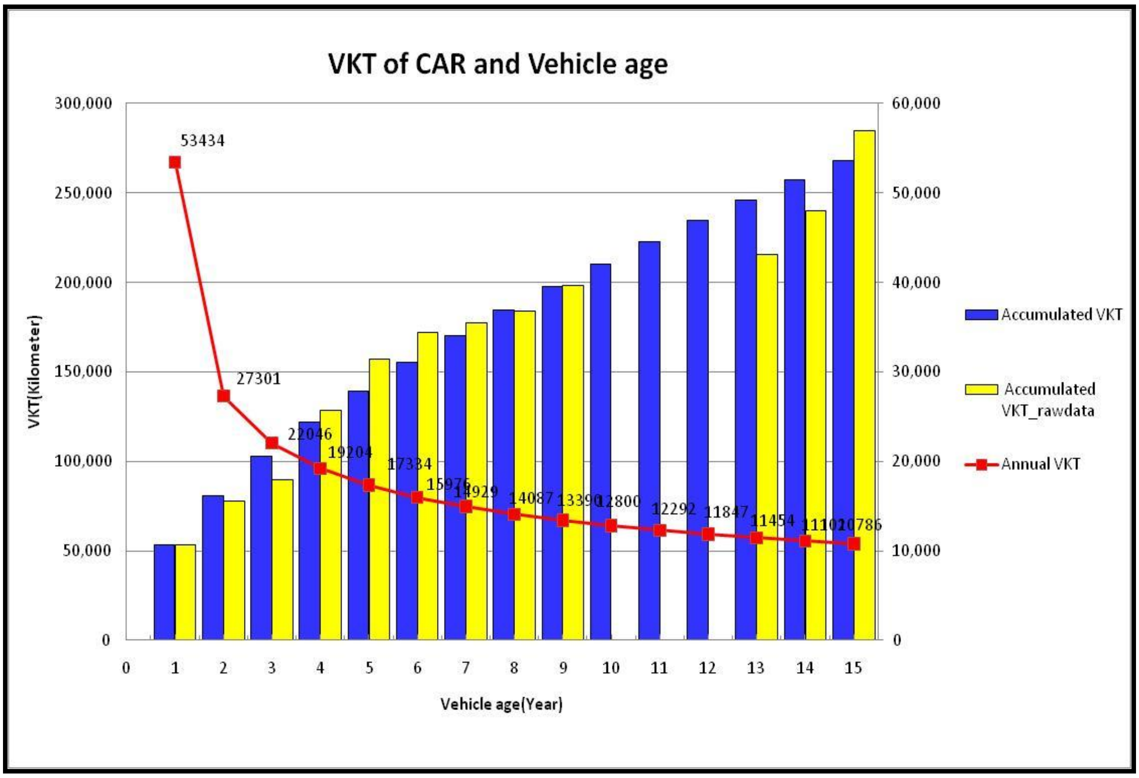
The independent variable is Vehicle Age.

Figure 4.2.1 Forecasted cumulative VKT of Sedans (not more than 7 passengers) using power models



From Figure 4.2.2, it is expected that the first year sedan travel, on average, 53,434 kilometers per year, and the mileage reduces to 17,334 kilometers in the 5th year (based on the power model).

Figure 4.2.2 Estimated cumulative and annual VKT by vehicle age for Sedans (not more than 7 passengers)



4.2.2 Vans/Pick-ups

The power models were developed to explicit the relationship between the cumulative VKT and the vehicle age. Table 4.2.2 summarizes the relevant statistics as well as the estimated coefficients for the models. Figure 4.2.3 shows the trends of the estimated cumulative VKT from the developed models in comparison with the observed data. As shown, use the power model to be the final model for Vans/Pick-ups. Figure 4.2.4 illustrates the final estimated cumulative VKT as well as annual VKT per vehicle age for Vans/Pick-ups, using the power model. Similarly to Sedans, it was found that the annual VKT decreases as the vehicle age increases, plausible with the same explanations.

Table 4.2.2 Summary of the statistics and the estimated coefficients of the developed models for Vans/Pick-ups

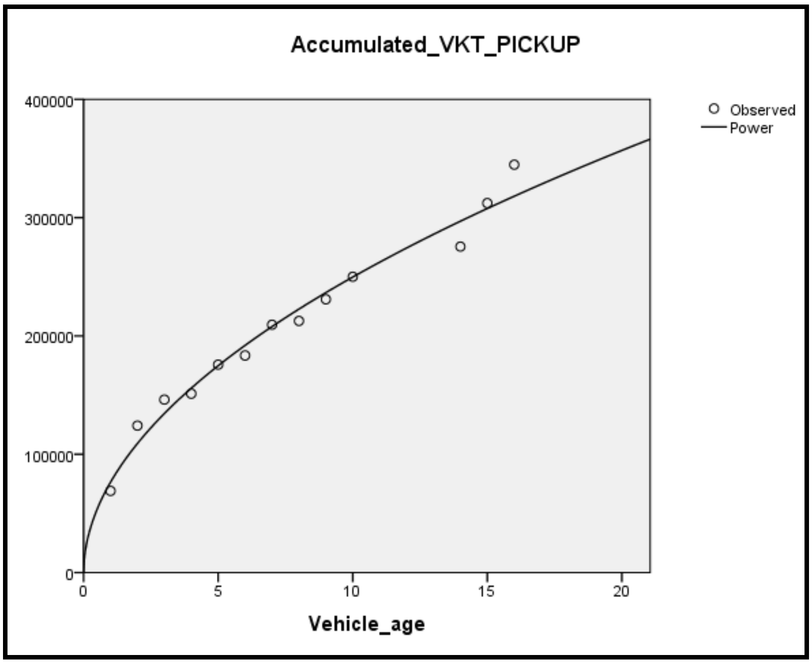
Model Summary and Parameter Estimates

Dependent Variable: Cumulated VKT

Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Power	.976	454.347	1	11	.000	7.639E4	.515

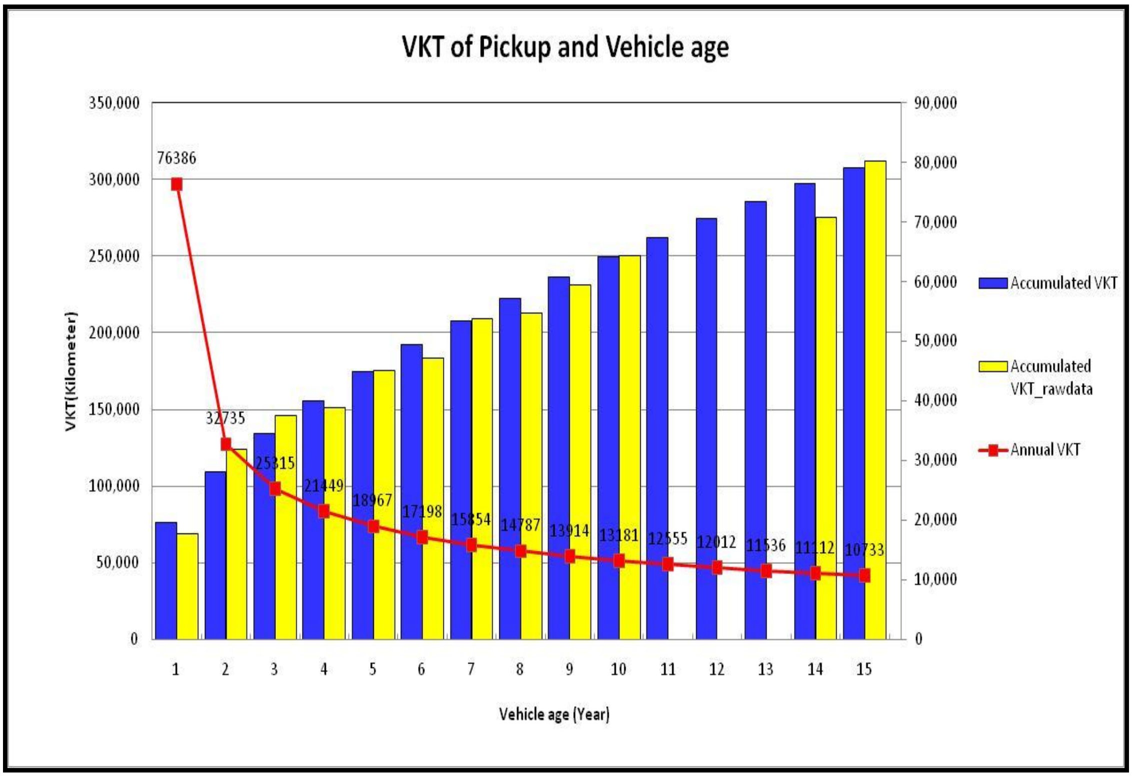
The independent variable is Vehicle age.

Figure 4.2.3 Forecasted cumulative VKT of Vans/Pick-ups using linear and quadratic models



From Figure 4.2.4, it is expected that the first year pick-ups travel, on average, 76,386 kilometers per year, and the mileage reduces to 17,198 kilometers in the 6th year (based on the quadratic model).

Figure 4.2.4 Estimated cumulative and annual VKT by vehicle age for Vans/Pick-ups



4.2.3 Motorcycles

The power models were developed to explicit the relationship between the cumulative VKT and the vehicle age. Table 4.2.3 summarizes the relevant statistics as well as the estimated coefficients for the models. Figure 4.2.5 shows the trends of the estimated cumulative VKT from the developed models in comparison with the observed data. As shown, use the power model to be the final model for Motorcycles. Figure 4.2.6 illustrates the final estimated cumulative VKT as well as annual VKT per vehicle age for Motorcycles, using the quadratic model. Similarly to Sedans and Pick-ups, it was found that the annual VKT decreases as the vehicle age increases, plausible with the same explanations.

Table 4.2.3 Summary of the statistics and the estimated coefficients of the developed models for Motorcycles

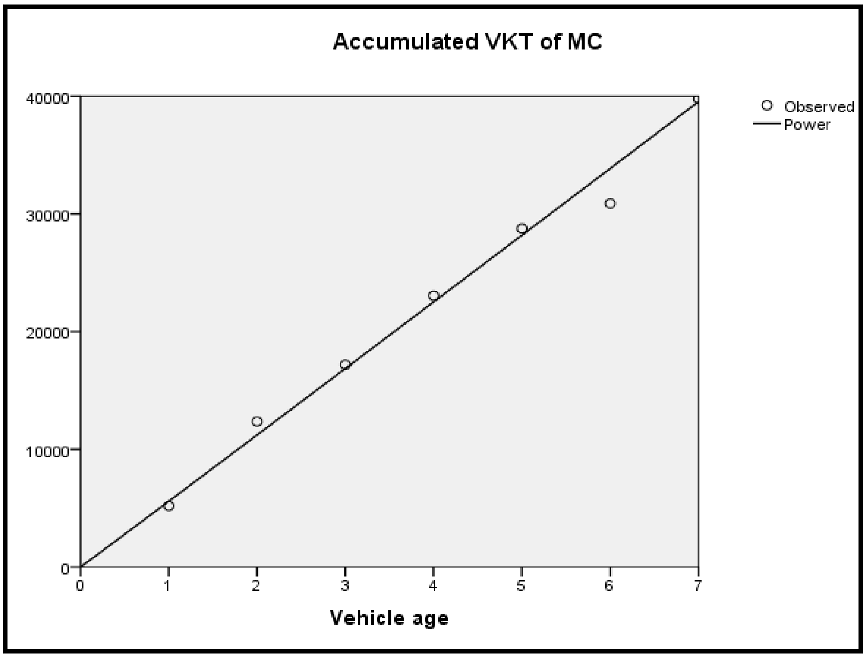
Model Summary and Parameter Estimates

Dependent Variable: Cumulated VKT

Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Power	.991	580.231	1	5	.000	5.588E3	1.005

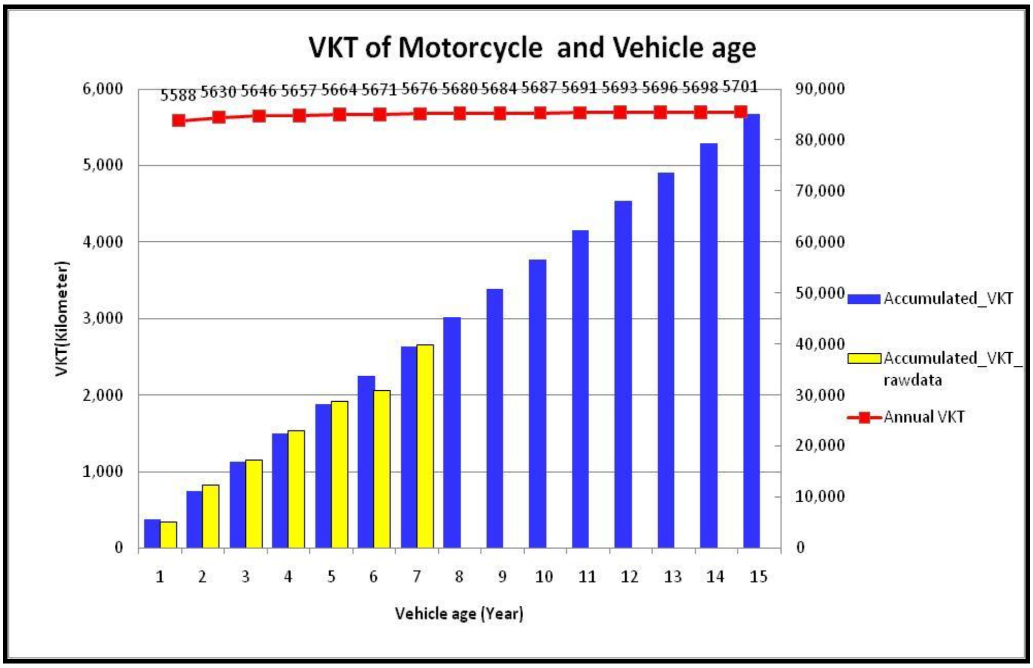
The independent variable is Vehicle age.

Figure 4.2.5 Forecasted cumulative VKT of Motorcycles using power models



From Figure 4.2.6, it is expected that the first year motorcycles travel, on average, 5,588 kilometers per year, and the mileage 5,657 kilometers in the 4th year (based on the power model).

Figure 4.2.6 Estimated cumulative and annual VKT by vehicle age for Motorcycles



4.2.4 Urban Taxis

The power models were developed to explicit the relationship between the cumulative VKT and the vehicle age. Table 4.2.4 summarizes the relevant statistics as well as the estimated coefficients for the models. Figure 4.2.7 shows the trends of the estimated cumulative VKT from the developed models in comparison with the observed data. As shown, the developed power model was rather irrational given that the annual VKT seems to increase with the vehicle age. It is possible that the limited number of samples (36 vehicles) as well as the short history of the urban taxis in Nakhon Ratchasima (less than 2 years) prevent us from developing a good power model. Thus, for this vehicle category, we decide to use a power model to represent the relationship between the cumulative VKT and the vehicle age. Note that the forecasting results should be used with special care, and the model should be updated as sufficient data are available. Figure 4.2.8 illustrates the final estimated cumulative VKT as well as annual VKT per vehicle age for Urban taxis, using the power model.

Table 4.2.4 Summary of the statistics and the estimated coefficients of the developed models for Urban Taxi

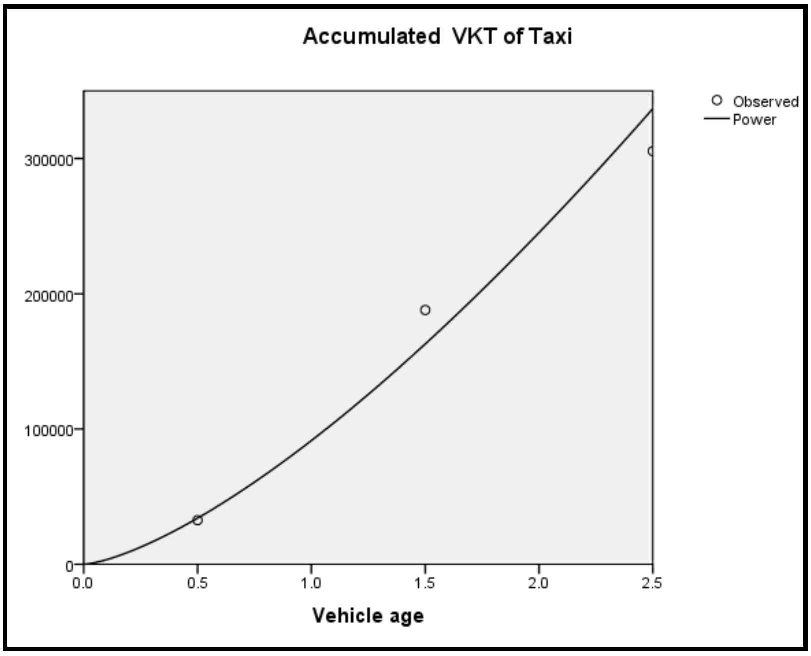
Model Summary and Parameter Estimates

Dependent Variable: Cumulated VKT

Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Power	.988	84.833	1	1	.069	9.148E4	1.423

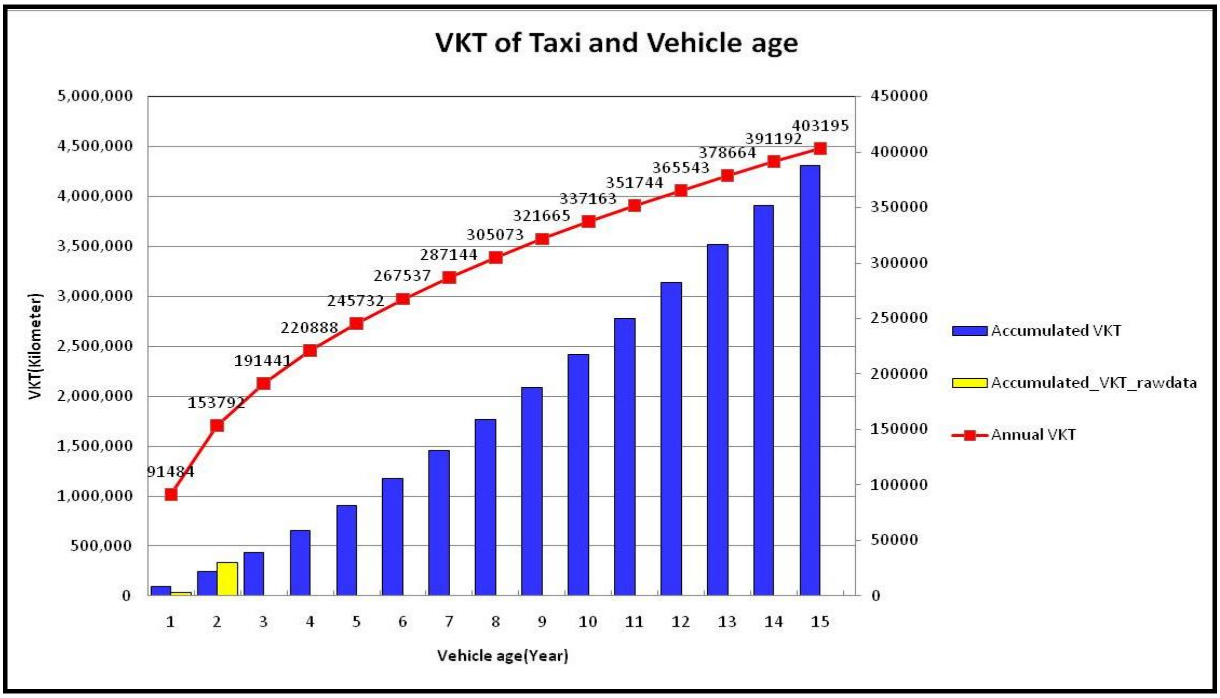
The independent variable is Vehicle age.

Figure 4.2.7 Forecasted cumulative VKT of Urban Taxi using power models



A simple estimate of the urban taxi annual VKT can be found from the power model (see Table 4.2.4) ,it is expected that the first year urban taxi travel, on average, 91,484 kilometers per year, and the mileage 220,888 kilometers in the 4th year (based on the power model).

Figure 4.2.8 Estimated cumulative and annual VKT by vehicle age for Urban Taxis



4.2.5 Tuk-tuks

The power models were developed to explicit the relationship between the cumulative VKT and the vehicle age. Table 4.2.5 summarizes the relevant statistics as well as the estimated coefficients for the models. Figure 4.2.9 shows the trends of the estimated cumulative VKT from the developed models in comparison with the observed data. As shown, use the power model to be the final model for Tuk-tuks. Figure 4.2.10 illustrates the final estimated cumulative VKT as well as annual VKT per vehicle age for Tuk-tuks, using the power model.

Table 4.2.5 Summary of the statistics and the estimated coefficients of the developed models for Tuk-tuks

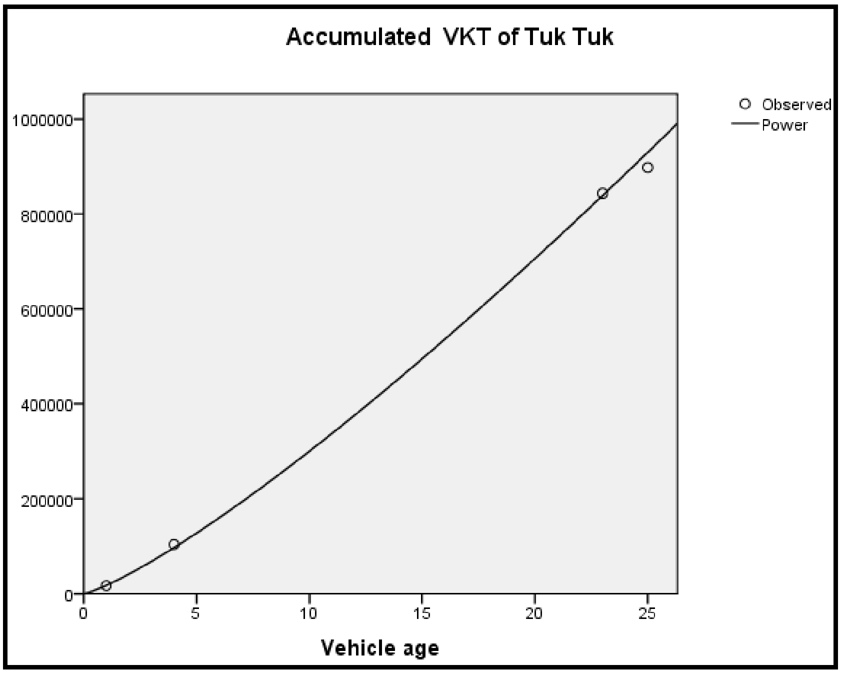
Model Summary and Parameter Estimates

Dependent Variable: Cumulated VKT

Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Power	.999	2.942E3	1	2	.000	1.747E4	1.235

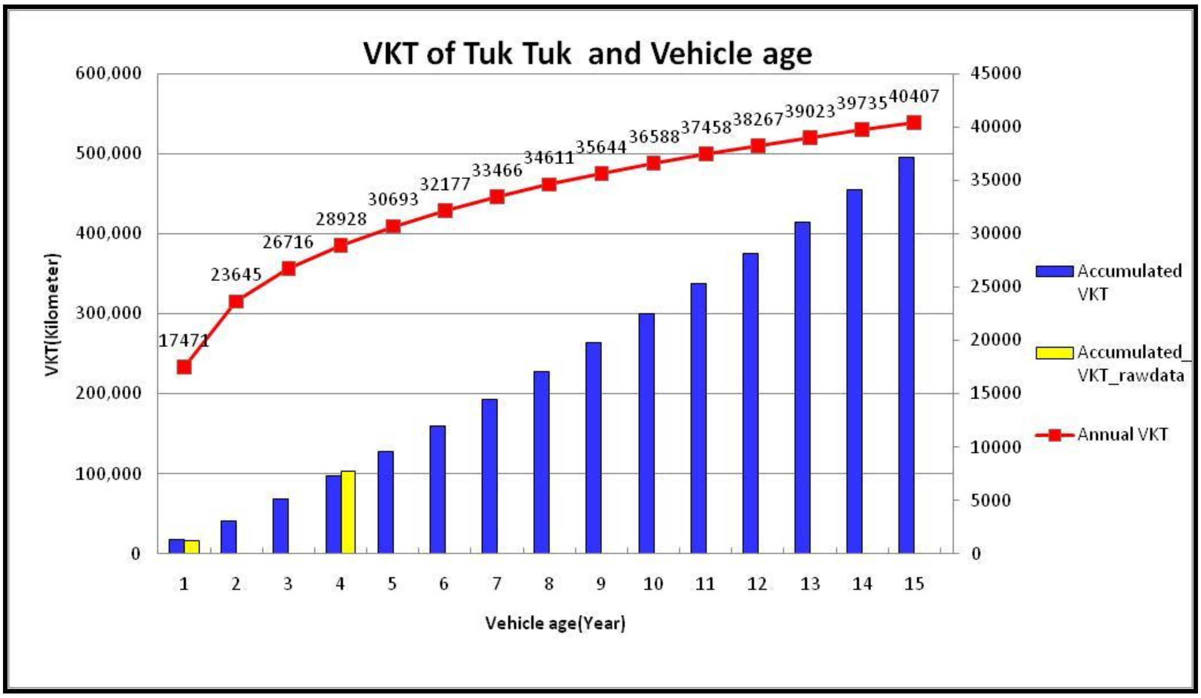
The independent variable is Vehicle age.

Figure 4.2.9 Forecasted cumulative VKT of Tuk-tuks using power models



A simple estimate of the tuk-tuks annual VKT can be found from the power model (see Table 4.2.5) it is expected that the first year Tuk-tuks travel, on average, 17,471 kilometers per year, and the mileage 28,928 kilometers in the 4th year (based on the power model).

Figure 4.2.10 Estimated cumulative and annual VKT by vehicle age for Tuk-tuks



4.2.6 Public motorcycles

The power models were developed to explicit the relationship between the cumulative VKT and the vehicle age. Table 4.2.6 summarizes the relevant statistics as well as the estimated coefficients for the models. Figure 4.2.11 shows the trends of the estimated cumulative VKT from the developed models in comparison with the observed data. As shown, use the power model to be the final model for Motorcycles. Figure 4.2.12 illustrates the final estimated cumulative VKT as well as annual VKT per vehicle age for Motorcycles, using the power model. Similarly to Sedans and Pick-ups, it was found that the annual VKT decreases as the vehicle age increases, plausible with the same explanations.

Table 4.2.6 Summary of the statistics and the estimated coefficients of the developed models for Public motorcycles

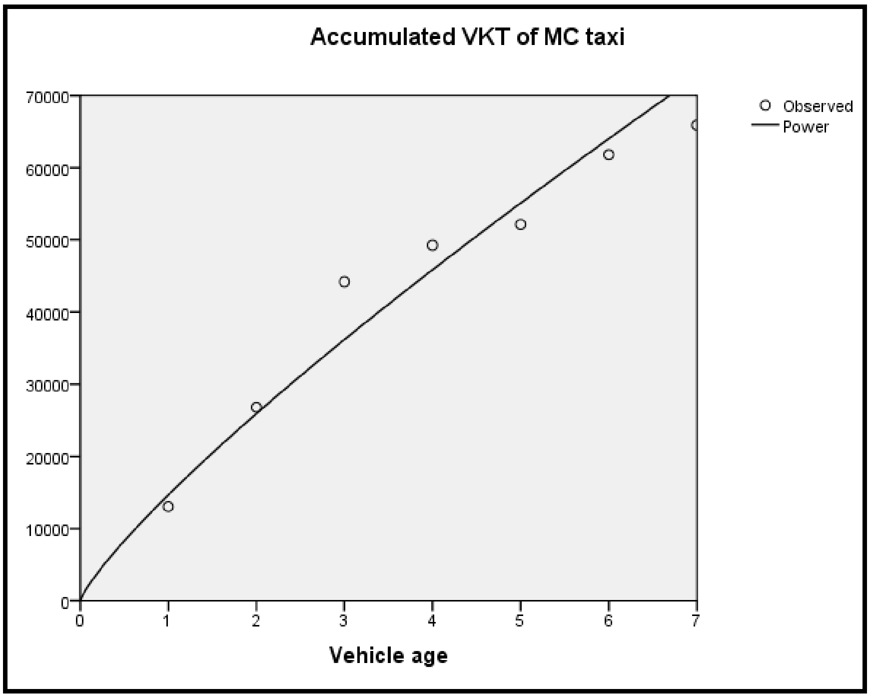
Model Summary and Parameter Estimates

Dependent Variable: Cumulated VKT

Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Power	.963	129.218	1	5	.000	1.466E4	.823

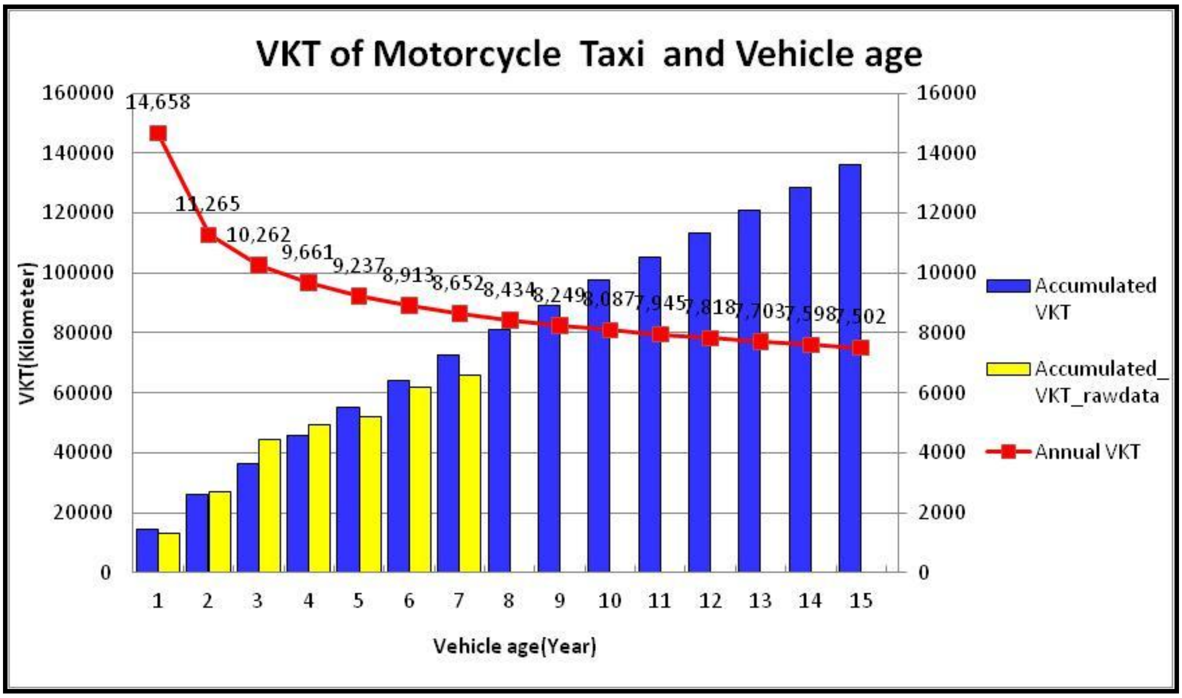
The independent variable is Vehicle age.

Figure 4.2.11 Forecasted cumulative VKT of Public motorcycles using power models



From Figure 4.2.12, it is expected that the first year public motorcycles travel, on average, 14,658 kilometers per year, and the mileage reduces to 10,262 kilometers in the 3rd year (based on the quadratic model).

Figure 4.2.12 Estimated cumulative and annual VKT by vehicle age for Public motorcycles



4.2.7 Fixed-route vans (Song-taews)

The power models were developed to explicit the relationship between the cumulative VKT and the vehicle age. Table 4.2.7 summarizes the relevant statistics as well as the estimated coefficients for the models. Figure 4.2.13 shows the trends of the estimated cumulative VKT from the developed models in comparison with the observed data. As shown, use the power model to be the final model for Song-taews. Figure 4.2.14 illustrates the final estimated cumulative VKT as well as annual VKT per vehicle age for Song-taews, using the power model. Similarly to most of the vehicle types, it was found that the annual VKT decreases as the vehicle age increases, plausible with the same explanations.

Table 4.2.7 Summary of the statistics and the estimated coefficients of the developed models for Songtaews

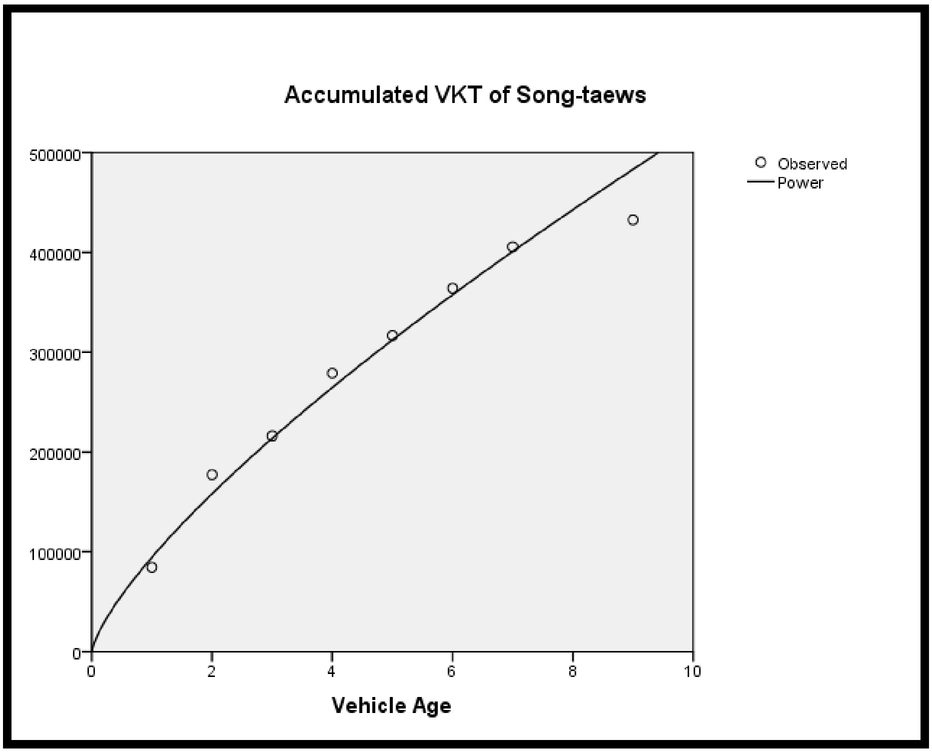
Model Summary and Parameter Estimates

Dependent Variable: Cumulated VKT

Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Power	.980	291.873	1	6	.000	9.451E4	.743

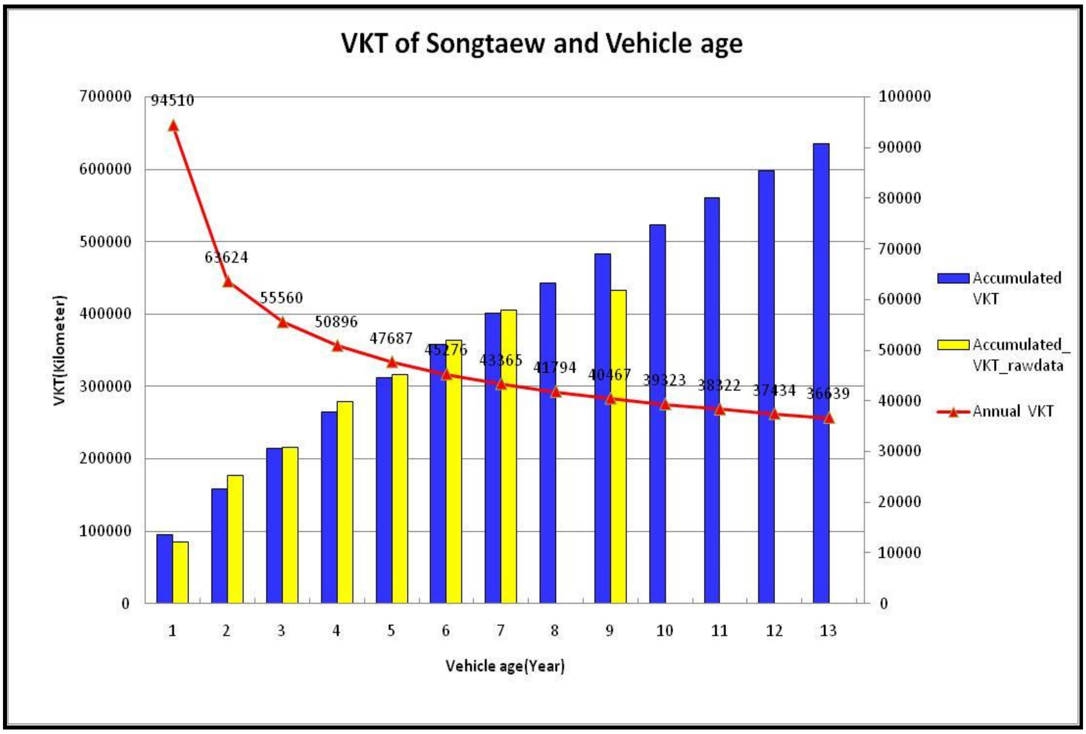
The independent variable is Vehicle age.

Figure 4.2.13 Forecasted cumulative VKT of Song-taews using power models



From Figure 4.2.14, it is expected that the first year Song-taews travel, on average, 94,510 kilometers per year, and the mileage reduces to 45,276 kilometers in the 6th year (based on the power model).

Figure 4.2.14 Estimated cumulative and annual VKT by vehicle age for Song-taews



4.2.8 Fixed-route buses

The linear, the quadratic and the cubic models were developed to explicit the relationship between the cumulative VKT and the vehicle age. Table 4.2.8 summarizes the relevant statistics as well as the estimated coefficients for the models. Figure 4.2.15 shows the trends of the estimated cumulative VKT from the developed models in comparison with the observed data. As shown, the cubic model yields the highest correlation coefficient among the three models, thus we decided to use the cubic model to be the final model for Fixed-route buses. Figure 4.2.16 illustrates the final estimated cumulative VKT as well as annual VKT per vehicle age for Fixed-route buses, using the cubic model. Similarly to most of the vehicle types, it was found that the annual VKT decreases as the vehicle age increases, plausible with the same explanations.

Table 4.2.8 Summary of the statistics and the estimated coefficients of the developed models for Songtaews

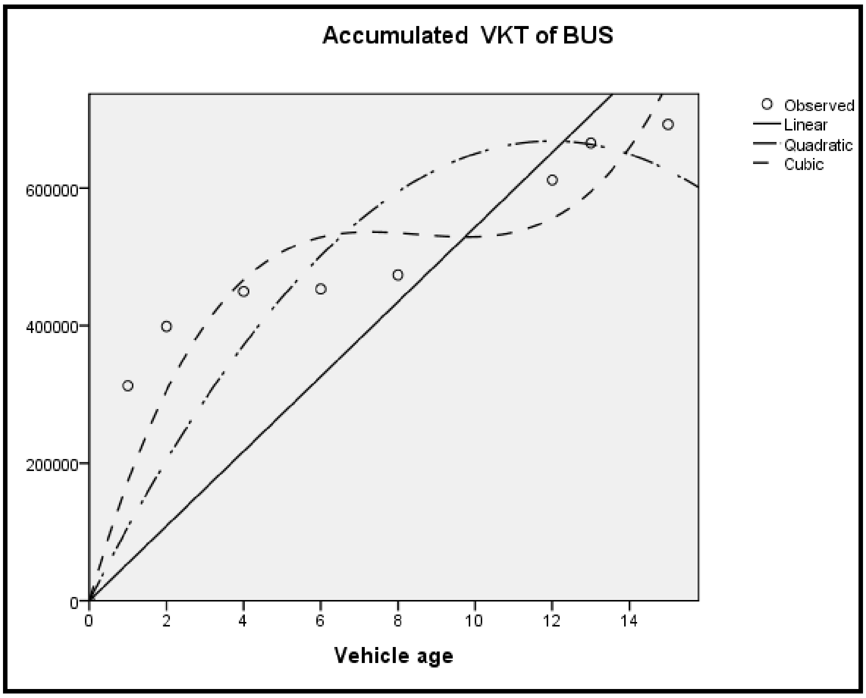
Model Summary and Parameter Estimates

Dependent Variable: Cumulated VKT

Equation	Model Summary					Parameter Estimates		
	R Square	F	df1	df2	Sig.	b1	b2	b3
Linear	.890	64.580	1	8	.000	5.433E4		
Quadratic	.949	65.507	2	7	.000	1.116E5	-4.655E3	
Cubic	.977	86.185	3	6	.000	1.958E5	-2.346E4	916.624

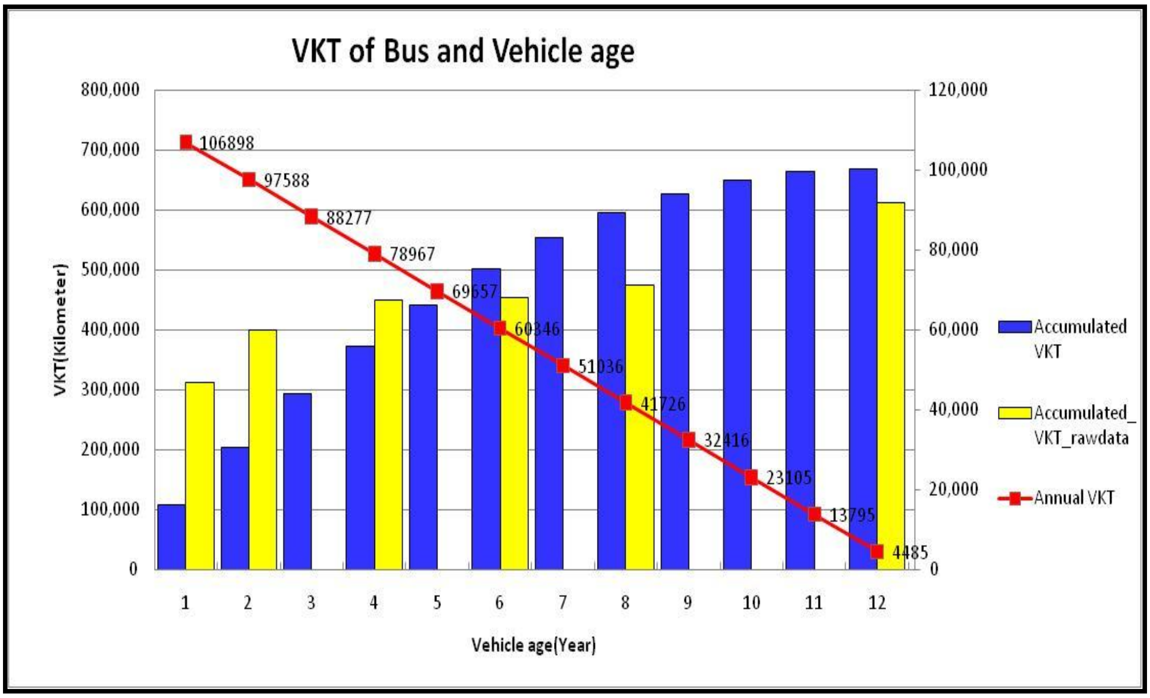
The independent variable is Vehicle age.

Figure 4.2.15 Forecasted cumulative VKT of Fixed-route buses using linear, quadratic and cubic models



From Figure 4.2.16, it is expected that the first year Fixed-route buses travel, on average, 106,898 kilometers per year, and the mileage reduces to 69,657 kilometers in the 5th year (based on the cubic model). A simple estimate of the annual VKT can be found from the linear model (see Table 4.2.8) that the annual VKT of Fixed-route buses is generally 54,328 kilometers per year for its life time.

Figure 4.2.16 Estimated cumulative and annual VKT by vehicle age for Fixed-route buses



4.2.9 Trucks

The linear, the quadratic and the cubic models were developed to explicit the relationship between the cumulative VKT and the vehicle age. Table 4.2.9 summarizes the relevant statistics as well as the estimated coefficients for the models. Figure 4.2.17 shows the trends of the estimated cumulative VKT from the developed models in comparison with the observed data. As shown, the cubic model yields the highest correlation coefficient among the three models, thus we decided to use the cubic model to be the final model for Truck .Figure 4.2.18 illustrates the final estimated cumulative VKT as well as annual VKT per vehicle age for Trucks, using the cubic model. Similarly to most of the vehicle types, it was found that the annual VKT decreases as the vehicle age increases, plausible with the same explanations.

Table 4.2.9 Summary of the statistics and the estimated coefficients of the developed models for Trucks

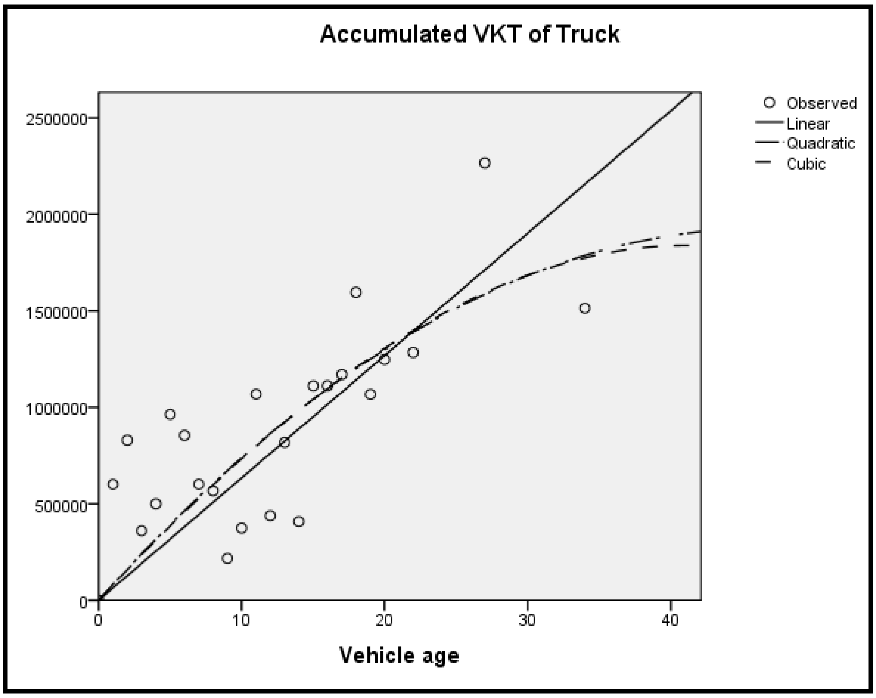
Model Summary and Parameter Estimates

Dependent Variable: Cumulated VKT

Equation	Model Summary					Parameter Estimates		
	R Square	F	df1	df2	Sig.	b1	b2	b3
Linear	.868	150.950	1	23	.000	6.342E4		
Quadratic	.879	80.075	2	22	.000	8.261E4	-883.940	
Cubic	.879	50.971	3	21	.000	8.020E4	-635.312	-5.543

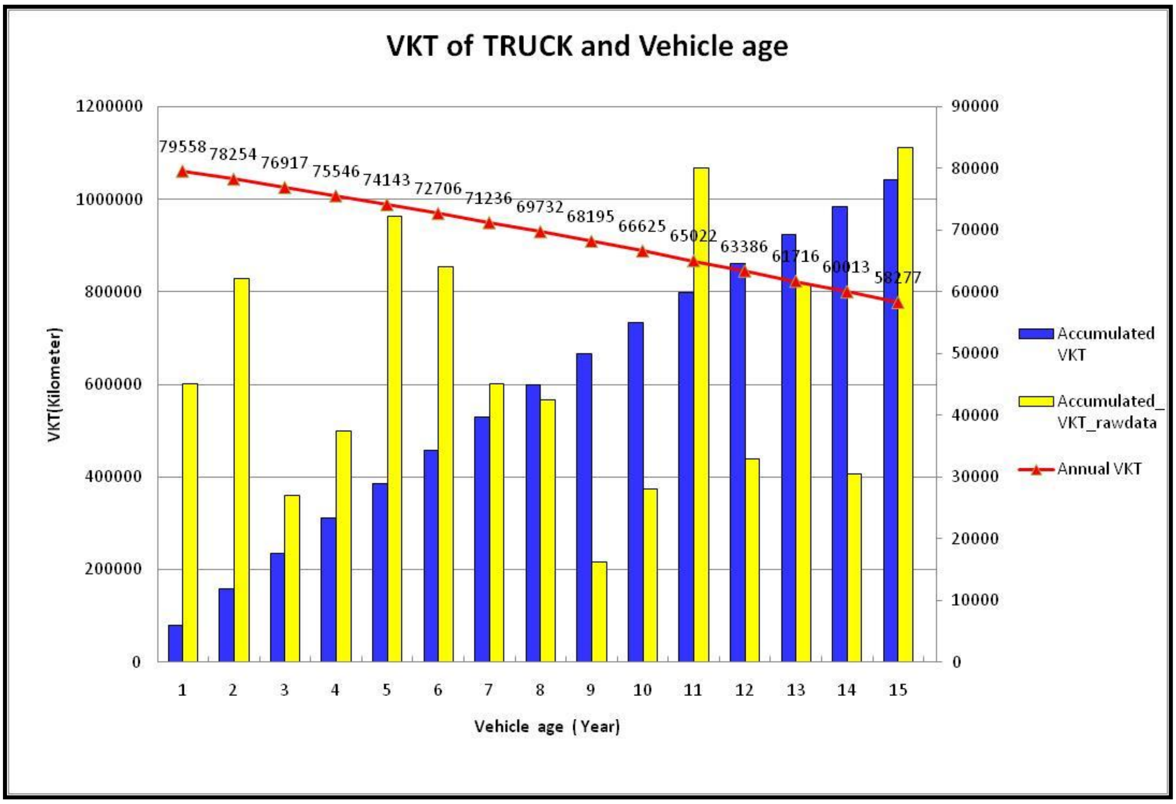
The independent variable is Vehicle age.

Figure 4.2.17 Forecasted cumulative VKT of Trucks using linear , quadratic and cubic models.



From Figure 4.2.18, it is expected that the first year trucks travel, on average, 79,558 kilometers per year, and the mileage reduces to 69,732 kilometers in the 8th year (based on the cubic model). A simple estimate of the annual VKT can be found from the linear model (see Table 4.2.9) that the annual VKT of Trucks is generally 63,417 kilometers per year for its life time.

Figure 4.2.18 Estimated cumulative and annual VKT by vehicle age for Trucks



4.3 Odometer reading data in Bangkok

From the odometer reading surveyed conducted in Bangkok, the research team summarize the cumulative VKT data by vehicle types as described below.

4.3.1 Sedans (not more than 7 passengers)

The total number of sample of this vehicle group was 336 vehicles, which had been collected from various locations in Bangkok, as described in Chapter 3. Figure 4.3.1 shows the collected cumulative VKT data versus the vehicle age of sedans (not more than 7 passengers). The average cumulative VKT and the number of samples per the vehicle age group are summarized in Table 4.3.1. As shown, the number of samples in each vehicle age group varies since it is a randomly selected surveyed. In order to make the analysis meaningful, the research team selected the data of the vehicle age groups that contain 10 or more samples for further analysis. (We assumed that the number of samples less than 10 vehicles would not be sufficiently represented the population of that group.) Table 4.3.2 lists those vehicle age groups that have more than 10 samples.

Figure 4.3.1 the distribution of the collected cumulative VKT Vs vehicle age of Sedans (not more than 7 passengers)

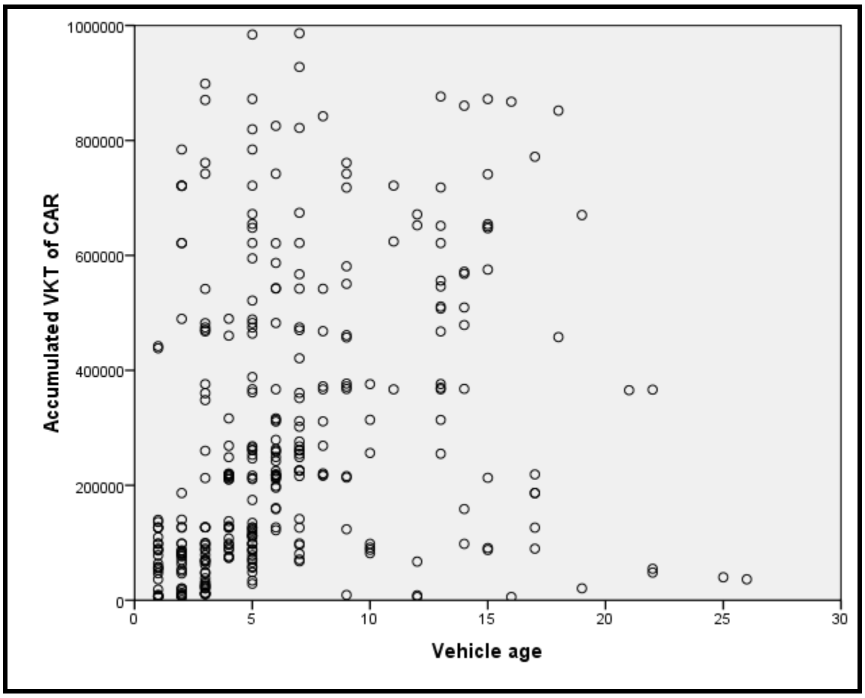


Table 4.3.1 Average cumulative VKT per vehicle age of Sedans (not more than 7 passengers)

Vehicle Age	Accumulated VKT	N	Vehicle Age	Accumulated VKT	N
1	70990	27	13	509243	14
2	79316	36	14	494165	8
3	87151	43	15	647212	9
4	173868	26	16	436527	2
5	210679	53	17	186539	6
6	249151	31	18	654931	2
7	267801	31	19	345443	2
8	339052	10	21	365461	1
9	417008	14	22	54812	3
10	98163	7	25	40000	1
11	67319	3	26	36454	1
12	67319	5	44	10761	1
Total			336		

N – sample size, in vehicle

Table 4.3.2 Average cumulative VKT per vehicle age of Sedans (not more than 7 passengers), only for the vehicle age groups with more than 10 samples.

Vehicle Age	Accumulated VKT	N
1	70990	27
2	79316	36
3	87151	43
4	173868	26
5	210679	53
6	249151	31
7	267801	31
8	339052	10
9	417008	14
13	509243	14
Total		285

N – sample size, in vehicles

4.3.2 Vans and Pick-ups

The total number of sample of this vehicle category was 284 vehicles, which had been collected from various locations in Bangkok. Figure 4.3.2 shows the collected cumulative VKT data versus the vehicle age of vans and pick-ups. The average cumulative VKT and the number of samples per the vehicle age group are summarized in Table 4.3.3. As shown, the number of samples in each vehicle age group varies since it is a randomly selected surveyed. In order to make the analysis meaningful, the research team selected the data of the vehicle age groups that contain 10 ore more samples for further analysis. (We assumed that the number of samples less than 10 vehicles would not be sufficiently represented the population of that group.) Table 4.3.4 lists those vehicle age groups that have more than 10 samples.

Figure 4.3.2 the distribution of the collected cumulative VKT Vs vehicle age of Vans/Pick-ups

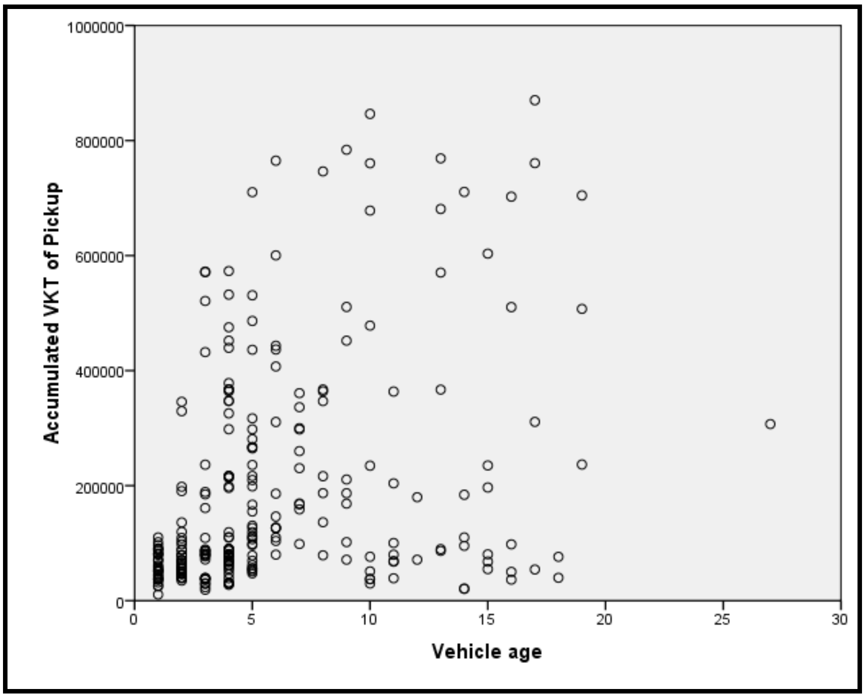


Table 4.3.3 Average cumulative VKT per vehicle age of Vans/Pick-ups

Vehicle age	Accumulated VKT	N	Vehicle age	Accumulated VKT	N
1	60984	33	11	131907	6
2	81492	43	12	125678	2
3	146038	28	13	427274	6
4	173531	50	14	190315	6
5	200550	32	15	206464	6
6	232772	18	16	279541	5
7	273352	13	17	499035	4
8	305409	8	18	58104	2
9	310774	8	19	482852	3
10	323022	10	27	307125	1
Total			284		

N – sample size, in vehicles

Table 4.3.4 Average cumulative VKT per vehicle age of Vans/Pick-ups, only for the vehicle age groups with more than 10 samples.

Vehicle Age	Accumulated VKT	N
1	60984	33
2	81492	43
3	146038	28
4	173531	50
5	200550	32
6	232772	18
7	273352	13
10	323022	10
Total		227

N – sample size, in vehicles

4.3.3 Motorcycles

The total number of sample of this vehicle category was 454 vehicles, which had been collected from various locations in Bangkok. Figure 4.3.3 shows the collected cumulative VKT data versus the vehicle age of motorcycles. The average cumulative VKT and the number of samples per the vehicle age group are summarized in Table 4.3.5, while Table 4.3.6 lists those vehicle age groups that have more than 10 samples.

Figure 4.3.3 the distribution of the collected cumulative VKT Vs vehicle age of Motorcycles

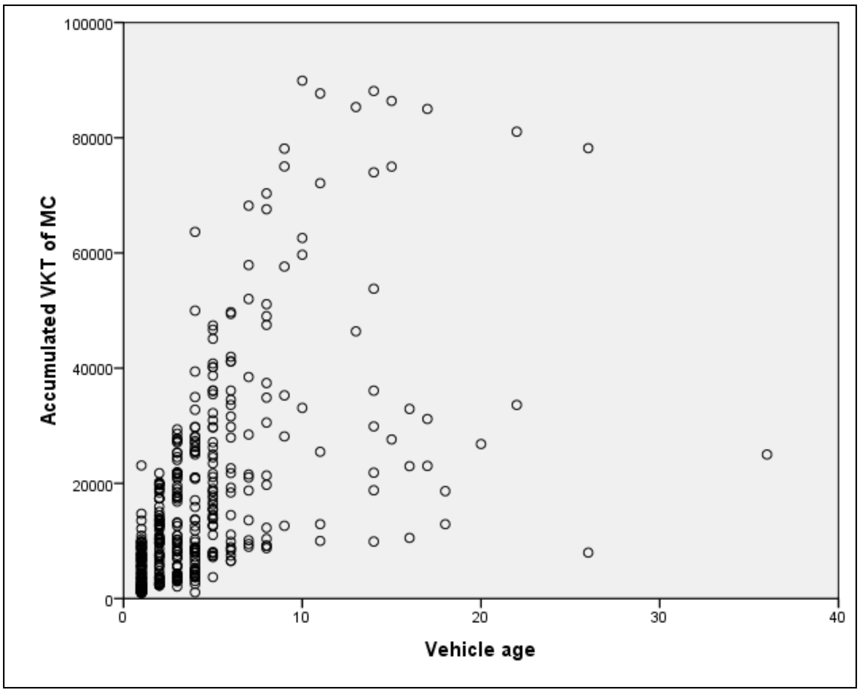


Table 4.3.5 Average cumulative VKT per vehicle age of Motorcycles

Vehicle age	Accumulated VKT	N	Vehicle age	Accumulated VKT	N
1	4812	120	13	65860	2
2	10002	83	14	41553	8
3	13272	60	15	63001	3
4	16167	51	16	22145	3
5	22232	47	17	46405	3
6	24204	24	18	15779	2
7	29047	12	20	26829	1
8	31950	15	22	57337	2
9	47802	6	26	43086	2
10	61322	4	36	25005	1
11	41637	5			
Total			454		

N – sample size, in vehicles

Table 4.3.6 Average cumulative VKT per vehicle age of Motorcycles, only for the vehicle age groups with more than 10 samples.

Vehicle Age	Accumulated VKT	N
1	4812	120
2	10002	83
3	13272	60
4	16167	51
5	22232	47
6	24204	24
7	29047	12
8	31950	15
Total		412

N – sample size, in vehicles

4.3.4 Urban Taxis

The total number of sample of this vehicle category was 430 vehicles, which had been collected from various locations in Bangkok. Figure 4.3.4 shows the collected cumulative VKT data versus the vehicle age of Urban Taxis. The average cumulative VKT and the number of samples per the vehicle age group are summarized in Table 4.3.7, while Table 4.3.8 lists those vehicle age groups that have more than 10 samples.

Figure 4.3.4 the distribution of the collected cumulative VKT Vs vehicle age of Urban taxis

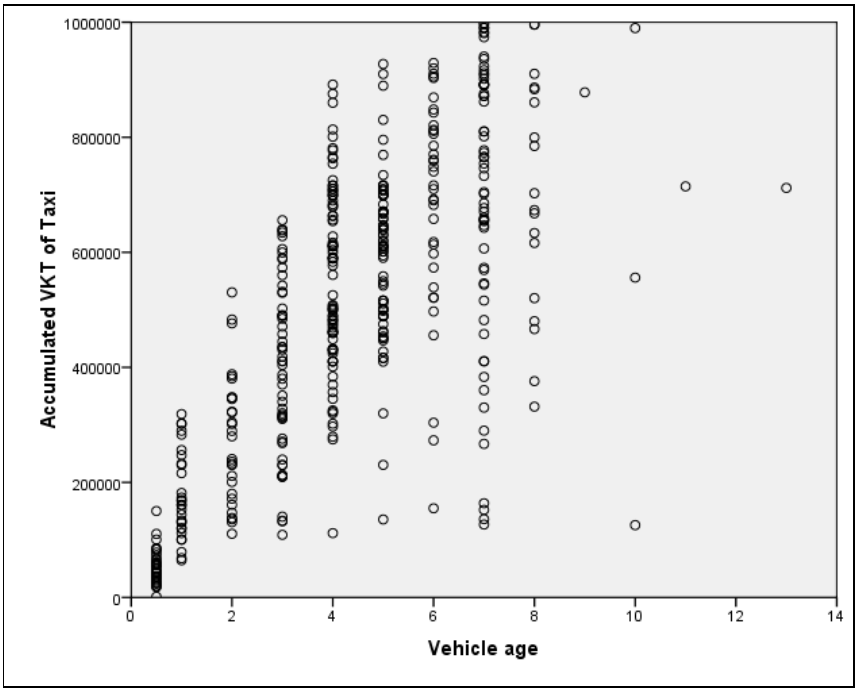


Table 4.3.7 Average cumulative VKT per vehicle age of Urban Taxis

Vehicle age	Accumulated VKT	N	Vehicle age	Accumulated VKT	N
0.5	53763	36	7	690657	63
1	177557	28	8	699303	18
2	276891	29	9	878201	1
3	401849	54	10	557253	3
4	555162	86	11	714563	1
5	593309	74	13	712009	1
6	687879	36			
Total			430		

N – sample size, in vehicles

Table 4.3.8 Average cumulative VKT per vehicle age of Urban Taxis, only for the vehicle age groups with more than 10 samples.

Vehicle age	Accumulated VKT	N
0.5	53763	36
1	177557	28
2	276891	29
3	401849	54
4	555162	86
5	593309	74
6	687879	36
7	690657	63
8	699303	18
Total	424	

N – sample size, in vehicles

4.3.5 Tuk-Tuks

Tuk-tuk is the vehicle type that has been presented in Bangkok for a few decades. It is rather difficult to collect the odometer readings of Tuk-tuks, since such vehicles do not have a odometer guage. In this study, the surveyor then requested supplementary information from the drivers, such as the average daily VKT, or the average daily amount of energy consumed. The information was then translated into the annual vehicle kilometers of travel of Tuk-tuks. The total number of sample of this vehicle category was 445 vehicles, which had been collected from various locations in Bangkok. Figure 4.3.5 shows the collected cumulative VKT data versus the vehicle age of tuk-tuks. The average cumulative VKT and the number of samples per the vehicle age group are summarized in Table 4.3.9, while Table 4.3.10 lists those vehicle age groups that have more than 10 samples.

Figure 4.3.5 the distribution of the collected cumulative VKT Vs vehicle age of Tuk-tuks

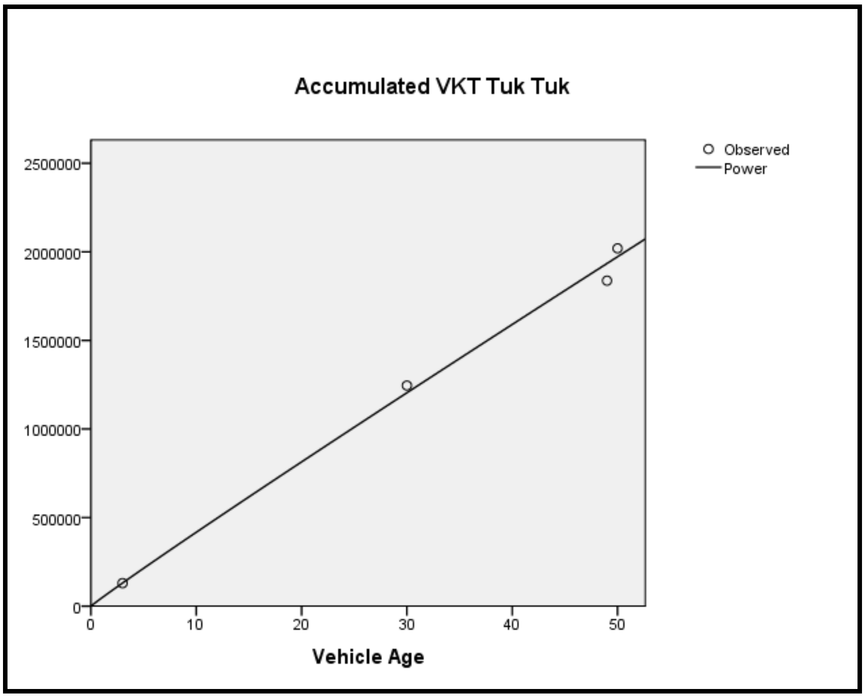


Table 4.3.9 Average cumulative VKT per vehicle age of Tuk-tuks

Vehicle age	Accumulated VKT	N	Vehicle age	Accumulated VKT	N
2	89400	1	30	1245400	12
3	129563	89	42	1899550	3
4	128100	1	43	1412370	1
14	629880	1	44	1833330	1
17	955350	1	45	1696543	3
18	1010107	3	47	2033130	6
19	971256	5	48	1751800	1
20	734900	1	49	1837127	130
29	1023813	6	50	2019333	180
Total			445		

N – sample size, in vehicles

Table 4.3.10 Average cumulative VKT per vehicle age of Tuk-tuks, only for the vehicle age groups with more than 10 samples.

Vehicle age	Accumulated VKT	N
3	129563	89
30	1245400	12
49	1837127	130
50	2019333	180
Total	411	

N – sample size, in vehicles

4.3.6 Public motorcycles

The total number of sample of this vehicle category was 263 vehicles, which had been collected from various locations in Bangkok. Figure 4.3.6 shows the collected cumulative VKT data versus the vehicle age of public motorcycles. The average cumulative VKT and the number of samples per the vehicle age group are summarized in Table 4.3.11, while Table 4.3.12 lists those vehicle age groups that have more than 10 samples.

Figure 4.3.6 the distribution of the collected cumulative VKT Vs vehicle age of Public motorcycles

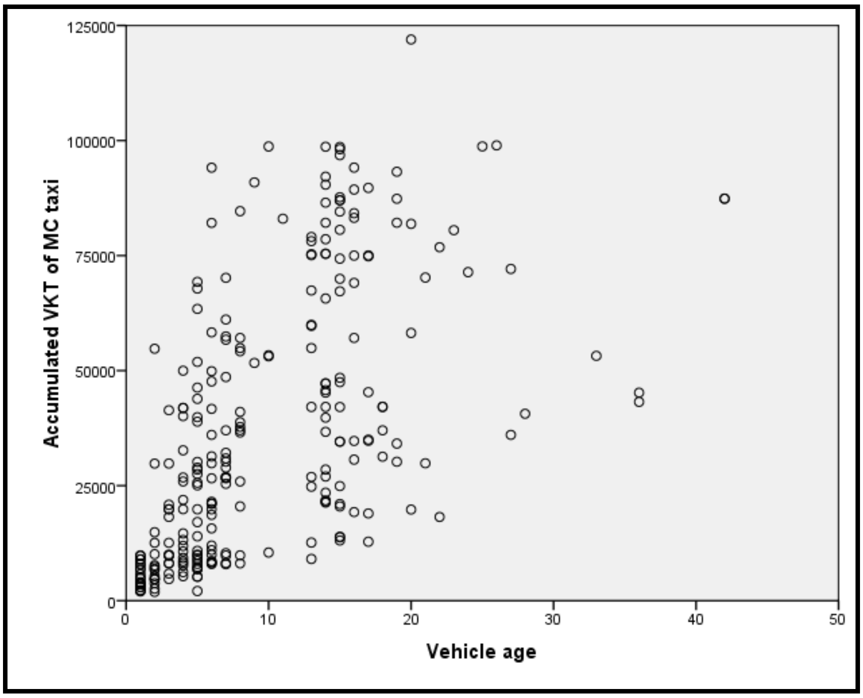


Table 4.3.11 Average cumulative VKT per vehicle age of Public motorcycles

Vehicle age	Accumulated VKT	N	Vehicle age	Accumulated VKT	N
1	5508	20	17	48305	8
2	11156	16	18	38138	4
3	15648	14	19	65410	5
4	20876	19	20	70463	4
5	25113	29	21	50045	2
6	29633	23	22	47511	2
7	33057	18	23	80529	1
8	38956	13	24	71402	1
9	71300	2	25	98737	1
10	53903	4	26	98941	1
11	83016	1	27	54069	2
13	51160	13	28	40630	1
14	54201	22	33	53206	1
15	56650	22	36	44211	2
16	63668	10	42	87372	2
Total			263		

N – sample size, in vehicles

Table 4.3.12 Average cumulative VKT per vehicle age of Public motorcycles, only for the vehicle age groups with more than 10 samples.

Vehicle age	Accumulated VKT	N
1	5508	20
2	11156	16
3	15648	14
4	20876	19
5	25113	29
6	29633	23
7	33057	18
8	38956	13
13	51160	13
14	54201	22
15	56650	22
16	63668	10
Total	219	

N – sample size, in vehicles

4.3.7 Fixed-route vans (Song-taews)

The total number of sample of this vehicle category was 334 vehicles, which had been collected from various locations in Bangkok. Figure 4.3.7 shows the collected cumulative VKT data versus the vehicle age of Song-taews. The average cumulative VKT and the number of samples per the vehicle age group are summarized in Table 4.3.13, while Table 4.3.14 lists those vehicle age groups that have more than 10 samples.

Figure 4.3.7 the distribution of the collected cumulative VKT Vs vehicle age of Song-taews

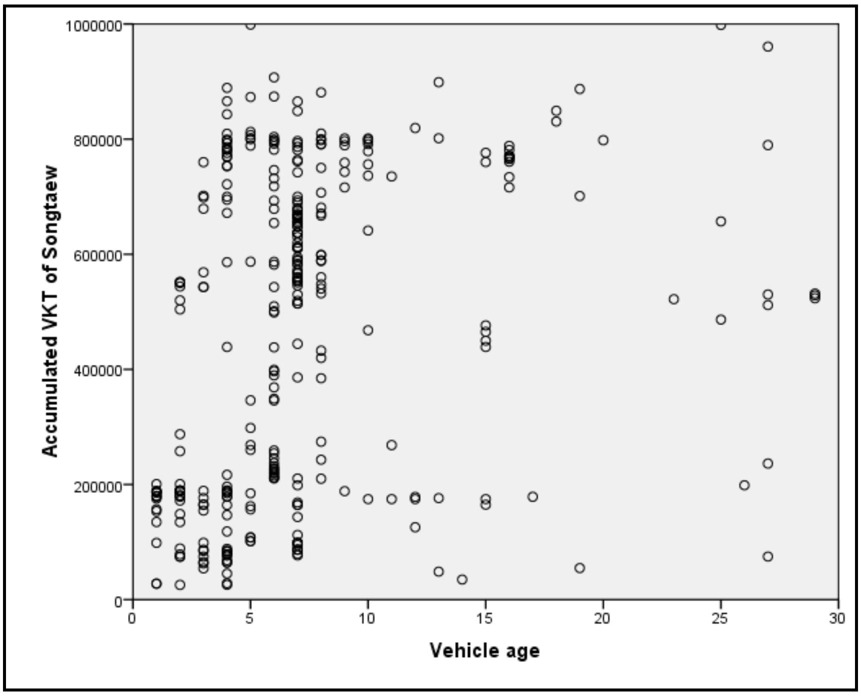


Table 4.3.13 Average cumulative VKT per vehicle age of Song-taews

Vehicle age	Accumulated VKT	N	Vehicle age	Accumulated VKT	N
1	155221	17	14	34862	1
2	243489	28	15	463279	8
3	309061	19	16	762337	10
4	413460	45	17	178635	1
5	450811	19	18	840032	2
6	484867	41	19	547747	3
7	521263	72	20	798213	1
8	594698	25	23	521980	1
9	684845	7	25	714033	3
10	697282	10	26	198661	1
11	392769	3	27	517258.5	6
12	324560	4	29	527957	3
13	481370	4			
Total			334		

N – sample size, in vehicles

Table 4.3.14 Average cumulative VKT per vehicle age of Song-taews, only for the vehicle age groups with more than 10 samples.

Vehicle age	Accumulated VKT	N
1	155221	17
2	243489	28
3	309061	19
4	413460	45
5	450811	19
6	484867	41
7	521263	72
8	594698	25
10	697282	10
Total	276	

N – sample size, in vehicles

4.3.8 Fixed-route buses

The total number of sample of this vehicle category was 385 vehicles, which had been collected from various locations in Bangkok. Figure 4.3.8 shows the collected cumulative VKT data versus the vehicle age of Fixed-rout buses. The average cumulative VKT and the number of samples per the vehicle age group are summarized in Table 4.3.15, while Table 4.3.16 lists those vehicle age groups that have more than 10 samples.

Figure 4.3.8 the distribution of the collected cumulative VKT Vs vehicle age of Fixed-route buses

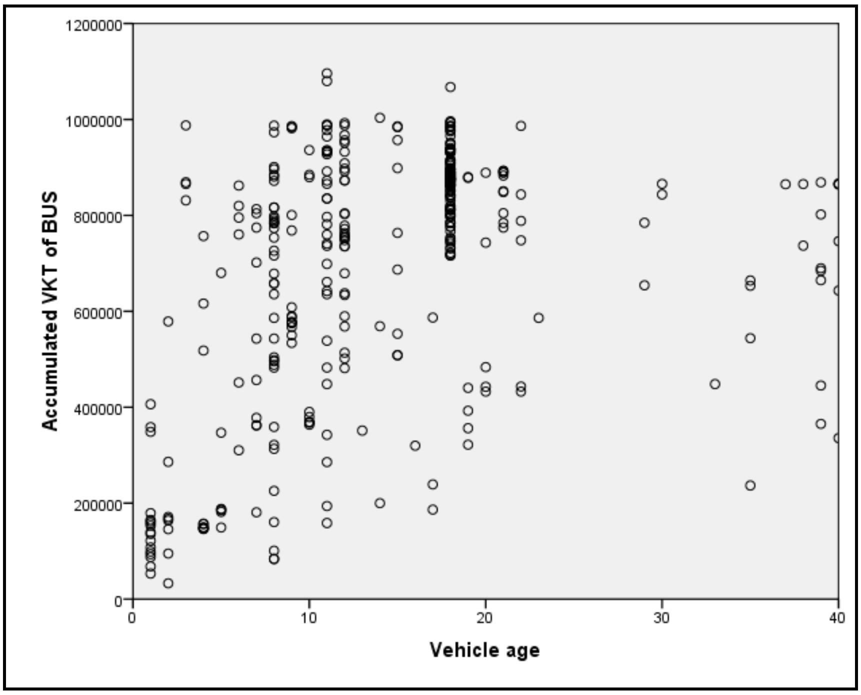


Table 4.1.15 Average cumulative VKT per vehicle age of Fixed-route buses

Vehicle age	Accumulated VKT	N	Vehicle age	Accumulated VKT	N
1	166944	18	17	337530	3
2	205183	8	18	870349	127
3	888377	4	19	544929	6
4	294471	10	20	598235	5
5	274136	7	21	851020	10
6	666618	6	22	707081	6
7	537755	10	23	586198	1
8	621306	38	29	719502	2
9	684333	15	30	854698	2
10	548812	9	33	448342	1
11	756081	33	35	524613	4
12	774833	30	37	864954	1
13	351342	1	38	801147	2
14	590838	3	39	645805	7
15	760651	9	40	720249	6
16	319852	1			
Total			385		

N – sample size, in vehicles

Table 4.1.16 Average cumulative VKT per vehicle age of Fixed-route buses, only for the vehicle age groups with more than 10 samples.

Vehicle age	Accumulated VKT	N
1	166944	18
4	294471	10
7	537755	10
8	621306	38
9	684333	15
11	756081	33
12	774833	30
18	870349	127
Total	281	

N – sample size, in vehicles

4.3.9 Trucks

The total number of sample of this vehicle category was 475 vehicles, which had been collected from various locations in Bangkok. Figure 4.3.9 shows the collected cumulative VKT data versus the vehicle age of Trucks. The average cumulative VKT and the number of samples per the vehicle age group are summarized in Table 4.3.17, while Table 4.3.18 lists those vehicle age groups that have more than 10 samples.

Figure 4.3.9 the distribution of the collected cumulative VKT Vs vehicle age of Trucks.

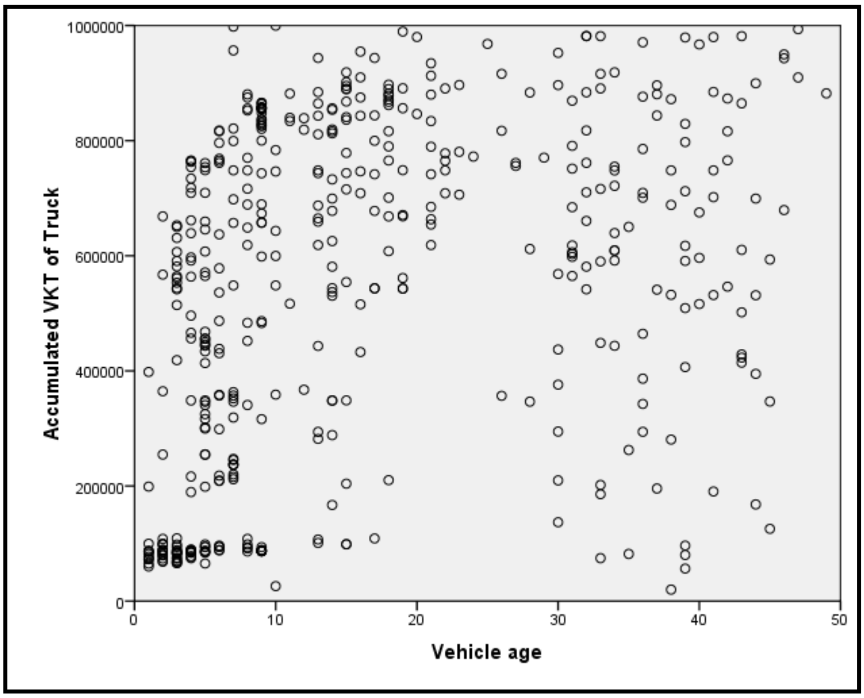


Table 4.3.17 Average cumulative VKT per vehicle age of Trucks

Vehicle age	Accumulated VKT	N	Vehicle age	Accumulated VKT	N
1	115527	12	26	696710	3
2	170260	18	27	758720	2
3	300862	29	28	613988	3
4	363134	32	29	770355	1
5	379180	35	30	483991	8
6	432403	24	31	676210	9
7	467437	21	32	768942	9
8	522737	18	33	556170	9
9	567371	41	34	670742	9
10	588262	7	35	331557	3
11	768060	4	36	614563	9
12	675143	3	37	671452	5
13	606003	16	38	523581	6
14	618077	20	39	515938	11
15	661395	16	40	688775	4
16	748278	8	41	672867	6
17	650335	8	42	750370	4
18	764805	14	43	603520	7
19	719161	9	44	538713	5
20	913177	2	45	355336	3
21	771375	10	46	857496	3
22	778192	5	47	951767	2
25	968121	1	49	882145	1
Total			475		

N – sample size, in vehicles

Table 4.3.18 Average cumulative VKT per vehicle age of Trucks, only for the vehicle age groups with more than 10 samples.

Vehicle age	Accumulated VKT	N	Vehicle age	Accumulated VKT	N
1	115527	12	8	522737	18
2	170260	18	9	567371	41
3	300862	29	13	606003	16
4	363134	32	14	618077	20
5	379180	35	15	661395	16
6	432403	24	18	764805	14
7	467437	21	21	771375	10
Total			306		

N – sample size, in vehicles

4.4 Data Analysis in Bangkok

In this section, we utilized a statistical approach to find the relationship between the cumulative VKT and the vehicle age. The cumulative VKT is the dependent variable of the model, while the vehicle age is the independent variable of the model. For each vehicle category, the model development follows the steps below:

1.Select the vehicle age groups that have more than 10 samples

2.Estimate the average cumulative VKT for each vehicle age group

3.Identify a statistical model that best fit the data in 2)

To identify the best fitted model, we have tried a few variations of regression models, including a power model and for some vehicle group, a cubic model. The model with the highest r^2 was selected to represent the relationship of the model. All of the models were developed using the commercial software SPSS.

4.4.1 Sedans (not more than 7 passengers)

The power models were developed to explicit the relationship between the cumulative VKT and the vehicle age. Table 4.4.1 summarizes the relevant statistics as well as the estimated coefficients for the models. Figure 4.4.1 shows the trends of the estimated cumulative VKT from the developed models in comparison with the observed data. As shown, use the power model to be the final model for Sedans (not more than 7 passengers). Figure 4.4.2 illustrates the final estimated cumulative VKT as well as annual VKT per vehicle age for Sedans (not more than 7 passengers) using the power model. As shown, it was found that the annual VKT decreases as the vehicle age increases. A plausible explanation is the owner excitement with a new vehicle, thus, they tend to drive a new vehicle more often and for a longer distance. In addition, it is highly probable that aged vehicles tend to be broken and thus spent more days in the mechanic shops; thus, it limits the number of days for the owner usage. In addition, aged vehicles tend to consume more gasoline and are likely to be broken, thus, the owners might decide to go with other travel options that are more convenient and safer for them, especially for the long-distance trips.

Table 4.4.1 Summary of the statistics and the estimated coefficients of the developed models for Sedans (not more than 7 passengers)

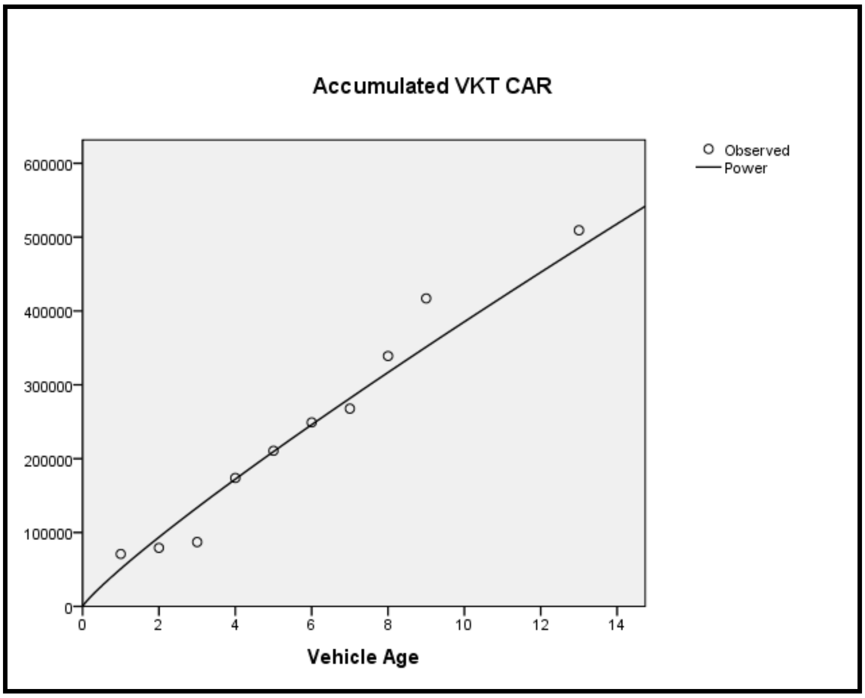
Model Summary and Parameter Estimates

Dependent Variable: Cumulated VKT

Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Power	.919	91.012	1	8	.000	5.096E4	.879

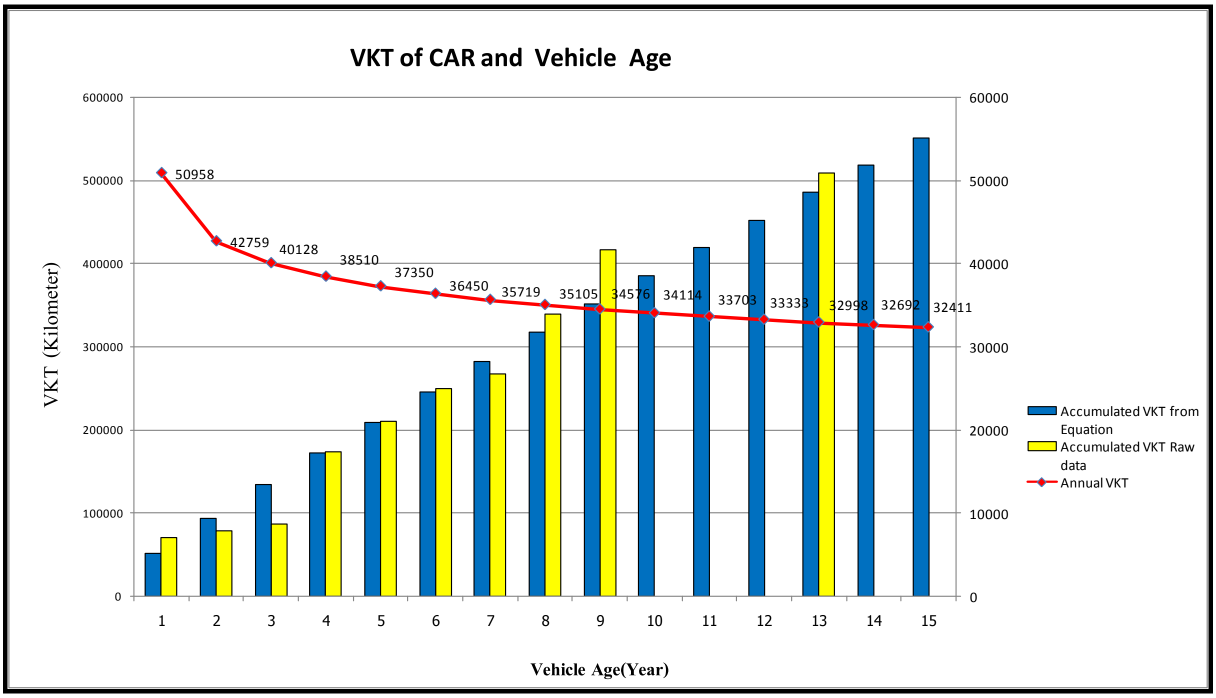
The independent variable is Vehicle Age.

Figure 4.4.1 Forecasted cumulative VKT of Sedans (not more than 7 passengers) using power models



From Figure 4.4.2, it is expected that the first year sedan travel, on average, 50,958 kilometers per year, and the mileage reduces to 37,350 kilometers in the 5th year (based on the power model).

Figure 4.2.2 Estimated cumulative and annual VKT by vehicle age for Sedans (not more than 7 passengers)



4.4.2 Vans/Pick-ups

The power models were developed to explicit the relationship between the cumulative VKT and the vehicle age. Table 4.4.2 summarizes the relevant statistics as well as the estimated coefficients for the models. Figure 4.4.3 shows the trends of the estimated cumulative VKT from the developed models in comparison with the observed data. As shown, use the power model to be the final model for Vans/Pick-ups. Figure 4.4.4 illustrates the final estimated cumulative VKT as well as annual VKT per vehicle age for Vans/Pick-ups, using the power model. Similarly to Sedans, it was found that the annual VKT decreases as the vehicle age increases, plausible with the same explanations.

Table 4.4.2 Summary of the statistics and the estimated coefficients of the developed models for Vans/Pick-ups

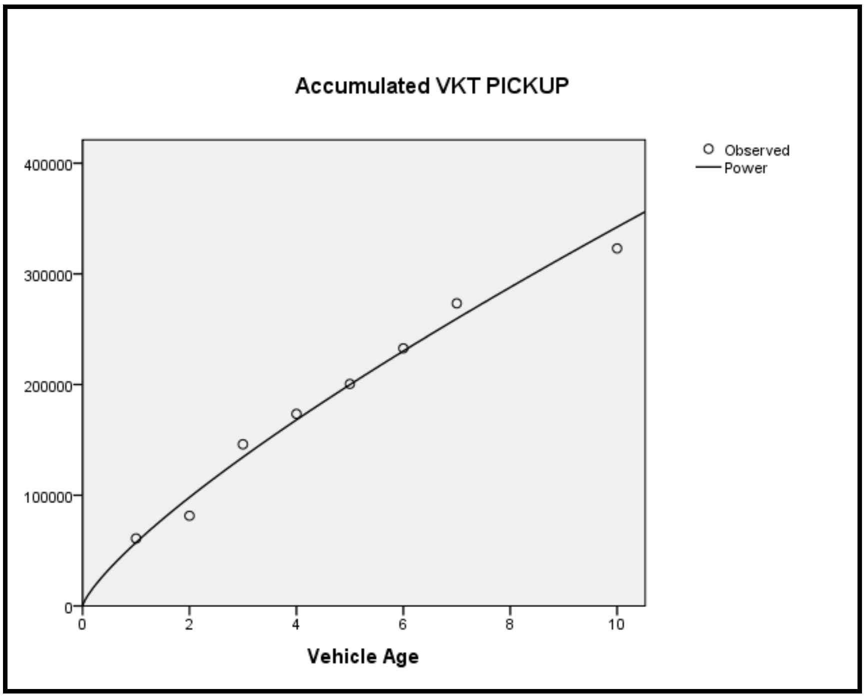
Model Summary and Parameter Estimates

Dependent Variable: Cumulated VKT

Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Power	.978	264.714	1	6	.000	5.730E4	.776

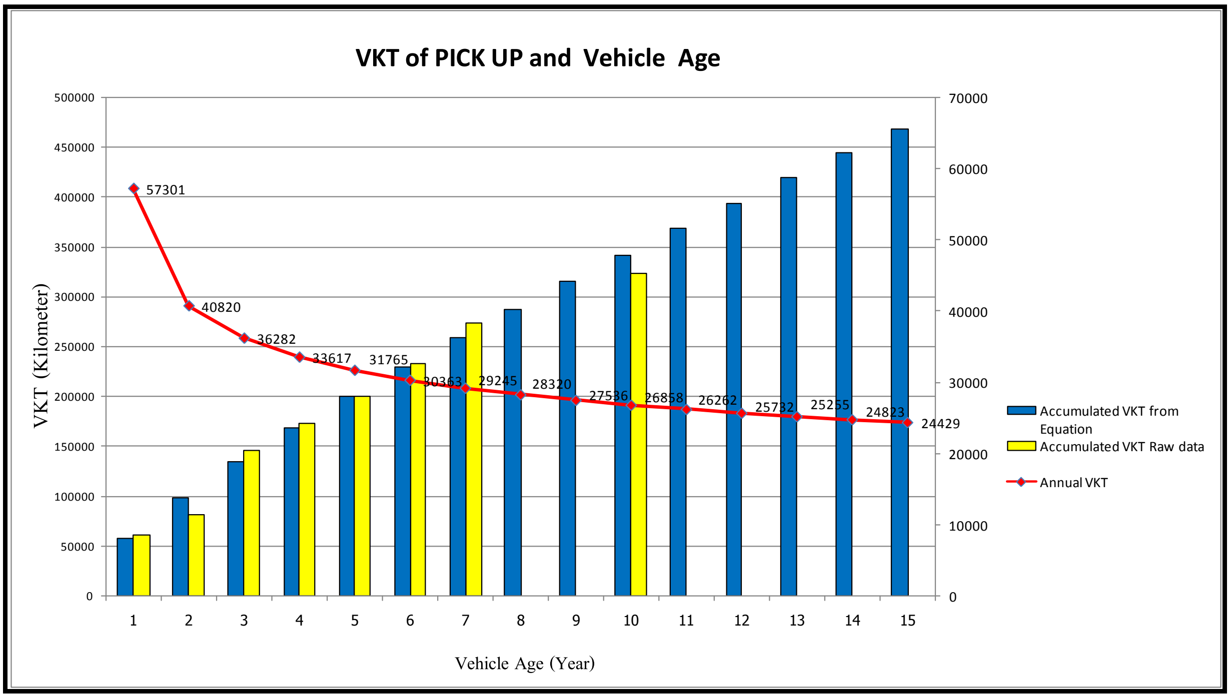
The independent variable is Vehicle Age.

Figure 4.4.3 Forecasted cumulative VKT of Vans/Pick-ups using power models



From Figure 4.4.4, it is expected that the first year pick-ups travel, on average, 57,301 kilometers per year, and the mileage reduces to 31,765 kilometers in the 5th year (based on the power model).

Figure 4.4.4 Estimated cumulative and annual VKT by vehicle age for Vans/Pick-ups



4.4.3 Motorcycles

The power models were developed to explicit the relationship between the cumulative VKT and the vehicle age. Table 4.4.3 summarizes the relevant statistics as well as the estimated coefficients for the models. Figure 4.4.5 shows the trends of the estimated cumulative VKT from the developed models in comparison with the observed data. As shown, use the power model to be the final model for Motorcycles. Figure 4.4.6 illustrates the final estimated cumulative VKT as well as annual VKT per vehicle age for Motorcycles, using the quadratic model. Similarly to Sedans and Pick-ups, it was found that the annual VKT decreases as the vehicle age increases, plausible with the same explanations.

Table 4.4.3 Summary of the statistics and the estimated coefficients of the developed models for Motorcycles

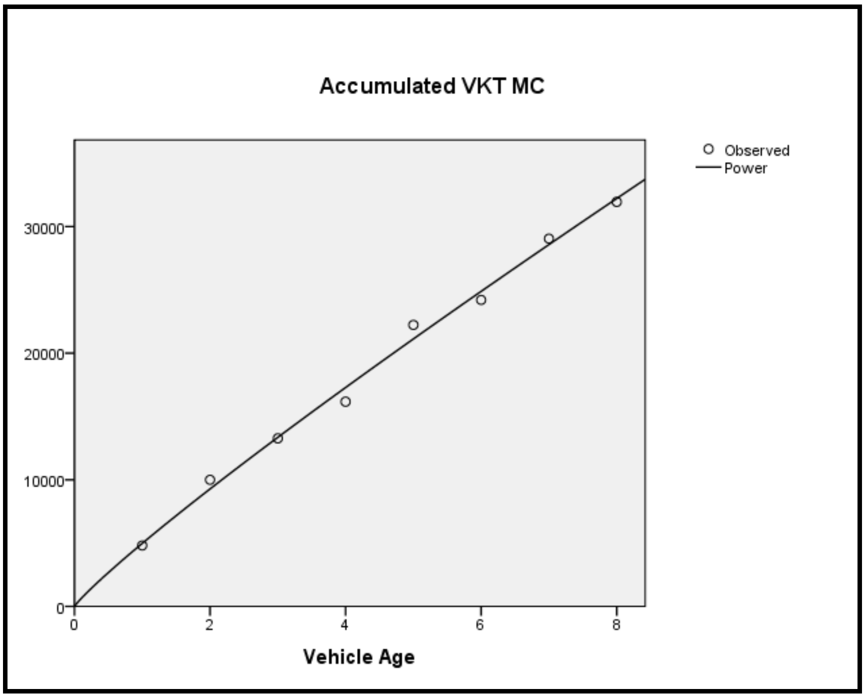
Model Summary and Parameter Estimates

Dependent Variable: Cumulated VKT

Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Power	.995	1.113E3	1	6	.000	4.978E3	.898

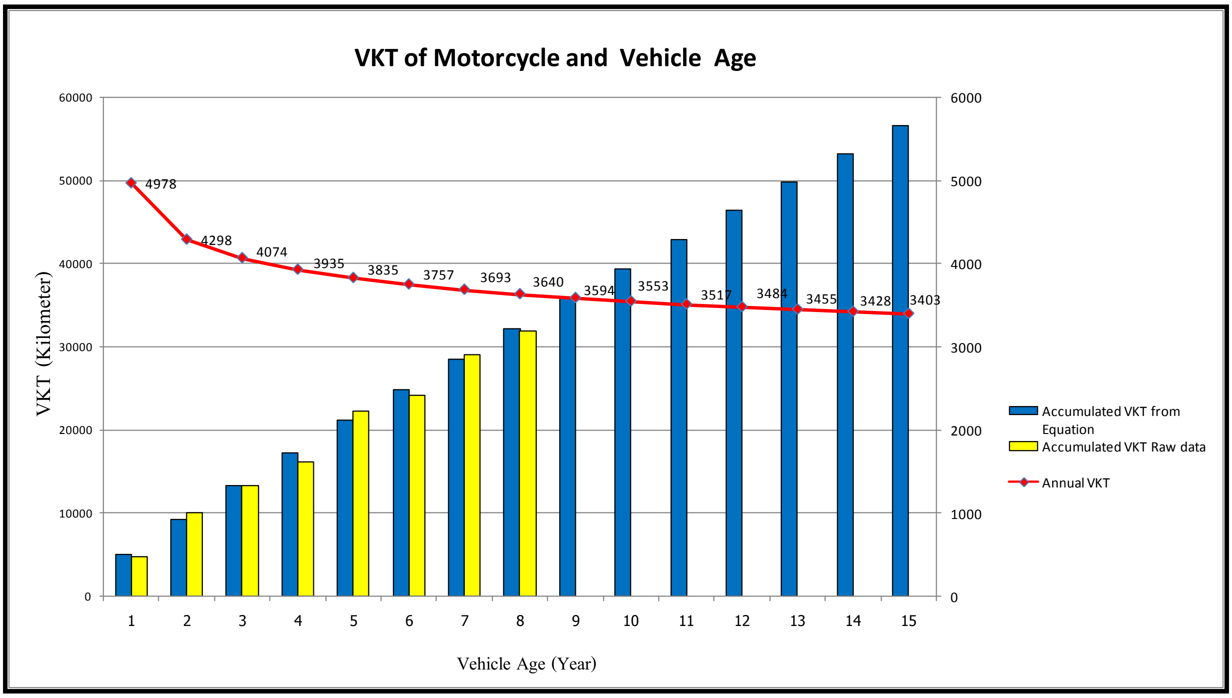
The independent variable is Vehicle Age.

Figure 4.4.5 Forecasted cumulative VKT of Motorcycles using power models



From Figure 4.2.6, it is expected that the first year motorcycles travel, on average, 4,978 kilometers per year, and the mileage 3,757 kilometers in the 6th year (based on the power model).

Figure 4.4.6 Estimated cumulative and annual VKT by vehicle age for Motorcycles



4.4.4 Urban Taxis

The power models were developed to explicit the relationship between the cumulative VKT and the vehicle age. Table 4.4.4 summarizes the relevant statistics as well as the estimated coefficients for the models. Figure 4.4.7 shows the trends of the estimated cumulative VKT from the developed models in comparison with the observed data. As shown, the developed power model was rather irrational given that the annual VKT seems to increase with the vehicle age. It is possible that the limited number of samples (36 vehicles) as well as the short history of the urban taxis in Bangkok(less than 2 years) prevent us from developing a good power model. Thus, for this vehicle category, we decide to use a power model to represent the relationship between the cumulative VKT and the vehicle age. Note that the forecasting results should be used with special care, and the model should be updated as sufficient data are available. Figure 4.4.8 illustrates the final estimated cumulative VKT as well as annual VKT per vehicle age for Urban taxis, using the power model.

Table 4.4.4 Summary of the statistics and the estimated coefficients of the developed models for Urban Taxi

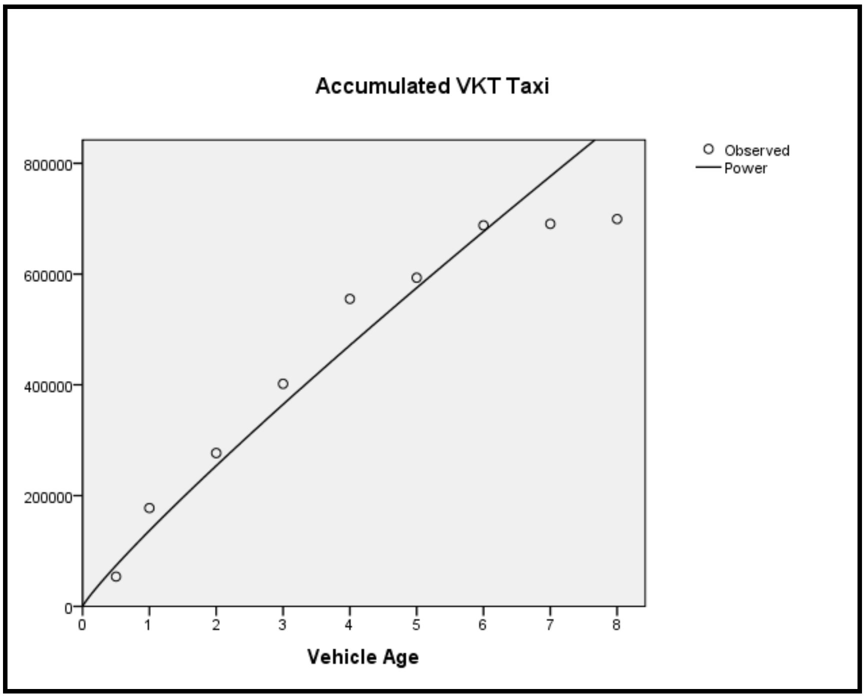
Model Summary and Parameter Estimates

Dependent Variable Cumulated VKT

Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Power	.953	142.836	1	7	.000	1.368E5	.892

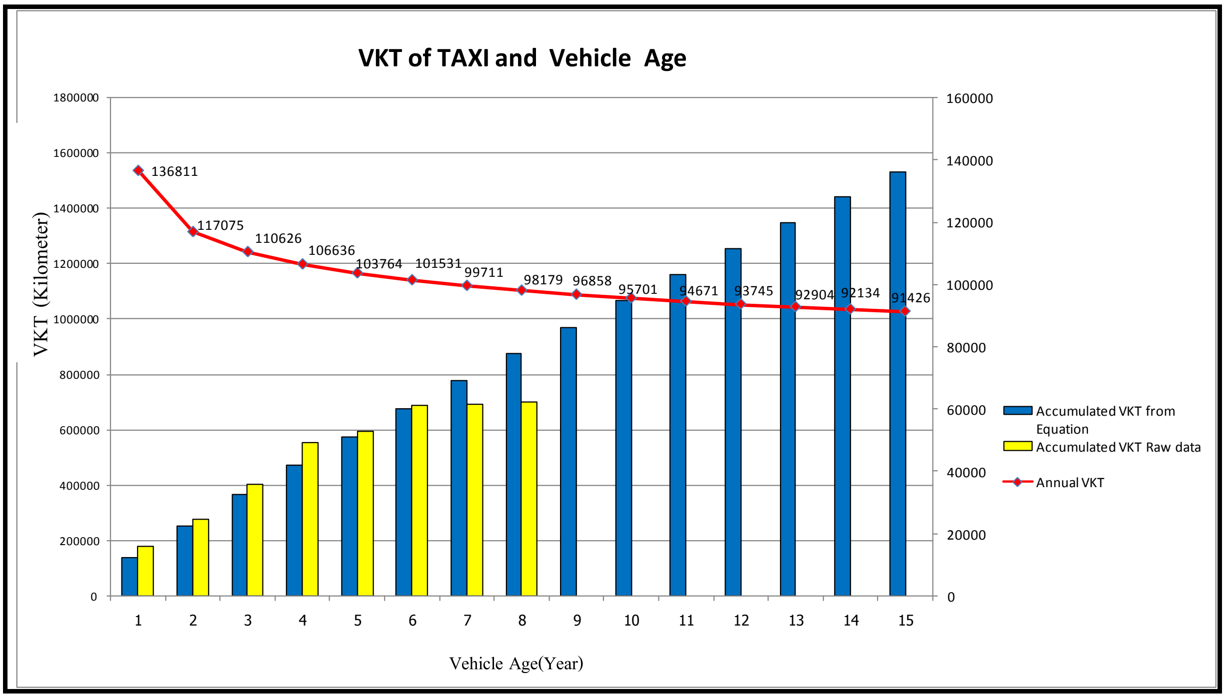
The independent variable is Vehicle Age.

Figure 4.4.7 Forecasted cumulative VKT of Urban Taxi using power models



A simple estimate of the urban taxi annual VKT can be found from the power model (see Table 4.2.4) ,it is expected that the first year urban taxi travel, on average, 136,811 kilometers per year, and the mileage 101,531 kilometers in the 6th year (based on the power model).

Figure 4.2.8 Estimated cumulative and annual VKT by vehicle age for Urban Taxis



4.4.5 Tuk-tuks

The power models were developed to explicit the relationship between the cumulative VKT and the vehicle age. Table 4.4.5 summarizes the relevant statistics as well as the estimated coefficients for the models. Figure 4.4.9 shows the trends of the estimated cumulative VKT from the developed models in comparison with the observed data. As shown, use the power model to be the final model for Tuk-tuks. Figure 4.4.10 illustrates the final estimated cumulative VKT as well as annual VKT per vehicle age for Tuk-tuks, using the power model.

Table 4.4.5 Summary of the statistics and the estimated coefficients of the developed models for Tuk-tuks

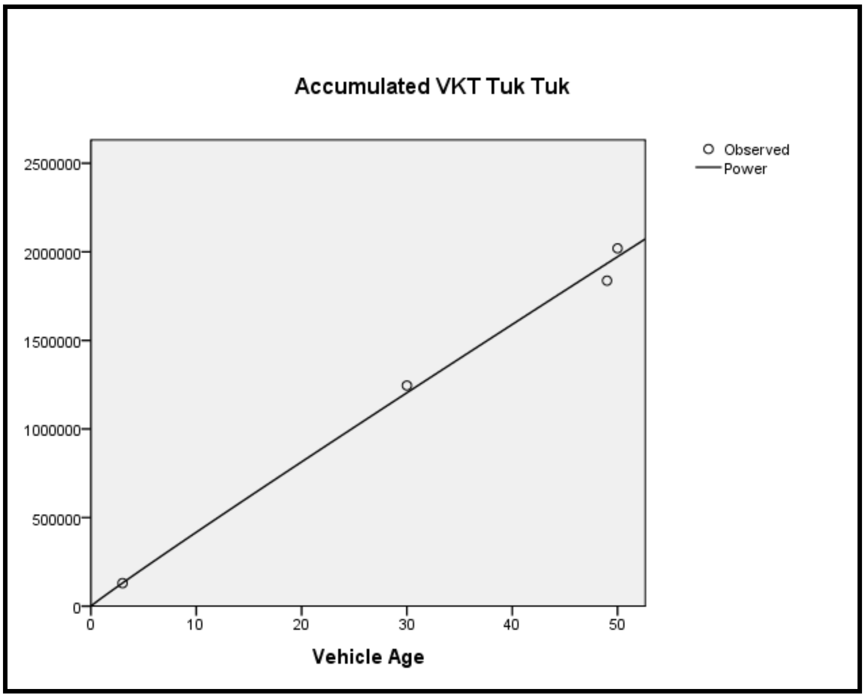
Model Summary and Parameter Estimates

Dependent Variable: Cumulated VKT

	Model Summary					Parameter Estimates	
Equation	R Square	F	df1	df2	Sig.	Constant	b1
Power	.999	2.298E3	1	2	.000	4.510E4	.966

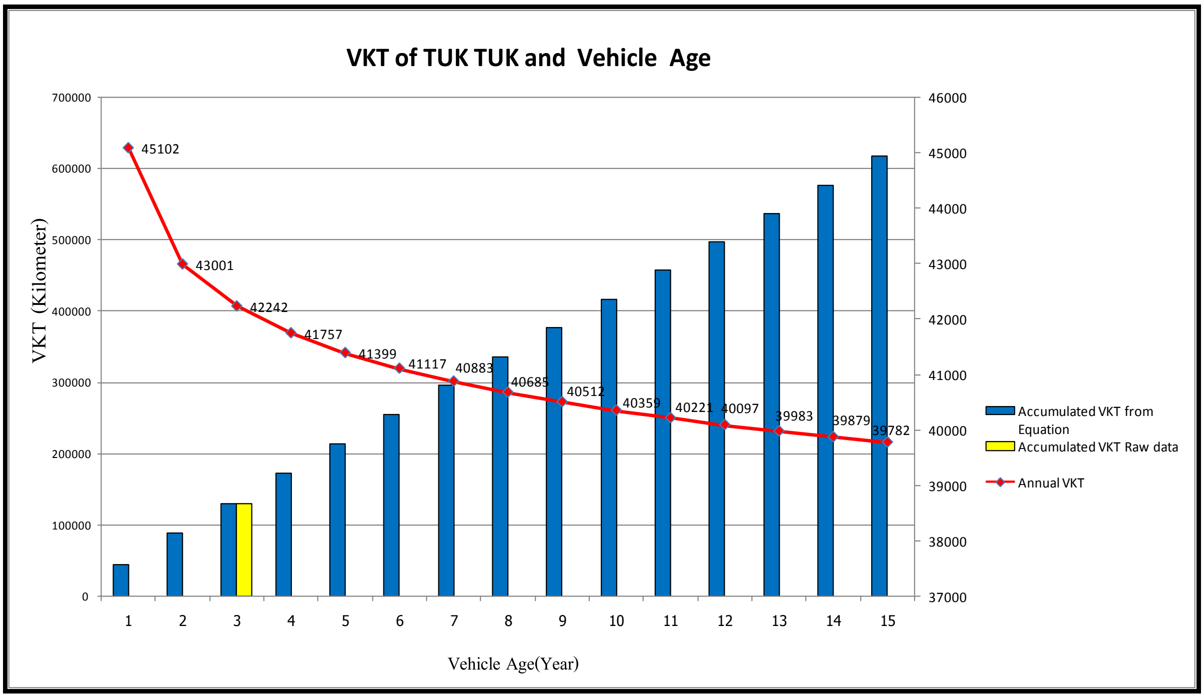
The independent variable is Vehicle Age.

Figure 4.4.9 Forecasted cumulative VKT of Tuk-tuks using power models



A simple estimate of the tuk-tuks annual VKT can be found from the power model (see Table 4.4.5) it is expected that the first year Tuk-tuks travel, on average, 45,102 kilometers per year, and the mileage 41,399 kilometers in the 5th year (based on the power model).

Figure 4.4.10 Estimated cumulative and annual VKT by vehicle age for Tuk-tuks



4.4.6 Public motorcycles

The power models were developed to explicit the relationship between the cumulative VKT and the vehicle age. Table 4.4.6 summarizes the relevant statistics as well as the estimated coefficients for the models. Figure 4.4.11 shows the trends of the estimated cumulative VKT from the developed models in comparison with the observed data. As shown, use the power model to be the final model for Motorcycles. Figure 4.4.12 illustrates the final estimated cumulative VKT as well as annual VKT per vehicle age for Motorcycles, using the quadratic model. Similarly to Sedans and Pick-ups, it was found that the annual VKT decreases as the vehicle age increases, plausible with the same explanations.

Table 4.4.6 Summary of the statistics and the estimated coefficients of the developed models for Public motorcycles

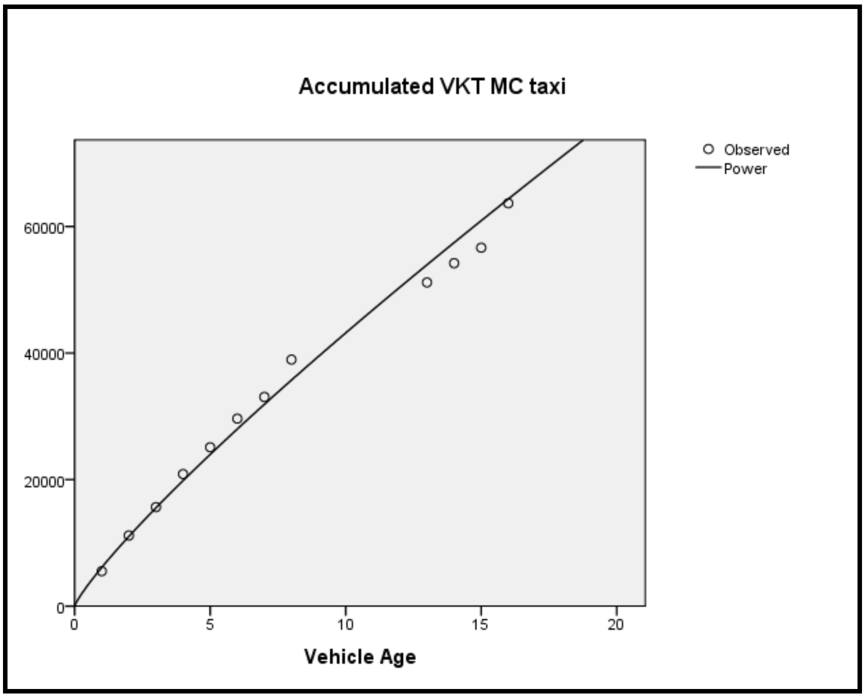
Model Summary and Parameter Estimates

Dependent Variable: Cumulated VKT

Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Power	.993	1.517E3	1	10	.000	6.111E3	.849

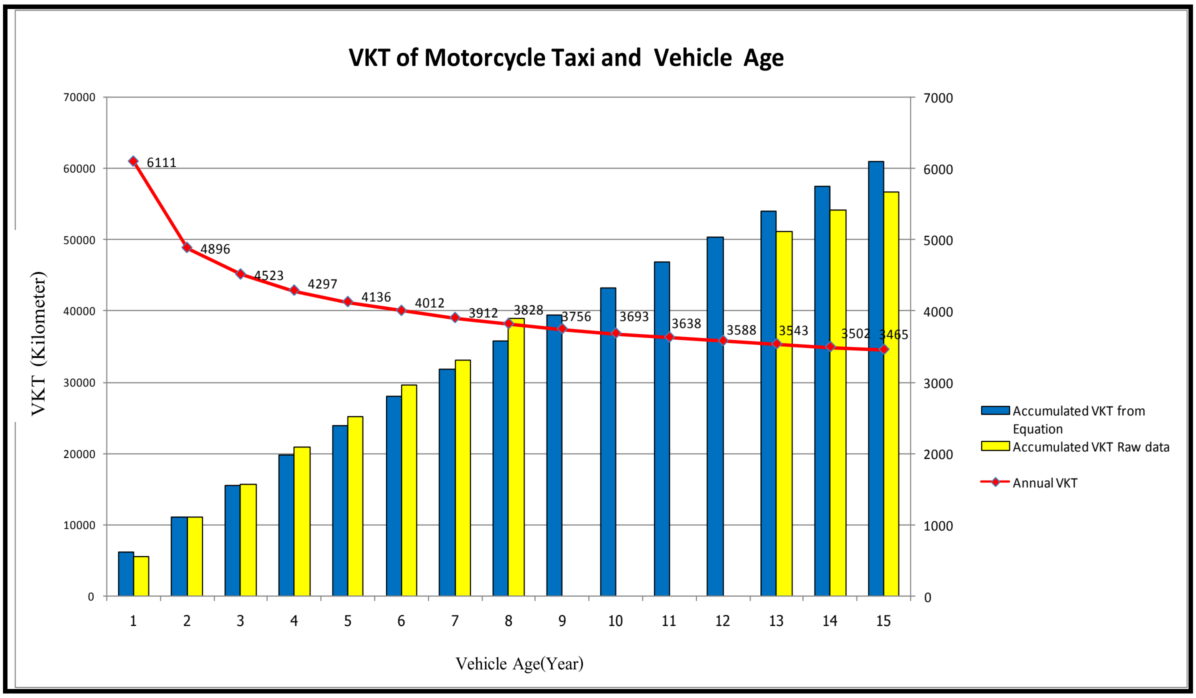
The independent variable is Vehicle Age.

Figure 4.4.11 Forecasted cumulative VKT of Public motorcycles using linear and quadratic models



A simple estimate of the Public motorcycles annual VKT can be found from the power model (see Table 4.4.6) it is expected that the first year Public motorcycles travel, on average 6,111 kilometers per year, and the mileage 4,297 kilometers in the 4^{th} year (based on the power model).

Figure 4.4.12 Estimated cumulative and annual VKT by vehicle age for Public motorcycles



4.4.7 Fixed-route vans (Song-taews)

The power models were developed to explicit the relationship between the cumulative VKT and the vehicle age. Table 4.4.7 summarizes the relevant statistics as well as the estimated coefficients for the models. Figure 4.4.13 shows the trends of the estimated cumulative VKT from the developed models in comparison with the observed data. As shown, use the power model to be the final model for Song-taews. Figure 4.2.14 illustrates the final estimated cumulative VKT as well as annual VKT per vehicle age for Song-taews, using the power model. Similarly to most of the vehicle types, it was found that the annual VKT decreases as the vehicle age increases, plausible with the same explanations.

Table 4.4.7 Summary of the statistics and the estimated coefficients of the developed models for Songtaews

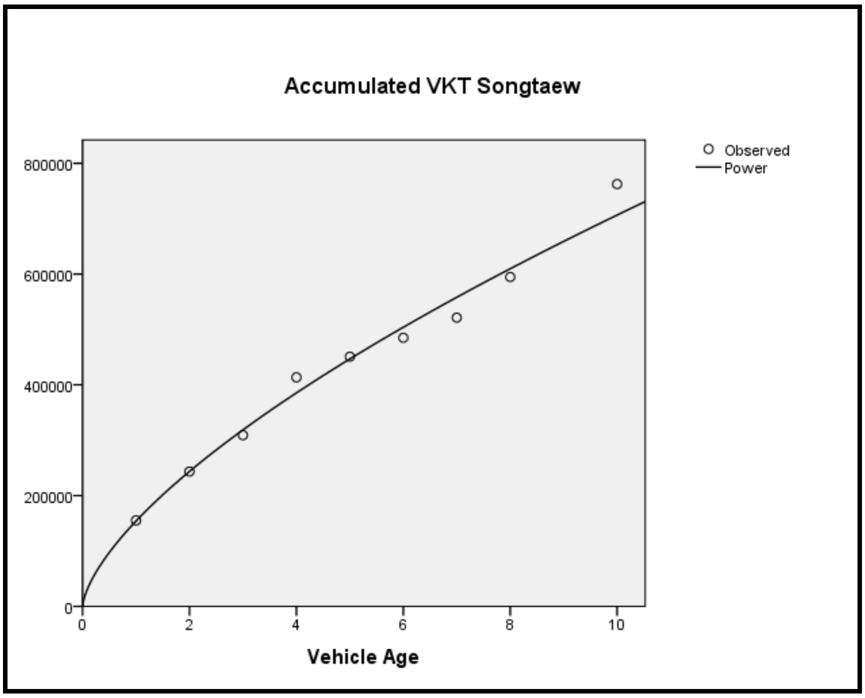
Model Summary and Parameter Estimates

Dependent Variable: Cumulated VKT

	Model Summary					Parameter Estimates	
Equation	R Square	F	df1	df2	Sig.	Constant	b1
Power	.994	1.173E3	1	7	.000	1.565E5	.643

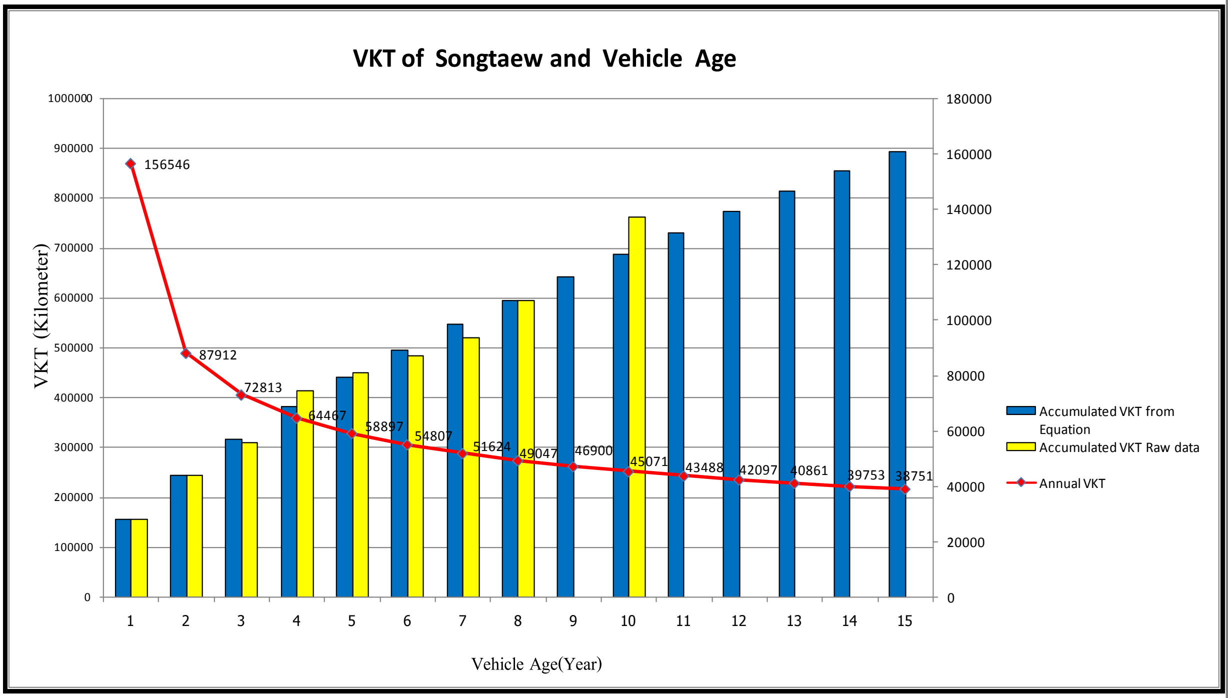
The independent variable is Vehicle Age.

Figure 4.4.13 Forecasted cumulative VKT of Song-taews using power models



From Figure 4.4.14, it is expected that the first year Song-taews travel, on average, 156,546 kilometers per year, and the mileage reduces to 54,807 kilometers in the 6th year (based on the power model).

Figure 4.2.14 Estimated cumulative and annual VKT by vehicle age for Song-taews



4.4.8 Fixed-route buses

The power models were developed to explicit the relationship between the cumulative VKT and the vehicle age. Table 4.4.8 summarizes the relevant statistics as well as the estimated coefficients for the models. Figure 4.4.15 shows the trends of the estimated cumulative VKT from the developed models in comparison with the observed data. As shown, use the power model to be the final model for Fixed-route buses. Figure 4.4.16 illustrates the final estimated cumulative VKT as well as annual VKT per vehicle age for Fixed-route buses, using the power model. Similarly to most of the vehicle types, it was found that the annual VKT decreases as the vehicle age increases, plausible with the same explanations.

Table 4.4.8 Summary of the statistics and the estimated coefficients of the developed models for Songtaews

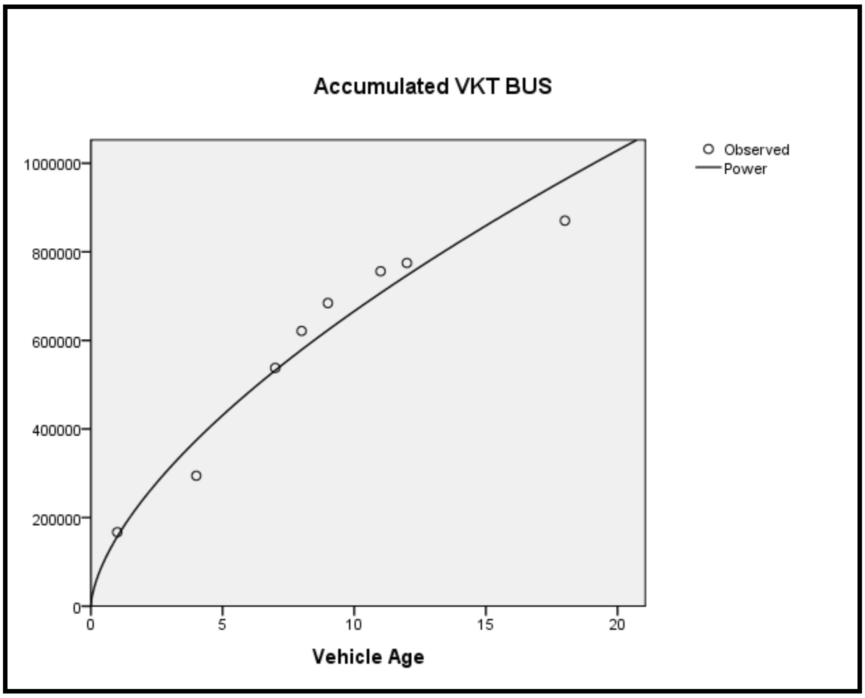
Model Summary and Parameter Estimates

Dependent Variable: Cumulated VKT

Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Power	.960	143.467	1	6	.000	1.568E5	.628

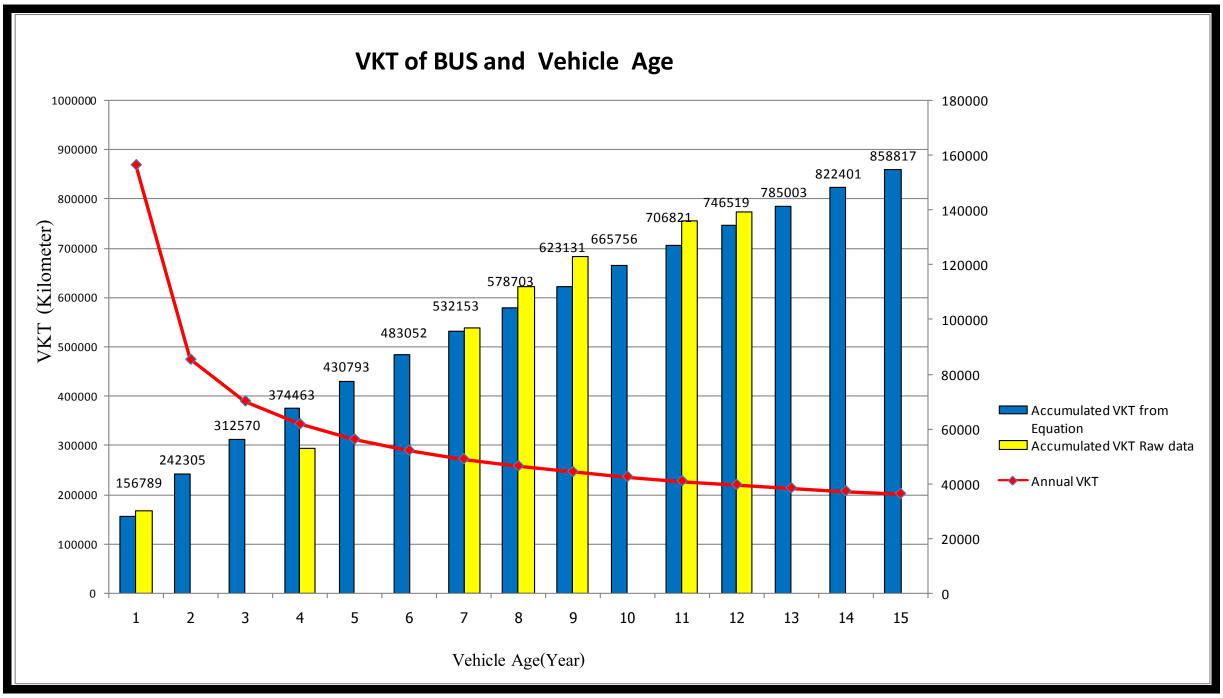
The independent variable is Vehicle Age.

Figure 4.4.15 Forecasted cumulative VKT of Fixed-route buses using linear, quadratic and cubic models



From Figure 4.4.16, it is expected that the first year Fixed-route buses travel, on average 156,789 kilometers per year, and the mileage reduces to 56,330 kilometers in the 5th year (based on the power model).

Figure 4.4.16 Estimated cumulative and annual VKT by vehicle age for Fixed-route buses



4.4.9 Trucks

The power models were developed to explicit the relationship between the cumulative VKT and the vehicle age. Table 4.4.9 summarizes the relevant statistics as well as the estimated coefficients for the models. Figure 4.4.17 shows the trends of the estimated cumulative VKT from the developed models in comparison with the observed data. As shown, use the power model to be the final model for Trucks. Figure 4.4.18 illustrates the final estimated cumulative VKT as well as annual VKT per vehicle age for Trucks, using the power model. Similarly to most of the vehicle types, it was found that the annual VKT decreases as the vehicle age increases, plausible with the same explanations.

Table 4.4.9 Summary of the statistics and the estimated coefficients of the developed models for Trucks

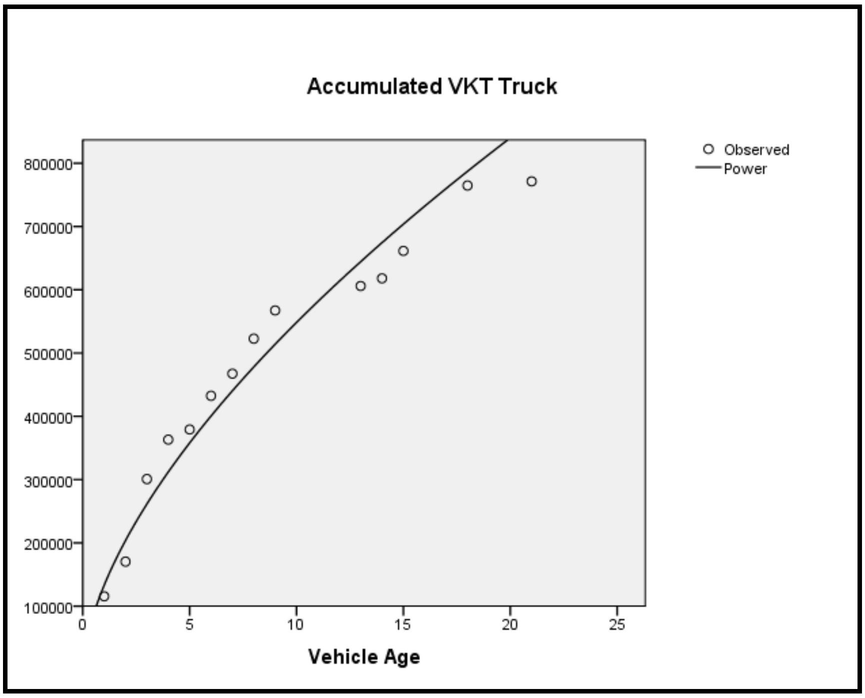
Model Summary and Parameter Estimates

Dependent Variable: Cumulated VKT

	Model Summary					Parameter Estimates	
Equation	R Square	F	df1	df2	Sig.	Constant	b1
Power	.961	297.441	1	12	.000	1.330E5	.615

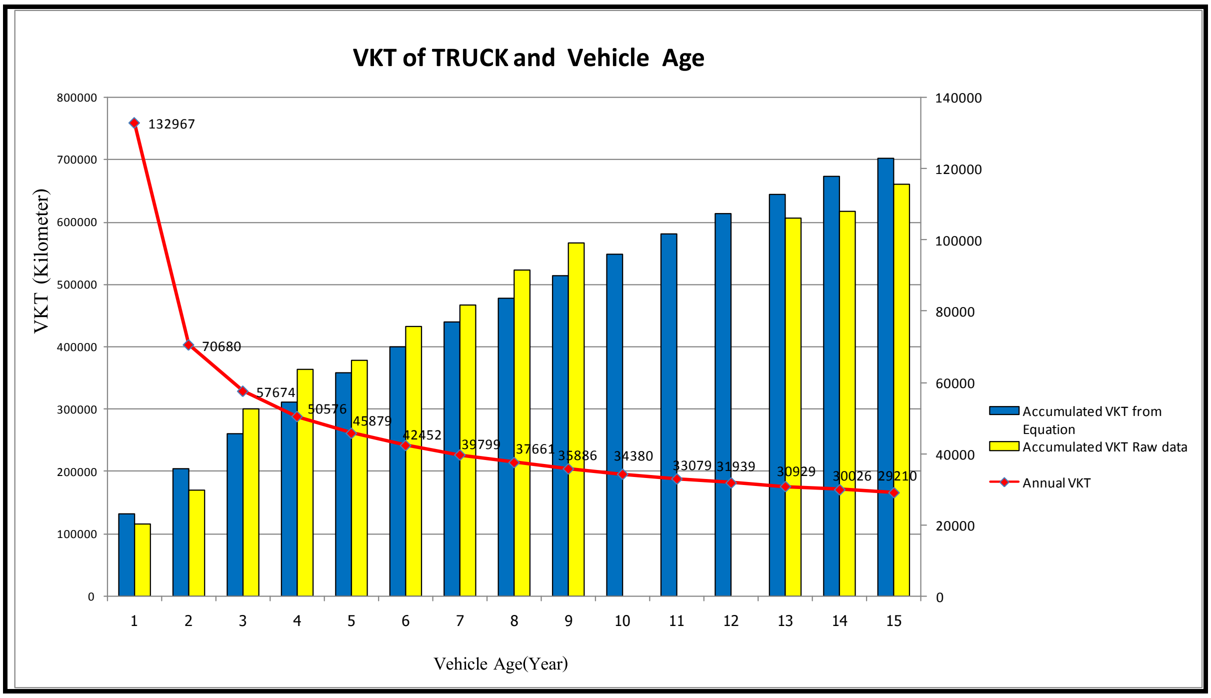
The independent variable is Vehicle Age.

Figure 4.4.17 Forecasted cumulative VKT of Trucks using power models



From Figure 4.4.18, it is expected that the first year trucks travel, on average, 132,967 kilometers per year, and the mileage reduces to 37,661 kilometers in the 8th year (based on the power model).

Figure 4.2.18 Estimated cumulative and annual VKT by vehicle age for Trucks



CHAPTER 5 Conclusion

Base on the collected data of vehicle kilometer of travel (VKT) from odometer reading in Nakornratchasima and Bangkok, the relationship of cumulative VKT and vehicle age of road transport vehicles, which including passenger car, pick up, motorcycle, taxi, 3-wheeler, bus and truck, can be determined. The results of the models and application of them to estimate the total VKT of road transport vehicles in each province are presented in following sections. Moreover, the estimated total VKT of each province are also compared with various cities worldwide.

5.1 Vehicle kilometer of travel models

The estimated coefficients of vehicle kilometer of travel (VKT) models of Nakornratchasima and Bangkok are shown in Table 5.1. The power, quadratic and cubic functions were employed as a model function. Most models approximate actual observed data very well as on can see from the R^2 value; they are higher than 0.80 for all vehicle types both in Nakornratchasima and Bangkok.

Table 5.1 Cumulative VKT models of road transport vehicles

Type of vehicle	Nakornratchasima		Bangkok	
	Equation	R^2	Equation	R^2
Motorcycle	$VKT = 5587.6960\ x^{1.005}$	0.99	$VKT = 4977.63\ x^{0.898}$	0.99
Motorcycle Taxi	$VKT = 14657.56x^{0.823}$	0.96	$VKT = 6110.998\ x^{0.849}$	0.99
TUK TUK	$VKT = 17471.48x^{1.235}$	0.99	$VKT = 45101.78x^{0.966}$	0.99
PICK UP	$VKT = 76386.16\ x^{0.515}$	0.98	$VKT = 57301.21x^{0.776}$	0.98
TAXI	$VKT = 91484.28x^{1.423}$	0.99	$VKT = 136810.682\ x^{0.892}$	0.95
CAR	$VKT = 53433.9\ x^{0.595}$	0.97	$VKT = 50958.33x^{0.879}$	0.92
BUS	$VKT = 111552.9x-4655.13x^2$	0.95	$VKT = 156788.83\ x^{0.628}$	0.96
TRUCK	$VKT = 80198.59-635.31x^2-5.543x^3$	0.88	$VKT = 132967.169\ x^{0.615}$	0.96
Songteaw	$VKT = 94509.91x^{0.743}$	0.98	$VKT = 156545.64x^{0.643}$	0.99

Where VKT is cumulative vehicle kilometer of travel (km) and x is age of vehicle (year).

5.2 Comparison of VKT in both provinces

5.2.1 Average annual VKT

An average annual VKT of each vehicle type in Nakornratchasima and Bangkok is presented in Table 5.2. Because of the different in economic and demographic characteristics, the travel demands of these two provinces are different. Bangkok, the capital of Thailand, has a very wide urbanized area and huge economic size. This province is sharing almost half of the country's gross domestic product (GDP) and has the highest GDP per capita in the country. Therefore, the average annual VKT of passenger vehicles, i.e. car, puck-up truck and bus, is much higher than in Nakornratchasima. In Bangkok area, the average annual VKT of these vehicles are estimated to be almost twice comparing to that of Nakornratchasima; average annual VKT of cars, pick-up trucks buses and Songteaw in Bangkok are 31,368 32,475 48,627 and 54,702 km, respectively, whereas there are 15,640 18,140 28,579 and 40,591 km in Nakornratchasima, respectively.

In contrast, because of lower income, the motorcycles are more popular to use as private vehicle in Nakornratchasima than a car as in Bangkok. As a result, they travel longer compare to Bangkok in each year. In Nakornratchasima, the private motorcycles and taxi motorcycles are travel 5,662 and 8,844 km a year, while in Bangkok are 4,015 and 4,219 km, respectively.

The taxi in Nakornratchasima has longer travel distance than Bangkok. This is because the different of using characteristics. Beside to hire from one place to another in urban area as usual, taxis in Nakornratchasima are hired for a long-distance travel to tourism attractions, such as Khao Yai National Park which about 100 km away from the downtown. In addition, the registered taxis in Nakornratchasima are just only 29 vehicles currently, compare to Bangkok area of around 100,000 vehicles. Probability to employ each taxi in Nakornratchasima is much higher than in Bangkok. The annual travel distance of taxis in Nakornratchasima is 132,476 km, whilst in Bangkok is 109,351 km. However, for another hired vehicle, i.e Tuk Tuk, the travel demand of this vehicle is not different in both provinces; 40,382 km in Nakornratchasima and 40,351 km in Bangkok

The trucks in Nakornratchasima are travel slightly longer than in Bangkok. The average annual VKT of first province is 59,115 km while another is 40,989 km. However, this information might be underestimated because the data collection had been conducted in day time, but most of trucks are travel in night time.

Table 5.3 Average annual VKT of vehicles

Vehicle Type	Average annual VKT (km)	
	Nakhonratchasima	Bangkok
Motorcycle	5,662	4,015
Motorcycle Taxi	8,844	4,219
TUK TUK	40,382	40,351
PICK UP	18,140	32,475
TAXI	132,476	109,351
CAR	15,640	31,368
BUS	28,579	48,627
TRUCK	59,115	40,989
Songteaw	40,591	54,702

5.2.2 The total VKT

The total VKT and VKT per capita each vehicle type in both provinces were estimated to analyze the total travel demand of road transport vehicles, as shown in Table 5.4 and 5.5. Shares of total VKT by vehicle type are also illustrated in Fig. 5.1 and 5.2.

The total VKT of road transport vehicles in Nakornratchasima is about 8,197 million vehicle-kilometers. As illustrated in Fig. 5.1, more than 90% of total travel demands in Nakornratchasima are travel by private vehicles. The most popular private vehicle, motorcycles, shares the highest number of total travel demand of 37.1% or 3,043 million vehicle-kilometers. The pick-up trucks and private cars share about 35.2% (2,889 million vehicle-kilometers) and 18.6% (1,528 million vehicle-kilometers) of total travel demand, respectively. The public transport vehicles, buses, taxi, songteaw and motorcycle taxi, share about 5.8% of total travel demand (476.8 million vehicle-kilometers) in this province. The freight transport vehicle, trucks, is traveling about 260 million vehicle-kilometers or 3.8% of total travel demand.

The total VKT of Bangkok is about 138,101 million vehicle-kilometers, accounting for 16.8 times of total travel demand in Nakornratchasima. The private transport is also the major transport mode in Bangkok. As presented in Figure 5.2, about 55.7% 21.2% and 6.1% of total VKT are shared by private cars, pick-up trucks and motorcycles. The vehicles of public transport mode, i.e. bus, taxi, songteaw and motorcycle taxi, share only 15.3% of total VKT (21,075 million vehicle-kilometers) in this province.

Table 5.4 Total VKT by vehicle type in Nakornratchasima

Vehicle Age	CAR			PICK UP			Motorcycle		
	Annual VKT (km)	Number of car (Vehicles)	Total VKT (10^6 veh-km)	Annual VKT (km)	Number of car (Vehicles)	Total VKT (10^6 veh-km)	Annual VKT (km)	Number of car (Vehicles)	Total VKT (10^6 veh-km)
1	53,434	6,254	334	76,386	7,116	544	5,588	51,075	285
2	27,301	6,297	172	32,735	9,403	308	5,630	48,090	271
3	22,046	6,132	135	25,315	9,418	238	5,646	58,222	329
4	19,204	6,265	120	21,449	9,656	207	5,657	63,253	358
5	17,334	6,587	114	18,967	10,204	194	5,664	60,254	341
6	15,976	5,656	90	17,198	9,449	163	5,671	50,298	285
7	14,929	4,082	61	15,854	6,982	111	5,676	36,440	207
8	14,087	3,422	48	14,787	4,846	72	5,680	22,297	127
9	13,390	2,400	32	13,914	4,734	66	5,684	17,835	101
10	12,800	1,891	24	13,181	4,494	59	5,687	11,329	64
11-15	11,496	16,715	192	11,590	44,656	518	5,696	79,139	451
16-20	10,786	11,137	120	10,733	26,422	284	5,701	29,034	166
> 20	10,786	7,804	84	10,733	11,884	128	5,701	10,234	58
Total VKT	18,053	84,642	1,528		159,264	2,889		537,500	3,043

Table 5.4 (cont.) Total VKT by vehicle type in Nakornratchasima

Vehicle Age	TAXI			TUK TUK			Motorcycle Taxi		
	Annual VKT (km)	Number of car (Vehicles)	Total VKT (10^6 veh-km)	Number of car (Vehicles)	Total VKT (10^6 km)	Total VKT (10^6 veh-km)	Annual VKT (km)	Number of car (Vehicles)	Total VKT (10^6 veh-km)
1	91,484	13	1	17,471	0	0	14,658	23	0
2	153,792	25	4	23,645	1	0	11,265	30	0
3	191,441	0	0	26,716	0	0	10,262	102	1
4	220,888	0	0	28,928	0	0	9,661	289	3
5	245,732	0	0	30,693	0	0	9,237	316	3
6	267,537	0	0	32,177	0	0	8,913	282	3
7	287,144	0	0	33,466	0	0	8,652	249	2
8	305,073	0	0	34,611	0	0	8,434	171	1
9	321,665	0	0	35,644	0	0	8,249	97	1
10	337,163	0	0	36,588	0	0	8,087	48	0
11-15	378,067	0	0	38,978	2	0	7,713	301	2
16-20	403,195	0	0	40,407	14	1	7,502	81	1
> 20	403,195	0	0	40,407	784	32	7,502	52	0
Total VKT		38	5		801	32		2,041	18

Table 5.4 (cont.) Total VKT by vehicle type in Nakornratchasima

Vehicle Age	Songteaw			BUS			TRUCK		
	Annual VKT (km)	Number of car (Vehicles)	Total VKT (10^6 veh-km)	Annual VKT (km)	Number of car (Vehicles)	Total VKT (10^6 veh-km)	Annual VKT (km)	Number of car (Vehicles)	Total VKT (10^6 veh-km)
1	94,510	178	17	106,898	78	8	79,558	255	20
2	63,667	224	14	97,588	94	9	78,254	243	19
3	55,609	180	10	88,277	138	12	76,917	363	28
4	50,947	243	12	78,967	194	15	75,546	197	15
5	47,740	175	8	69,657	211	15	74,143	353	26
6	45,330	202	9	60,346	204	12	72,706	535	39
7	43,420	180	8	51,036	173	9	71,236	218	16
8	41,848	200	8	41,726	241	10	69,733	139	10
9	40,522	150	6	32,416	120	4	68,196	159	11
10	39,378	111	4	23,105	88	2	66,626	62	4
11-15	36,771	1,703	63	6,347	864	5	61,684	538	33
16-20	36,694	2,303	85	4,485	542	2	58,279	344	20
> 20	36,694	1,882	69	4,485	633	3	58,279	325	19
Total VKT		7,731	314		3,580	108		3,731	260

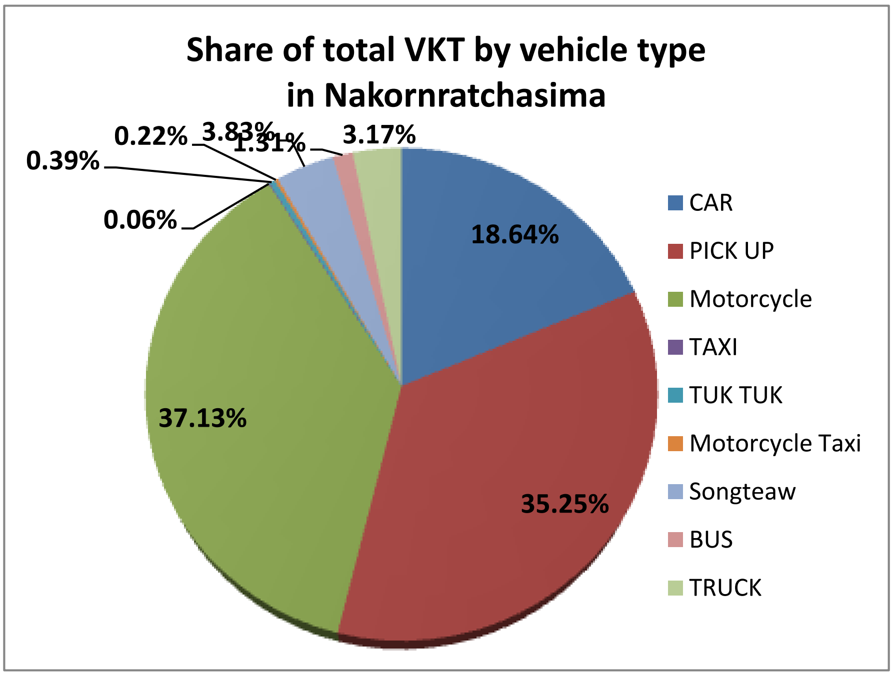


Figure 5.1 Share of Total VKT in Nakornratchasima by vehicle type

Table 5.5 Total VKT by vehicle type in Bangkok

Vehicle Age	CAR			PICK UP			Motorcycle		
	Annual VKT (km)	Number of car (Vehicles)	Total VKT (10^6 veh-km)	Annual VKT (km)	Number of car (Vehicles)	Total VKT (10^6 veh-km)	Annual VKT (km)	Number of car (Vehicles)	Total VKT (10^6 veh-km)
1	50,958	175,571	8,947	57,301	67,186	3,850	4,978	294,666	1,467
2	42,759	178,337	7,626	40,820	91,052	3,717	4,298	291,528	1,253
3	40,128	164,136	6,586	36,282	87,956	3,191	4,074	305,526	1,245
4	38,510	176,500	6,797	33,617	97,218	3,268	3,935	256,909	1,011
5	37,350	163,705	6,114	31,765	77,871	2,474	3,835	211,654	812
6	36,450	148,591	5,416	30,363	64,356	1,954	3,757	147,648	555
7	35,719	119,496	4,268	29,245	50,134	1,466	3,693	123,519	456
8	35,105	88,027	3,090	28,320	32,258	914	3,640	69,089	251
9	34,576	66,145	2,287	27,536	30,979	853	3,594	49,080	176
10	34,114	53,906	1,839	26,858	29,218	785	3,553	35,380	126
11-15	33,028	357,595	11,811	25,300	161,453	4,085	3,457	159,520	551
16-20	32,411	240,681	7,801	24,429	78,677	1,922	3,403	97,139	331
> 20	32,411	132,542	4,296	24,429	34,515	843	3,403	61,352	209
Total VKT		2,065,232	76,878		902,873	29,321		2,103,010	8,442

Table 5.5 (cont.) Total VKT by vehicle type in Bangkok

Vehicle Age	TAXI			TUK TUK			Motorcycle Taxi		
	Annual VKT (km)	Number of car (Vehicles)	Total VKT (10^6 veh-km)	Annual VKT (km)	Number of car (Vehicles)	Total VKT (10^6 veh-km)	Annual VKT (km)	Number of car (Vehicles)	Total VKT (10^6 veh-km)
1	136,811	12,366	45,102	61	3	1,692	45,102	61	3
2	117,075	8,028	43,001	831	36	940	43,001	831	36
3	110,626	10,866	42,242	910	38	1,202	42,242	910	38
4	106,636	13,573	41,757	38	2	1,447	41,757	38	2
5	103,764	8,207	41,399	52	2	852	41,399	52	2
6	101,531	7,529	41,117	14	1	764	41,117	14	1
7	99,711	8,109	40,883	6	0	809	40,883	6	0
8	98,179	5,532	40,685	36	1	543	40,685	36	1
9	96,858	4,693	40,512	7	0	455	40,512	7	0
10	95,701	2,032	40,359	5	0	194	40,359	5	0
11-15	92,976	1,800	39,993	48	2	167	39,993	48	2
16-20	91,426	650	39,782	357	14	59	39,782	357	14
> 20	91,426	357	39,782	7,256	289	33	39,782	7,256	289
Total VKT		83,742		9,621	388	9,157		9,621	388

Table 5.5 (cont.) Total VKT by vehicle type in Bangkok

Vehicle Age	Songteaw			BUS			TRUCK		
	Annual VKT (km)	Number of car (Vehicles)	Total VKT (10^6 veh-km)	Annual VKT (km)	Number of car (Vehicles)	Total VKT (10^6 veh-km)	Annual VKT (km)	Number of car (Vehicles)	Total VKT (10^6 veh-km)
1	6,111	3,133	19	156,546	10,003	1,566	156,789	2,247	352
2	4,896	3,537	17	87,912	13,248	1,165	85,516	1,244	106
3	4,523	6,401	29	72,813	10,135	738	70,265	1,112	78
4	4,297	11,922	51	64,467	9,499	612	61,893	736	46
5	4,136	11,823	49	58,897	6,848	403	56,330	652	37
6	4,012	9,224	37	54,807	7,146	392	52,260	946	49
7	3,912	8,645	34	51,624	6,659	344	49,101	1,274	63
8	3,828	4,486	17	49,047	5,888	289	46,550	1,386	65
9	3,756	2,570	10	46,900	4,623	217	44,428	690	31
10	3,693	1,160	4	45,071	3,434	155	42,625	531	23
11-15	3,547	2,161	8	40,990	29,814	1,222	38,612	2,051	79
16-20	3,465	698	2	38,751	39,475	1,530	36,416	3,043	111
> 20	3,465	122	0	38,751	37,805	1,465	36,416	3,174	116
Total VKT		65,882	278		184,577	10,097		19,086	1,154

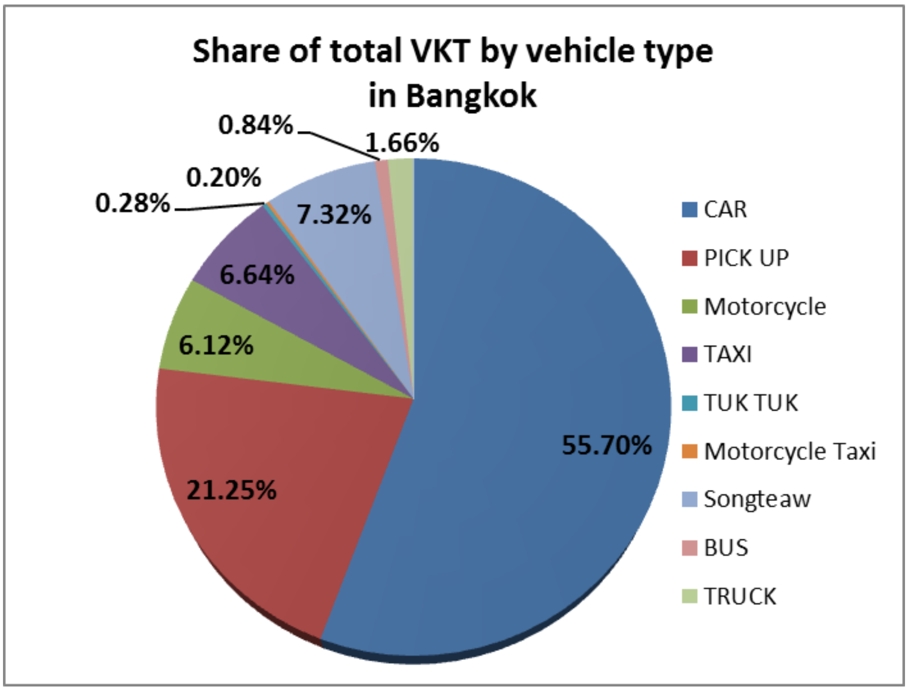


Figure 5.2 Share of Total VKT in Bangkok by vehicle type

5.2.3 VKT per capita

As presented in Table 5.6, per capita VKT of total population and working age population (15-59 years old) were estimated to compare travel demand of both provinces fairly. In addition, both per capita VKT were further divided into two groups of vehicles – business vehicles and passenger vehicles.

In Nakornratchasima, the total VKT per total population and per working age population are 3,091 and 4,616 vehicle-kilometers per person, respectively. The per capita of passenger vehicles, which included i.e. cars, motorcycles, tuk tuk, songteaw and buses, is more than that of business vehicles, i.e. pick-up trucks and trucks. The passenger vehicles VKT per total population and working age are 1,882 and 2,810 vehicle-kilometers per person, respectively, whereas the business vehicles VKT per total population and working age are 1,209 and 1,806 vehicle-kilometers per person, respectively.

Because of higher transport activities, the per capita VKT of Bangkok is much higher than Nokornratchasima. The total VKT per total population and working age population are 21,987 and 32,534 vehicle-kilometers per person, respectively, accounting for about 7 times compare to Nakornratchasima. However, the per capita of each vehicle groups is similar. The passenger vehicles have higher per capita VKT than the business vehicles. The passenger vehicles VKT per total population and working age are 16,496 and 24,409 vehicle-kilometers per person, respectively, whereas the business vehicles VKT per total population and working age are 5,491 and 8,125 vehicle-kilometers per person, respectively.

Table 5.5 VKT per capita of Nakornratchasima and Bangkok

Province	Total VKT per capita (veh-km/person)		Business vehicle VKT per capita (veh-km/person)		Passenger vehicle VKT per capita (veh-km/person)	
	Total population	Working age	Total population	Working age	Total population	Working age
Nakornratchasima	3,091	4,616	1,209	1,806	1,882	2,810
Bangkok	21,987	32,534	5,491	8,125	16,496	24,409

5.3 International comparison of VKT per capita

Two important indicators of urban land use and economic characteristics – population density and GDP per capita - are employed for travel demand comparison in each city. Population density is one of the key indicators of urban land use as it affects transport. Generally, high densities tend to be associated with lower average trip distances for all modes [Kenworthy, J. R. and Laube, F.B (1996)], as presented in Fig. 5.3. On the other hand, income has positive impact to travel demand in urban area; high GDP per capita tend to make people travel more, as illustrated in Fig. 5.4.

Income has more effect than population density for non-urbanized area like Nakornratchasima. Because of a low per capita GDP, Nakornratchasima has low VKT per capita comparing to other cities, even it has low population density similar as New Mexico. However, the results are quite different for Bangkok city – a highly urbanized area. Its travel demand is much higher than the city which has similar GDP per capita; Bangkok has VKT per capita more than two times compare to Willington. Moreover, its travel demand is also much higher than other cities even it has very high population density; Bangkok has similar VKT per capita to Sydney, but its population density is about 3.75 times higher.

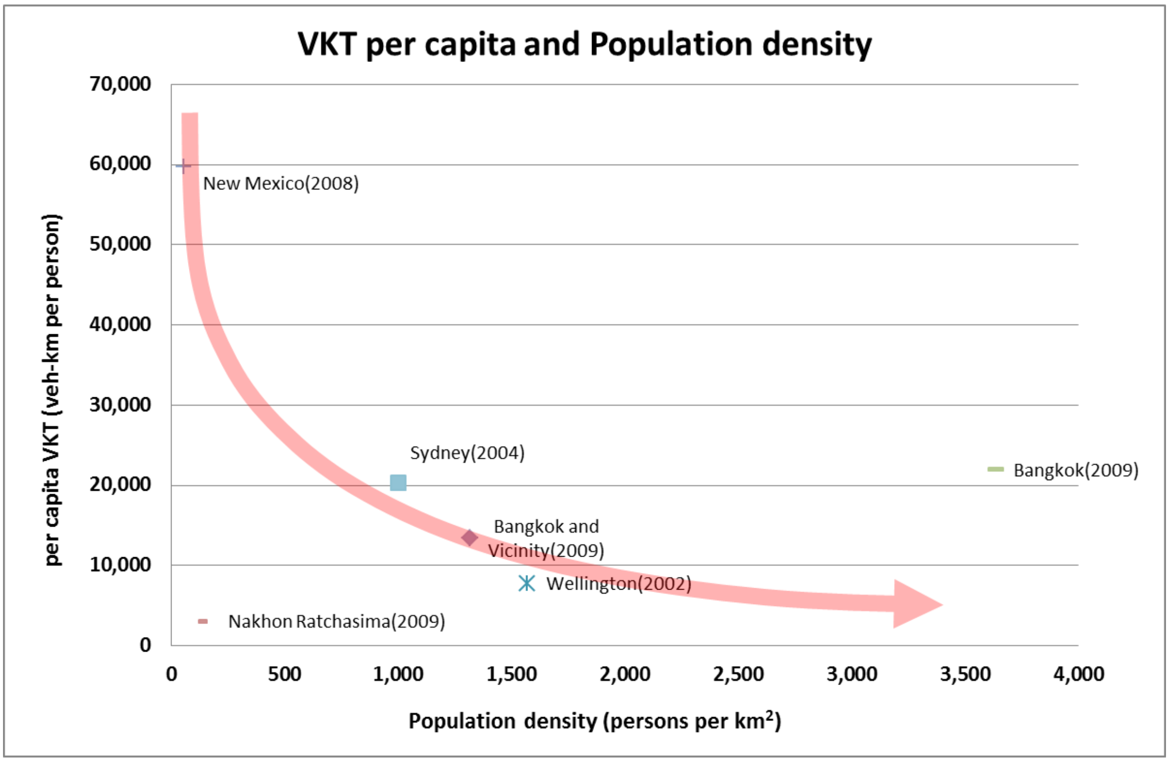


Figure 5.3 VKT per capita and population density of selected cities

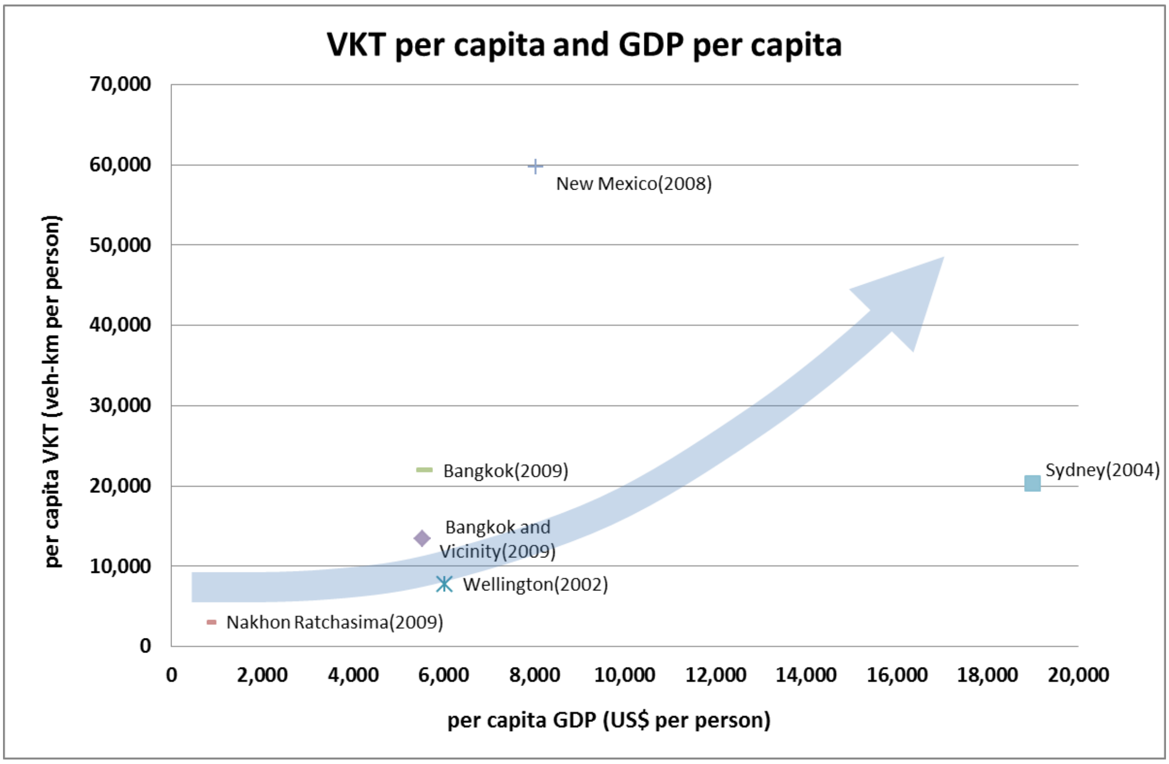


Figure 5.4 VKT per capita and GDP per capita of selected cities

5.4 Policy recommendation

In developing countries like Thailand, the road transport mode currently shares almost of total travel demand in the transport sector. If this situation is still growing as a result of economic development, the total demand of road transport will seriously drive up total fuel demand and greenhouse gas emissions of the road transport sector in the near future. Not only the large consumption of fuel demand and huge emission of GHG, but more infrastructures to support those travel demand also be needed.

From sustainable transport planning point of view, the appropriate policies and measures on urban land use and transport planning should be urgently implemented to slow down the travel demand of the road vehicles. The land use planning should concern more in transit-oriented, high density and mixed land uses which help to halt the growth in auto-based travel demand. The transport planning should direct to reduce travel demand of private transport mode and induce the demand of public or non-motorized transport modes. Measures to limit car use and less emphasis on infrastructure for cars as well as improvement on the quality of transit systems, especially rail, and promotion of safety and amenity walking and cycling infrastructures, should be concerned.

Additionally, since the motorcycles are popular to use as private vehicles in rural area and to use for short and medium distances traveling in urban area. To reduce fuel demand and to mitigate emissions from these vehicles, the government and policy makers should focus on how to improve their fuel economy and efficiency. Hence, the policies to promote new environmental friendly vehicle technologies, such as electric motorcycle, to replace the traditional internal combustion technology should be implemented.

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APPENDIX

Interim Report

Research Grant 2010

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