Singapore Road Vehicle Fleet Evolution

Wei Wei and Lynette Cheah

Abstract. Vehicle fleet modeling is a useful tool to analyze the dynamics of motor vehicles and their environmental impact at a macroscopic level, and has been applied in the USA and Europe. In this article, a road fleet model is constructed for the city-state Singapore. Policies that control vehicle ownership and congestion road pricing employed since 1998 differentiate Singapore's vehicle market from other markets, making it a particularly interesting case to investigate. The fleet model is constructed using spreadsheets that track vehicle age, vehicle population, vehicle kilometers travelled, fleet fuel use and greenhouse gas (GHG) emissions. The authors hope that the model can be used as a tool to help stakeholders assess the social and environmental impact of relevant policies like capping vehicle growth, scrappage policy, reducing vehicle mileage and adopting green vehicles.

1 Introduction

In Singapore, transport sector is projected to account for 14.5% of greenhouse gas emissions in year 2020 under a business-as-usual scenario (National Climate Change Secretariat 2012). In terms of energy, road vehicles are responsible for most of domestic transport energy demanded (Asia Pacific Energy Research Centre 2013). Vehicle fleet analysis has been used to investigate road vehicle fleet fuel use and GHG emissions under various policy scenarios in the US (Bandivadekar et al. 2008), Europe (Bodek and Heywood 2008; Brand 2010) as well as on a global scale (Facanha et al. 2012), yet it has not been applied to fleets in city-states like Singapore. To understand the current and future environmental impact of Singapore road transportation system, a dynamic road fleet model is constructed to study the timescale of impact of policy changes projected till year 2030.

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M.-A. Cardin et al. (eds.), *Complex Systems Design & Management Asia*,
DOI: 10.1007/978-3-319-12544-2_5

2 Model Structure and Data Source

A Vehicle Quota Scheme (VQS) was introduced in Singapore in May 1990 as a policy instrument to control vehicle ownership (Chin and Smith 1997). Road vehicles must be registered and re-registered under one of the five following categories: cars with engine capacity less than or equal to 1600 cc (category A), cars with engine capacity over 1600 cc (category B), buses, goods vehicles and motorcycles. Potential car buyers must bid for a Certificate of Entitlement (COE) in order to drive on the road. This is tax on top of the cost of purchasing the vehicle. The open bidding process happens twice a month, with a quota pre-allocated by government to restrict vehicle population growth. Therefore, new registration of motor vehicles is equivalent to sales. At the end of year 2013, the road vehicle population numbered 974,170 motor vehicles, among which 66.9% are cars (including taxis), 1.8% are buses, 16.5% are goods vehicles and 14.9% are motorcycles.

An overview of the fleet model's structure is provided in Figure 1. The model is composed of spreadsheets in Microsoft Excel that details vehicle registration and de-registration under VQS, population of different types of motor vehicles, vehicle age distribution and survival rate, vehicle kilometers traveled (VKT), fuel consumption and GHG emissions. Each module of the fleet model is discussed in detail in the next section.

The Singapore Land Transport Authority (LTA) publishes data annually on the city-nation's transportation system, and is the primary source of data for the model. Historical data from 1998 to 2013 is used for the model. Due to limitations in the age distribution data, the model does not include taxis and tax-exempted vehicles. The model stabilizes after year 2008.

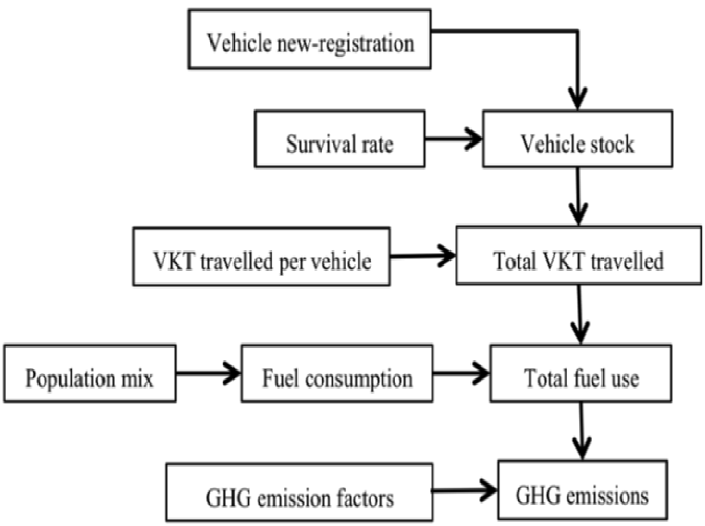


Fig. 1 Overview of Fleet Model Structure

3 Building Blocks of Fleet Model

3.1 New Registration of Motor Vehicles

The annual new registration and de-registration of five categories of road vehicles under VQS is shown in Figure 2. New-registration growth rate of buses and motorcycles have not changed much over the past 16 years, with that of goods vehicles has declined from 2005 to 2010, followed by a slight rebound. New car registration peaked at 116,741 cars in year 2006, and has been declining since due to strict government control. As shown in Figure 2, vehicle quota is imposed based on vehicle de-registration in the preceding months.

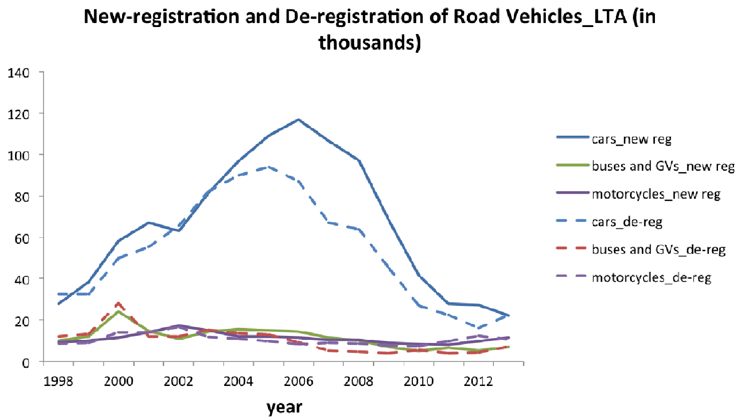


Fig. 2 New Registration and De-registration of Motor Vehicles 1998 -2013 (in thousands)

3.2 Survival Rate and Lifetime Distribution

Age distribution of motor vehicles is made available by LTA from year 1998 to 2013 for four vehicle categories: cars (excluding taxis), buses, goods vehicles and motorcycles. Based on this data, we can infer the lifetime distribution of vehicles registered in each year and estimate the survival rate of motor vehicles. Survival rate of vehicles in a given model year is defined as the fraction of that vehicles remaining on the road. Detailed methodology of finding a lifetime distribution that fits LTA data is discussed below.

3.2.1 Cars

In Singapore, the car survival rate is highly influenced by the scrappage policy. For the years studied in the model, COE is only effective for 10 years. Vehicle owners can choose to either renew their COE for another 5 or 10 years by paying the prevailing quota premium for the corresponding year, or de-register their vehicles and have them scrapped or exported. Considering the soaring COE price in recent years, most owners choose to de-register the vehicle at or before 10 years after registration.

The car survival rate estimated from LTA's data, and preliminarily used in the fleet model is shown in Figure 3.

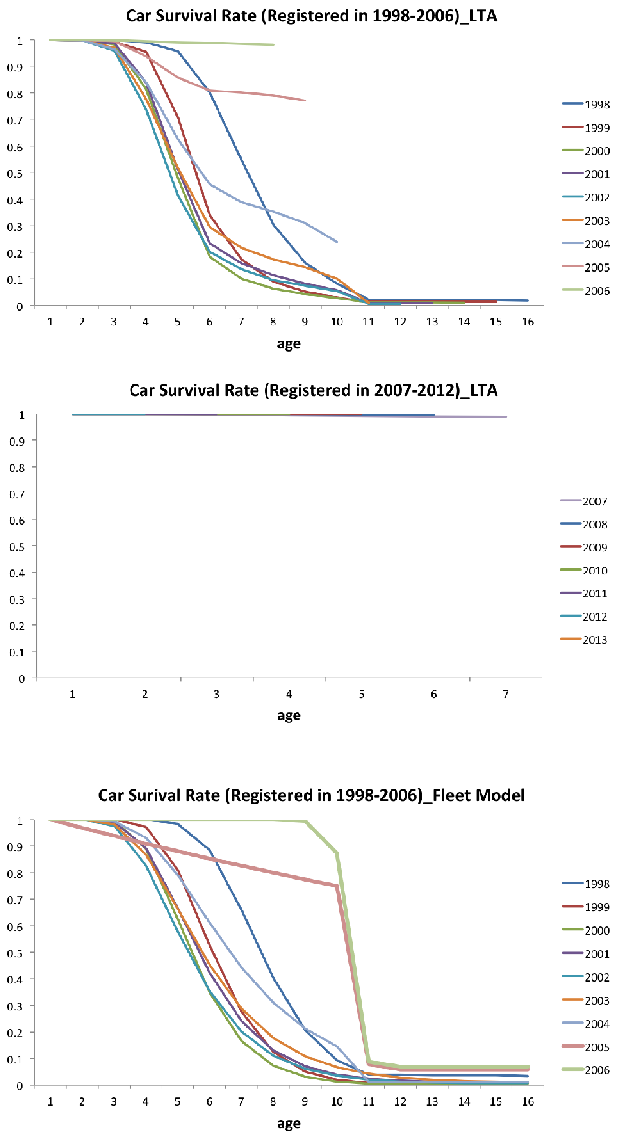


Fig. 3 Car Survival Rate 1998 – 2013 (LTA and Fleet Model)

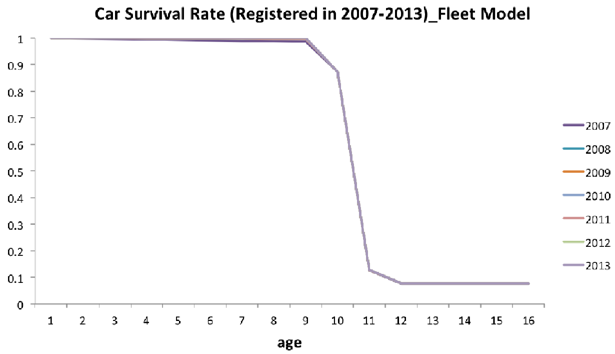


Fig. 3 (*continued*)

In the literature, a logistic model is argued to better describe the removal of vehicles from US fleet, as opposed to an exponential curve as it captures the rapid removal of old cars in the fleet (Field et al. 2000). Bandivadekar et al. likewise use a logistics curve to estimate the scrappage rate of light-duty vehicles in US (2008). Melo discusses three models: normal model, Weibull model and beta model in modeling the disposal of products containing aluminum (1999). It is suggested that the Weibull distribution is the most commonly used model for lifetime distribution, while the beta distribution is more flexible and can model a wide range of distribution shapes. Kolli et al. have fitted beta, gamma, lognormal and Weibull distribution to light car age distribution in France and found Beta and Weibull to be the best fit (2010).

Car survival rate has been quite erratic for the past 16 years. Therefore it is necessary to examine survival rate for each registration year separately in this model. For the Singapore car fleet, logistics curve does not approximate survival rate well as we adjust the parameters. On the other hand, lifetime distribution of cars is found to be suitable for estimating a distribution. Among the four distributions tested: beta, gamma, lognormal and Weibull, lognormal appears to be the best model for year 1998-2004 and year 2006. For cars registered in year 2005 and 2007 onwards, a decay model with constant decay rate is more suitable to estimate car survival rate. The sharp removal of cars at age 11 after year 2005 cannot be modeled by any distribution above. In this case, we assume that the percentage of vehicles removed at age 11 from year 2004 onwards is the same as that of 2003. The removal of cars after age 11 is also assumed to be at a constant rate of 1-100 vehicles per year. In Singapore, cars have a median lifetime of around 5 years only.

Table 1 Car Lifetime Distribution Parameters

1998	1999	2000	2001	2002	2003	2004	2005
Lognormal	Lognormal	Lognormal	Lognormal	Lognormal	Lognormal	Lognormal	Decay
$\mu = 1.8883$ $\sigma = 0.2339$	$\mu = 1.6271$ $\sigma = 0.2758$	$\mu = 1.4857$ $\sigma = 0.3163$	$\mu = 1.5345$ $\sigma = 0.3554$	$\mu = 1.4602$ $\sigma = 0.3877$	$\mu = 1.5556$ $\sigma = 0.4110$	$\mu = 1.7204$ $\sigma = 0.4214$	$\beta = 0.9685$

2006	2007	2008	2009	2010	2011	2012	2013
Lognormal	Decay	Decay	Decay	Decay	Decay	Decay	Decay
$\mu = 2.2874$ $\sigma = 0.0825$	$\beta = 0.9983$	$\beta = 0.9996$	$\beta = 0.9996$	$\beta = 0.9996$	$\beta = 0.9996$	$\beta = 0.9996$	$\beta = 0.9996$

For Singapore, the deviation from previous literature of modeling lifetime distribution as beta, Weibull or survival rate as logistics curve is speculated to be a result of government control of vehicle ownership. A PARF (Preferential Additional Registration Fee) rebate and a COE rebate are the two rebate schemes to encourage early car de-registration. Essentially, COE affects both vehicle sales directly and de-registration indirectly. The decision made by car owners can be considered as a trade-off between the rebate and Quota Premium required to pay to buy a new car. In previous studies, a life cycle cost analysis for vehicles in Singapore has been performed (Wong et al. 2010). In Figure 4 below, we visualize the timescale of this relationship for a Toyota Corolla registered in year 2002 with an Open Market Value (OMV) of $19,384 and a Quota Premium of $ 32,981. The COE rebate decreases linearly with time, while PARF rebate is tiered. Quota premium reached its lowest during 2008's economic crisis and has been soaring in recent years. It is reasonable for car owners to keep their cars while the aggregated value of rebate and quota premium is positive. It should be noted that at each given point in time, car owners do not know the quota premium in the future.

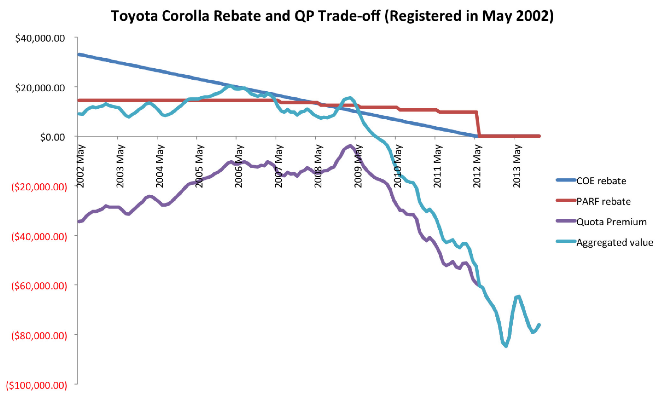


Fig. 4 Illustrative Example of Trade-off between Rebate and QP for Cars

3.2.2 Buses

For buses, there are some uncertainties in different registration years' survival rate. A common pattern is that around 80% of buses remain in the fleet before COE expires at 10 years after registration, with a steeper slope at the 10-year point representing the influence of the scrappage policy. For simplicity, we categorize registration years into two groups based on population decay rate and use two decay models to describe vehicle population change. For time periods 1998 - 2001 and 2004 - 2030, we use the same decay rate as year 1998; for time period 2002 – 2003 we use the same decay rate as year 2002 in LTA data (Figure 5). The result of this assumption appears to be coherent with LTA vehicle population data shown in Figure 5.

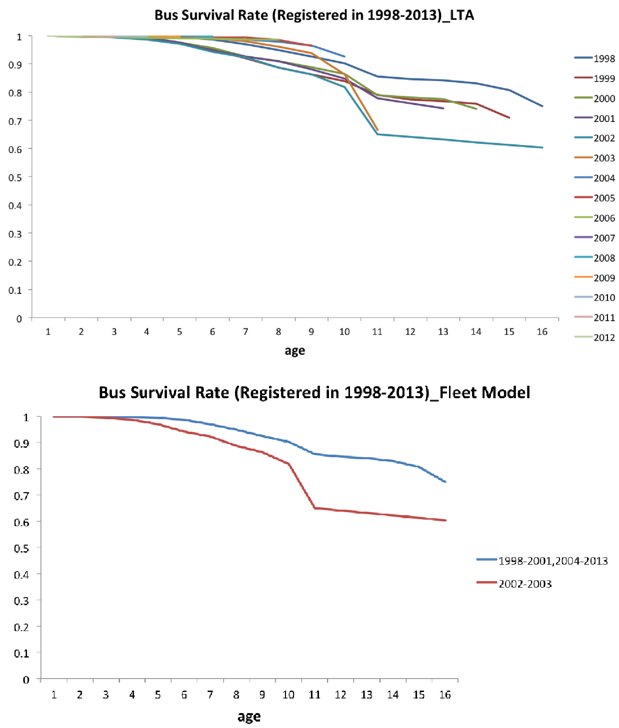


Fig. 5 Bus Survival Rate 1998 – 2013 (LTA and Fleet Model)

3.2.3 Goods Vehicles

There is very high variability in goods vehicles' survival rate, especially for years 1998-2003. To ensure the accuracy of the model, similar with bus population, we separate the registration years into 3 groups based on their similarities in population decay rate: 1998-1999, 2000-2002 and 2003 onwards. The result is shown in Figure 6.

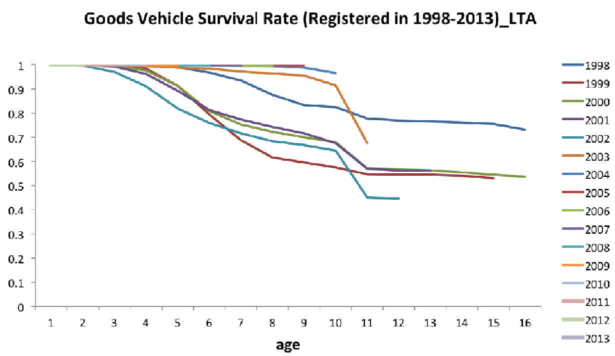


Fig. 6 Goods Vehicles Survival Rate 1998 – 2013 (LTA and Fleet Model)

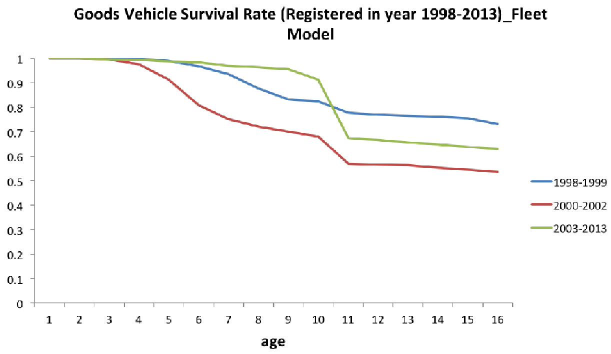
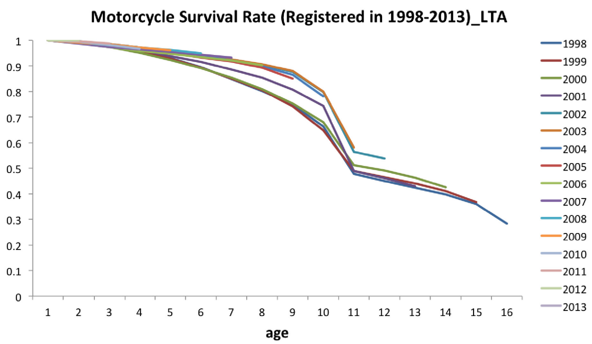


Fig. 6 (*continued*)

3.2.4 Motorcycles

Motorcycles' survival rate behaves reasonably consistent so we use the same population decay rate as year 2002 in LTA data for all registration years in the fleet model. The result is shown in Figure 7.



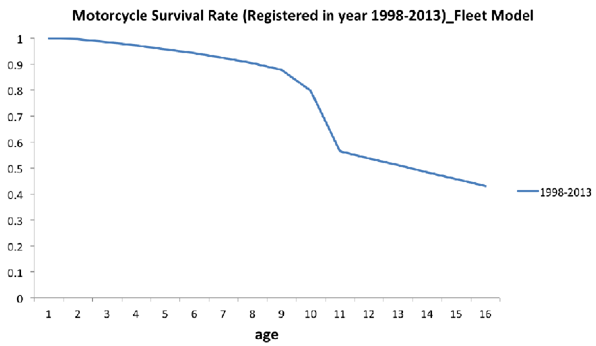


Fig. 7 Motorcycle Survival Rate 1998 – 2013 (LTA and Fleet Model)

3.3 Vehicle Kilometers Travelled (VKT)

The model uses the following equation to calculate total VKT in year j:

$$VKT_j = \sum_i N_{i,j} \times VKT_{i,j} \quad (1)$$

Where $N_{i,j}$ denotes the number of vehicles registered in year i remained in calendar year j's stock, $VKT_{i,j}$ denotes the average per-vehicle kilometers travelled in calendar year j for vehicles registered in year i.

As average per-vehicle kilometers travelled data from LTA is only available from year 2003 to 2012, the model assumes the same values for year 1998-2002 as 2003 data and for year 2013 as 2012 data. Since the data does not distinguish vehicles registered in different years, we assume each registration year's vehicle model behaves in the same way, though this may not be the case and more data collection is needed to account for the difference. Figure 8 shows total VKT for four vehicle categories calculated using the equation above.

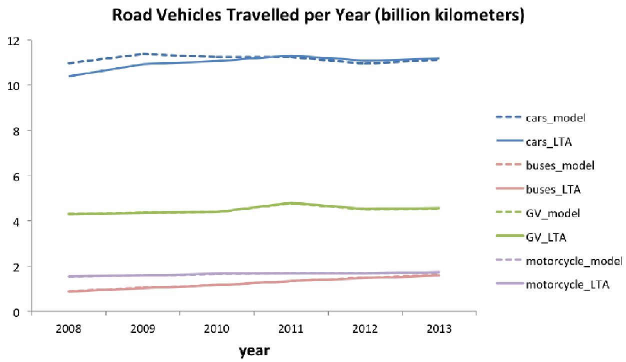


Fig. 8 Motor Vehicles Travelled per Year in Billion Kilometers (LTA and Fleet Model)

3.4 Vehicle Fuel Use

A Fuel Economy Labeling Scheme (FELS) was first launched as a voluntary program in Singapore in 2003, it then become mandatory for all car retailers to display fuel economy labels in their showrooms since 2009. The fuel economy data provided by LTA only includes year 2003, 2004, 2007 and 2008 for Category A cars (≤1600cc), Category B cars (>1600cc), light goods vehicles (LGV), heavy goods vehicles (HGV) and very heavy goods vehicles (VHGV) (excluding year 2003) (See Table 2).

Table 2 Fuel Consumption Data (Land Transport Authority 2005; Land Transport Authority 2008; Mercedes-Benz 2014)

Fuel Consumption (liters/100km)					
From LTA Statistics Brief					From Mercedes-Benz Website
	2003	2004	2007	2008	2012
Category A Car	8.3	10.0	9.6	9.4	-
Category B Car	12.5	12.9	12.0	11.5	-
LGV	10.0	10.0	10.1	10.0	-
HGV	12.5	11.9	14.7	14.9	-
VHGV	-	47	50.5	50.2	-
Buses	-				42.31

To speculate fuel consumption data for the missing years, we investigate the top 8 car makes sold in Singapore, which constitutes 80% of total car population on average. From Figure 9, the car mix has not experienced a big change over the past 11 years. Fuel economy data from US-based fueleconomy.gov also suggests that different model yeas have quite consistent fuel economy performance for popular car models like Toyota Corolla, Toyota Camry for model year 2003-2008, Nissan Sentra for model year 2003-2006, and Mercedes SLK, CLK series for model year 2003-2011 (US Department of Energy et al. 2014). The fleet model takes these factors into account and presents an estimation of the fuel consumption performance for cars.

For goods vehicles, Toyota, Nissan, Mitsubishi and Isuzu account for on average 73.5% of total population for year 2003 – 2013. Mercedes Benz and Toyota are the top two car makes for bus category. Due to the lack of fuel consumption data for these makes, we estimate the figure for goods vehicles from LTA's data in Table 2 and for buses from Mercedes Benz bus models. As for motorcycles, Honda and Yamaha are the two dominant makes in Singapore, occupying 72.7% of total population for the past 11 years. The fuel consumption for motorcycle is estimated by taking the average of Honda and Yamaha models from totalmotorcycle.com (2014).

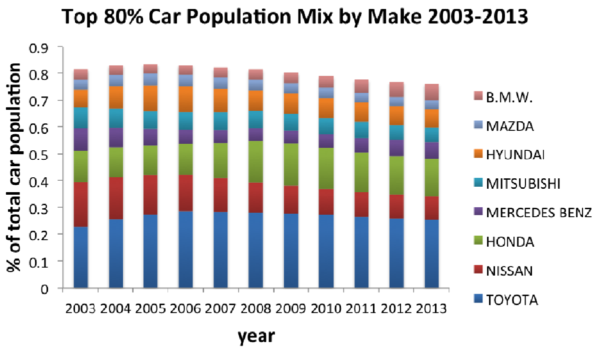


Fig. 9 Car Population by Make (Land Transport Authority 2013b)

Figure 10 shows the resultant vehicle fuel use from year 2008 to 2013 calculated using the following equation:

$$F_j = \sum_i N_{i,j} \times VKT_{i,j} \times f_{i,j} \quad (2)$$

Where $N_{i,j}$ and $VKT_{i,j}$ have the same meaning as that equation (1) and $f_{i,j}$ denotes the fuel consumption in calendar year j for vehicles registered in year i.

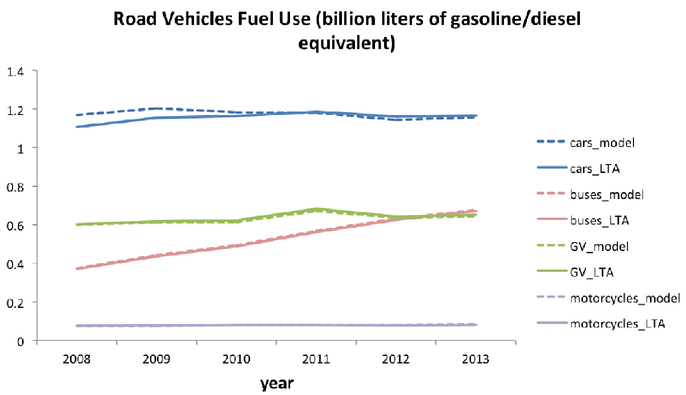


Fig. 10 Motor Vehicles Fuel Consumption in Billion Liters (LTA and Fleet Model)

The model assumes that cars with engine capacity less than or equal to 1600 cc (Category A) has the same average per-vehicle VKT as cars with engine capacity larger than 1600 cc (Category B), so total VKT for cars is split into the two car categories using the population ratio.

3.5 Greenhouse Gas (GHG) Emissions

Greenhouse gas emission is calculated by multiplying fuel use result obtained in 3.4 by GHG emission factors provided by Carbon Trust (2013). 99% of cars and motorcycles use gasoline from 2003 to 2013, while around 93% of buses and goods vehicles use diesel. The model thus treats all cars and motorcycles as gasoline-powered, and all buses and goods vehicles as diesel-powered. Detailed data is shown in Table 3.

Table 3 GHG Emissions Factors (Carbon Trust 2013)

GHG Emission Factors (kgCO_2/liter)				
	Cars	Buses	Goods Vehicles	Motorcycles
Gasoline	2.2144	-	-	2.2144
Diesel	-	2.6008	2.6008	-

4 Model Findings

The projection of the fleet model till year 2030 is then evaluated under three scenarios: a baseline scenario with 0.5% vehicle new registration growth rate, scenario I with 5% vehicle new registration growth rate and scenario II with 10% vehicle new registration growth rate. The projected vehicle stock of cars, buses, goods vehicles and motorcycles is included in Figure 11.

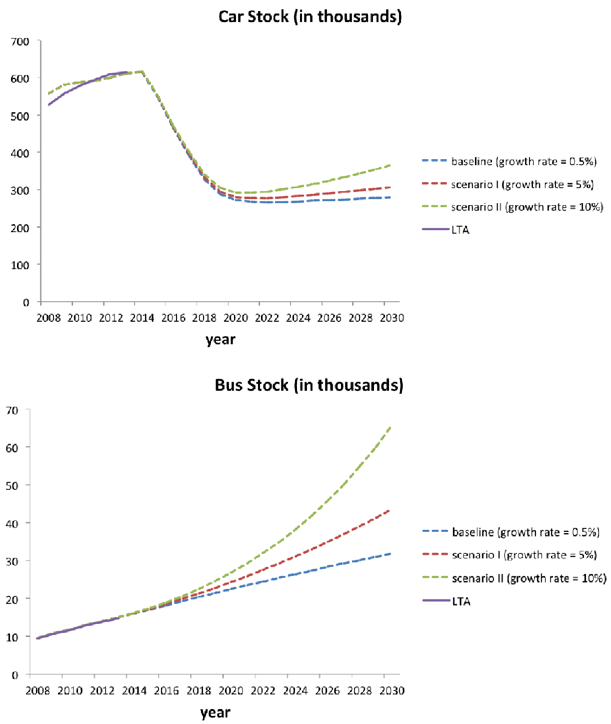


Fig. 11 Model Projected Vehicle Stock in Thousands till Year 2030

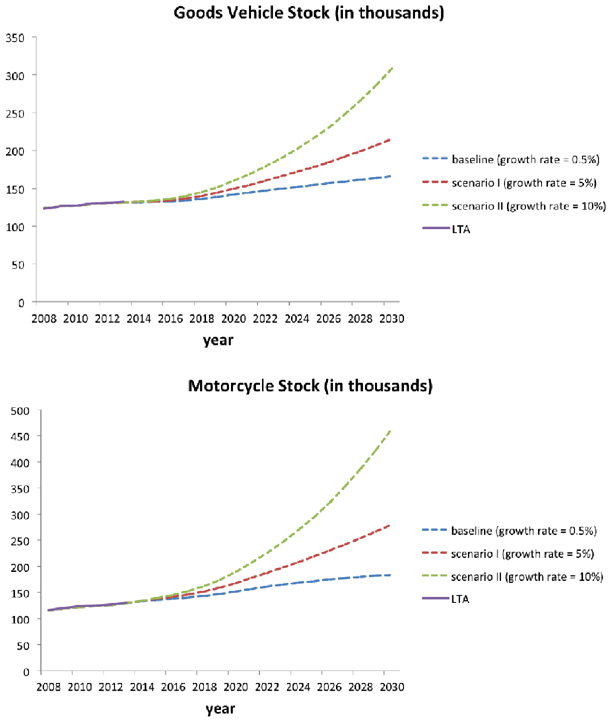


Fig. 11 (*continued*)

It is observed that car population will decrease from year 2014 to 2020 even at an annual 10% vehicle new registration growth rate. This is attributed to the high new registration of cars in 2004-2008. The removal of a large percentage of vehicles when a bulk of existing COE expires after 10 years causes this drop in car stock. The new registration and de-registration of motor vehicles from the model are shown in Figure 12. For buses, goods vehicles and motorcycles, there is no such phenomena and the increase in new-registration growth rate leads to increase in vehicle stock. VKT and fuel consumption roughly follow the same distribution as vehicle stock, as there is no big change in VKT per vehicle or fuel economy in the model. The result for cars is shown in Figure 13.

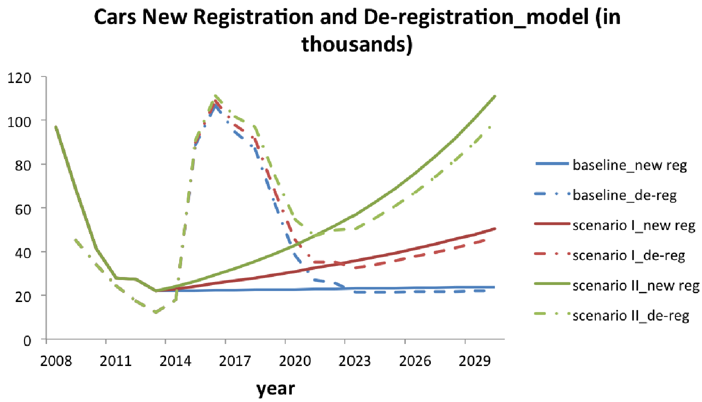


Fig. 12 Cars New registration and De-registration from Fleet Model (in thousands)

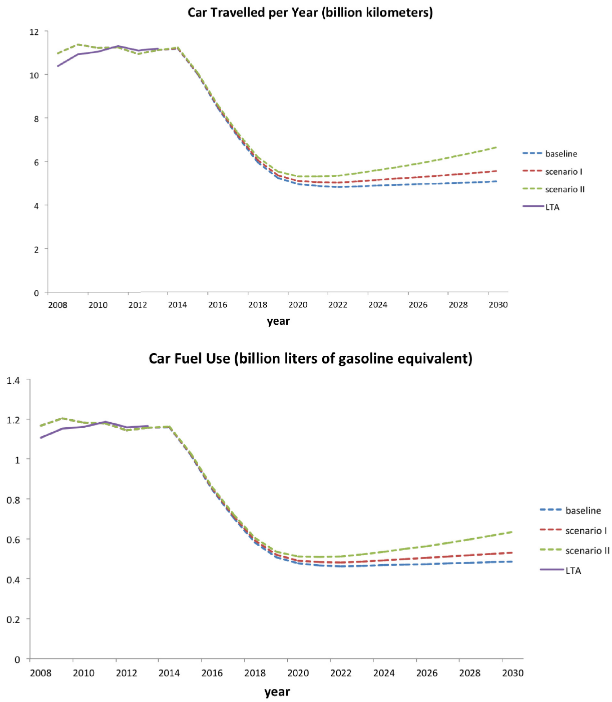


Fig. 13 Car Projected VKT and Fuel Use till year 2030

The relative vehicle stock, VKT, fuel consumption and GHG emissions of cars, buses, goods vehicles and motorcycles under the baseline scenario is shown in Figure 14. It can be observed that the decrease in car stock after year 2014 makes the VKT of cars and goods vehicles roughly the same after year 2020. Total fuel consumption of road fleet is mainly attributed to cars for time period 1998-2014, then to buses for year 2014 onwards.

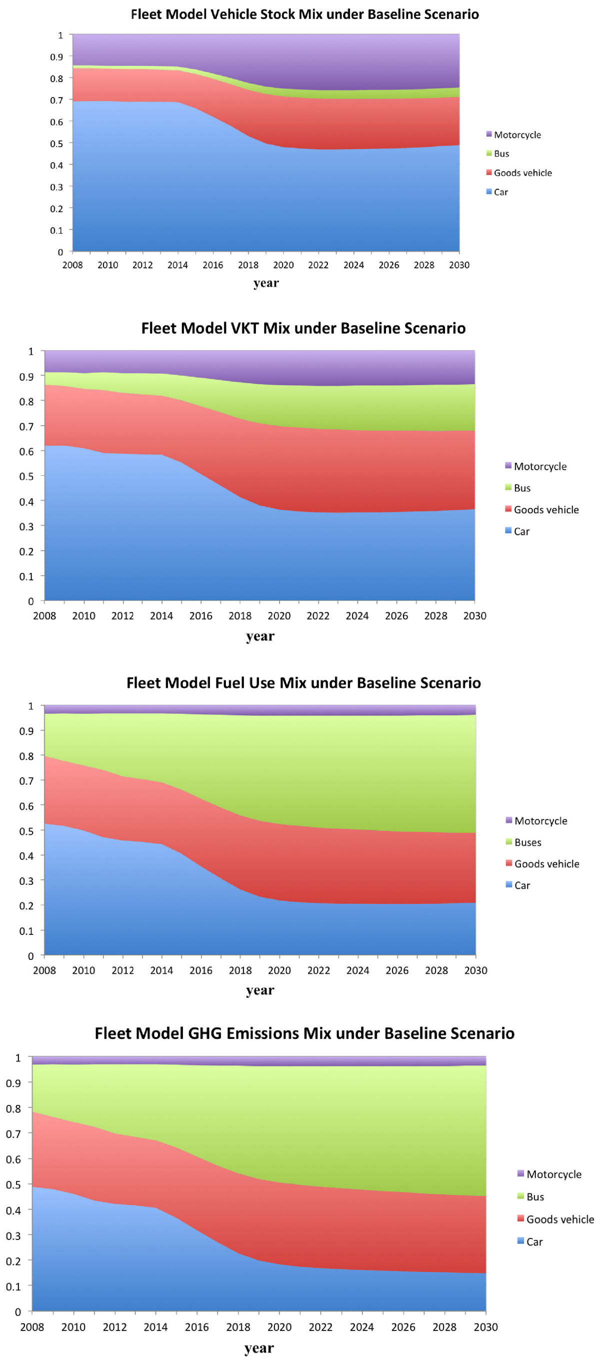


Fig. 14 Fleet Model Vehicle Stock, VKT, Fuel Use and GHG Emissions Mix under Baseline Scenario

5 Future Work

Using the fleet model, a sensitivity analysis will be performed to evaluate the impact of different input parameters including scrappage policy, adoption of green vehicles, VKT change on vehicle population and fuel consumption. The energy outlook and emission target for year 2020 can also be compared with the model result under different scenarios.

6 Conclusions

The paper presents the construction of a road fleet model for Singapore and how it can be used to analyze vehicle stock, vehicle kilometers travelled, fuel consumption and GHG emissions of Singapore road vehicles. A lognormal and decay model is found to best describe the lifetime distribution for cars, while for buses, goods vehicles and motorcycles, decay model is a good approximation. Singapore road fleet is highly influenced by government policies, thus differentiating its behavior from other countries. Based on the model's projection till year 2030, car stock is predicted to decrease from year 2014 to 2020 even when vehicle new-registration annual growth rate is kept at 10% from 2014. This also leads to the dominating role of buses in road transport fuel use after year 2014. The authors hope that this road fleet model can be used as a tool to assess policy impact on road transport system in Singapore.

Acknowledgements. The authors would like to thank Land Transport Authority (LTA) for its kind assistance in providing data for this study.

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