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Effects of Vehicle Age on Fuel Economy for Urban Driving Cycles

(Kesan Umur Kenderaan Penumpang terhadap Ekonomi Bahan Api untuk Kitaran Pemanduan Bandar)

Fauziana Lamin[a*], Afiqah Omar[b], Noor Kamaliah Alias[b], Azhar Hamzah[c], Syaiful Bahri Ismail[d], Md Razif Md Berhannudin[d], Mohd Redza Bin Abdul Razak[d] & Miminorazeahsuhaila Loman[e]

[a] Passenger Vehicle and Occupant Safety Unit,

[b] Centre Vulnerable Road User and Mobility Unit,

Vehicle Safety and Biomechanics Research Centre

c Director-General Office,

Malaysian Institute of Road Safety Research, Lot 125-135, Jalan TKS 1, Taman Kajang Sentral, 43000 Kajang, Selangor,

[d] Department of Mechanical and Electrical Engineering, Kuala Lumpur City Hall, Tingkat 11, Menara DBKL 3, Jalan Raja Abdullah, 50300 Kuala Lumpur,

[e] Faculty of Mechanical Engineering & Automotive Technology, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia

**Corresponding author: fauziana@miros.gov.my*

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ABSTRACT

Optimal service life is among the most crucial determinant factors in vehicle life-cycle planning and management. A multi-dimensional operational cost covering asset acquisition, operating, and maintenance until disposal requires a strategic analysis to ensure economic vehicle ownership. The economic service life issue is more prominent for transportation management with a high number of vehicle ownership capacity. Accordingly, two-year fuel consumption data of a local authority passenger vehicle fleet that is mainly used for urban driving cycles was retrieved. Taking advantage of the actual fuel consumption data, this study explores the effect of vehicle age on fuel economy. Based on the fuel consumption and odometer reading, the average fuel consumption profile reveals a significant decrease following the addition of passenger vehicle age. In particular, vans showed a negative gradient in fuel consumption per year of -0.8 L/year, the highest decrement rate as compared to cars, -0.5 L/year and SUVs, -0.19 L/year. In terms of fuel economy, a comparatively low performance was recorded by cars, which is 9.38 km/L, as compared to SUVs, 27.05 km/L. Nevertheless, the fuel economy degradation for SUVs is 35% higher compared to cars. This result confirms the hypothesis that the longer the vehicle ages, the lower its fuel economy. Interestingly, this study suggests seven years as the start of a decline in the passenger vehicle fuel economy, independent of vehicle type. This research framework could be replicated to a bigger data scale for the economic vehicle service life determination in Malaysia that currently continues to be voluntary. It is vital as part of the basis for the future establishment of the national ELV definition.

Keywords: End-of-life vehicles; Fuel consumption; Fuel economy; Ownership period; Vehicle age.

ABSTRAK

Hayat perkhidmatan optimal adalah antara faktor penentu terpenting dalam perancangan kitaran hayat dan pengurusan kenderaan. Kos pengoperasian pelbagai dimensi meliputi perolehan aset, pengoperasian, penyelenggaraan sehingga pelupusan memerlukan analisis strategik bagi memastikan pemilikan kenderaan yang ekonomik. Isu hayat perkhidmatan *ekonomik ini adalah lebih ketara untuk sesebuah pengurusan pengangkutan dengan kapasiti bilangan pemilikan kenderaan yang tinggi. Sehubungan itu, data penggunaan bahan api dalam tempoh dua tahun bagi kenderaan penumpang sebuah pihak penguasa tempatan diperoleh. Dengan mengambil kira data penggunaan bahan api sebenar ini, kajian ini mengekplorasi kesan umur kenderaan terhadap ekonomi bahan api. Berdasarkan bacaan odometer, profil purata penggunaan bahan api mempamerkan penurunan yang ketara dengan peningkatan umur kenderaan. Secara khususnya, van menunjukkan suatu kecerunan negatif bagi purata penggunaan bahan api iaitu -0.8 L/tahun, kadar kemerosotan tertinggi berbanding kereta, -0.5 L/tahun dan SUV, -0.19/tahun. Daripada sudut ekonomi bahan api pula, prestasi yang lebih rendah direkodkan oleh kereta iaitu 9.38 km/L berbanding SUV, 27.05 km/L. Walaupun begitu, penurunan ekonomi bahan api bagi SUV adalah 35% lebih tinggi berbanding kereta. Dapatan ini mengesahkan hipotesis lebih panjang hayat sesebuah kenderaan, maka lebih rendah ekonomi bahan api. Menariknya, kajian ini mencadangkan tujuh tahun sebagai permulaan kemerosotan ekonomi bahan api, bagi semua jenis kenderaan penumpang. Rangka kerja kajian ini boleh direplikasi untuk skala data yang lebih besar untuk penentuan hayat perkhidmatan kenderaan ekonomik di Malaysia. Usaha ini adalah penting sebagai asas penghasilan definisi ELV kebangsaan kelak.*

Kata Kunci: Jangka hayat kenderaan; Penggunaan bahan api; Ekonomi bahan api; Tempoh pemilikan; Umut kenderaan.

INTRODUCTION

Engineering component lifespan has long been a question of great interest in a wide range of transportation fields, from aviation to maritime (Elsayed et al. 2019; Raposo et al. 2019). Likewise, passenger vehicle life is one of the major issues highlighted in roadworthiness discussions. From the vehicle safety aspect, consideration of a roadworthy vehicle depends on reliable structural integrity (Ary et al. 2020), smooth engine and transmission (Joshi 2021, Rakic et al. 2017), efficient braking (Caban et al. 2016), effective steering and manoeuvring (Kulkarni et al. 2019, Vukelic & Brcic 2016), well-functioned light and signalling (Ahmadi et al. 2020, Boyce 2008), etc. Ageing factors contributed by thermo-mechanical failures, due to excessive thermal deformation (Chung et al. 2010), fatigue (Yildiz et al. 2017), cracking (Mackin et al. 2002), buckling (Do 2019, Topaç et al. 2019), corrosion (Sonsino 2022) and unexpected wear at tribological contacts (Farroni et al. 2017) due to lubricant degradation (Ropandi et al. 2022), restrict a longer vehicle lifespan. Accordingly, maximum age or mileage is frequently prescribed for end-of-life vehicles (ELV) definition worldwide (Harun et al. 2021). The various definitions available between countries imply a different appropriate strategy for a specific region.

Big developed countries like the United States, the European Union, Australia and Japan stipulate the recycling responsibility of vehicles that reach the end of their useful life to automotive manufacturers. As for Malaysia, the last two decades have seen growing attempts by the government towards implementing the ELV policy. Road accident casualties related to unroadworthy vehicles and the environmental effect as a result of the dumping of abandoned aged vehicles are the main catalysts. Without a proper plan, opposition from various parties resulted in unsuccessful ELV implementation to date. The 2009 Directive of mandatory periodic technical inspection for 15 years aged vehicles (National Automotive Policy, 2020) was soon dropped. Despite an urged requirement for a proper recycling scheme, the vehicle age basis of the ELV preliminary screening is somewhat ambiguous. Although previous studies have recognised details of an ELV management system (Raja Mamat et al. 2016) and current practices by other countries (Hamzah et al. 2012), research has yet to systematically investigate the effect of the increasing operating age on vehicle useful life in the Malaysian context. The lack of national technical data to support the ELV implementation could be the reason for the inadequate public awareness and acceptance. However, it is remarkable to highlight that the existing Authorised Automotive Treatment Facility in Malaysia has an excellent recycling rate of 90% (Sulaiman et al. 2023). This is one of the crucial pre-requisite systems towards a positive ELV implementation.

Generally speaking, it is a big challenge for the government to implement new policies when it incurs additional costs to the people. Indonesia is Malaysia's neighbourhood country that has an identical growth of the automotive sector and community background. A recent study conducted by Sitinjak et al. (2022) in Indonesia showed that social influence, attitude, knowledge, health condition and trust in institutional management affect social acceptance of ELV. However, another public survey conducted by Harun et al. (2021) has shown that almost 75% of the respondents are not willing to pay for vehicle disposal or recycling fees. To reflect the adverse effect of a prolonged ownership period, a reveal of the fuel economic impact is suggested. Previous findings revealed that fuel consumption affects engine life and maintenance intervals (Krivoshapov et al. 2023). In this paper, the correlated effect of vehicle age on fuel economy was discussed. It was hypothesised that aged vehicles have a lower fuel economy. In this study, the urban driving cycle was selected as the study scope. A drive cycle defines how a vehicle is mainly used. According to the ASEAN NCAP safety assist assessment protocol (2019), the urban driving cycle refers to in-town usage, where vehicle speed is expected to be lower than the expressway suggested speed limit and short-distance travel. This study also set out to explore the influence of the studied parameter on different passenger vehicle types, i.e. cars, SUVs and vans. It is beyond the scope of this study to examine the economic impact of electric-driven, light trucks and heavy vehicles. This investigation will enhance our understanding of the local automotive scenario, particularly on passenger-carrying vehicles ownership period on fuel economic impact.

METHODOLOGY

The use of actual field data has a relatively long tradition within policy and standard protocol development. In this study, the research data are drawn from a local authority vehicle fleet, intended for urban usage. The fleet population consisted of 4,317 vehicles and 30% of the active fleet belonged to passenger vehicles. The passenger vehicle group was chosen as the focus of the study due to the impact of policy implementation on the relatively larger community compared to commercial vehicles.

The fleet was selected for the registration year and fuel consumption data availability. The centralised fuel pumping management system offers another advantage of data reliability. Information on the vehicle registration year, t_0 was retrieved to calculate the vehicle's age, t as in Equation (1).

$$t = t_i - t_0 \tag{1}$$

where t_i is the current year of data retrieval. The centralised fuel pumping management system records an odometer reading at each refuelling, i. This data record was utilised to obtain the vehicle kilometre-travelled, km as in Equation (2).

$$km = km_i - km_{i-1} \tag{2}$$

where km_i is an odometer reading and km_{i-1} is the previous odometer reading at each fuelling record for a vehicle fleet identification number. Accordingly, fuel consumed, FC for the calculated kilometre-travelled was retrieved from the previous fuelling record at km_{i-1}.

Vehicle age effect on two fuel-related indicators i.e. fuel consumption and fuel economy was observed. The average annual fuel consumption per unit vehicle j, FC was calculated, as in Equation (3).

$$FC = \frac{\sum_{j=1}^{N} FC_i}{N} \tag{3}$$

where N is the number of a passenger vehicle type fleet. For comparison, the calculation was replicated for every passenger vehicle type, i.e. car, SUV and van. As for fuel economy analysis, average fuel economy, FE was derived from the fuel consumption and kilometre travelled at each refuelling k, as in Equation 4.

$$FE = \frac{\sum_{k=1}^{M} \left(\frac{km}{FC}\right)}{M} \tag{4}$$

where M is the total number of refuelling. A linear correlation analysis was then carried out to observe the relationship between fuel consumption and fuel economy against vehicle age.

RESULTS AND DISCUSSION

This paper begins with a discussion on fleet fuel consumption. This analysis reveals the most active passenger vehicle type of the studied fleet. The discussion will then go on to fuel economy, the suggested measure for passenger vehicle lifespan determination. Findings are discussed in the following subsections.

FUEL CONSUMPTION

The first set of analyses examined the impact of vehicle age on fuel consumption. Figure 1 shows the average annual fuel consumption per unit vehicle, FC_T according to the passenger vehicle type. For the studied fleet, there are three types of passenger vehicles, which are cars, SUVs and vans. Looking at Figure 1, it is apparent that there is a negative linear relationship between the total fuel consumption and the vehicle age. This finding is consistent with a previous report that revealed a significant impact on the fuel consumption of an ageing fleet (Abreu & Gomes 2012). Unlike this study, the previous finding was evidenced by a locomotive fleet. Accordingly, a linear correlation for the studied sample was derived for each vehicle type.

The results of the correlational analysis for the three passenger vehicle types are also indicated in the respective graph. The *y*-intercept of the relationship estimates the average fuel consumption in the initial year of service. The most interesting aspect of this graph is the identical average fuel consumption for all vehicle types in the initial year of service. A slight variation in total fuel consumption exists, ranging from 44.57 L/unit to 49.18 L/unit. This figure explains that there is an equal demand for every vehicle type of the fleet. The highest fuel consumption was recorded by vans, closely followed by SUVs and the lowest was cars. This result is expected, in which vans and SUVs have a bigger engine capacity compared to cars. Furthermore, vans and SUVs are heavier and able to carry more passengers due to the higher laden mass and seat capacity. Thus, these factors may also contribute to a higher fuel required to operate the vehicle.

Following the addition of vehicle age, a significant decrease in the average total fuel consumption was displayed. Even though initially vans showed the highest average fuel consumption, the fuel consumption decrement rate revealed an opposing result. A decrement of -0.8 L/year in the average fuel consumption per year was recorded by vans. Unlike the initial fuel consumption where vans and SUVs recorded an almost similar demand, the decrement rate of SUVs is the lowest among others, which is -0.19 L/year. An interesting aspect that emerges from this finding is SUVs' fuel consumption is more consistent than the other two, regardless of their age. In terms of seating capacity, SUVs and vans are capable of carrying a large number of passengers. However, SUVs showed higher demand as compared to vans due to the more active refuelling activities. This finding could indirectly reflect their better roadworthiness over the increasing age.

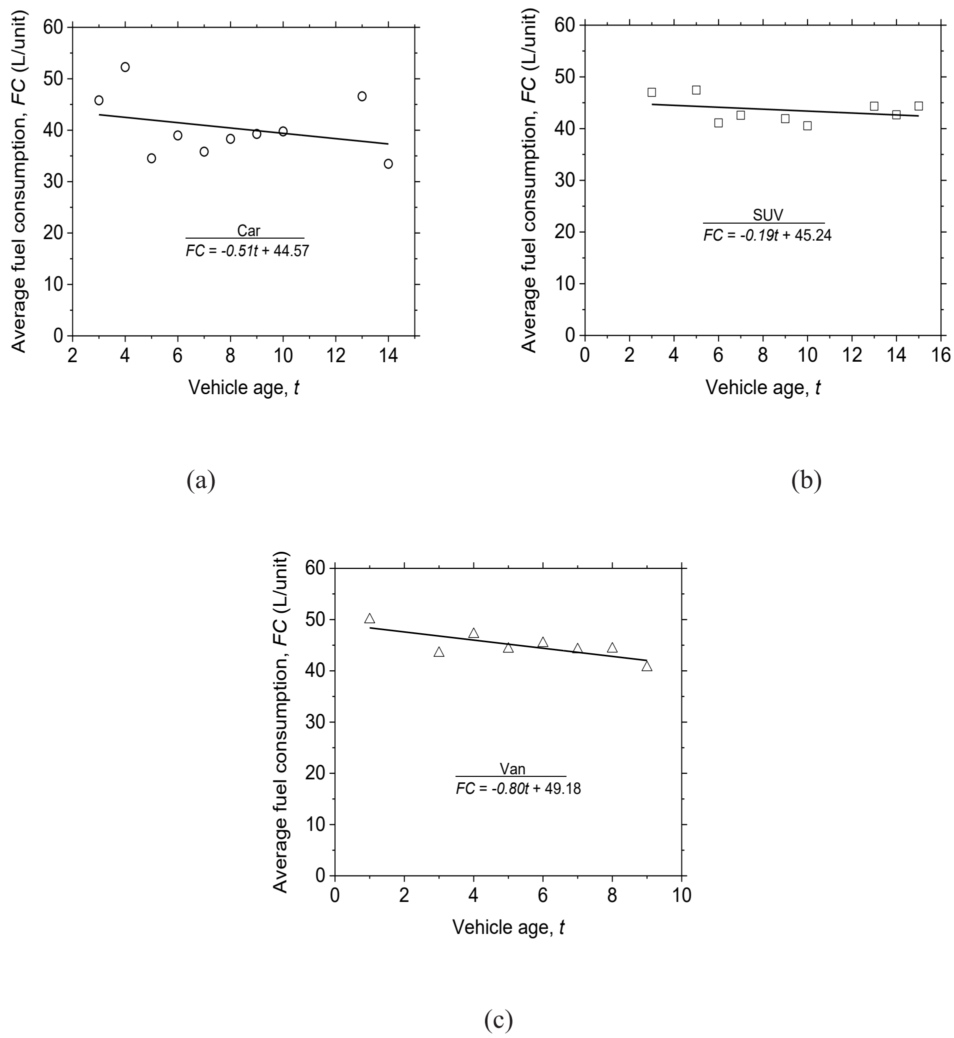
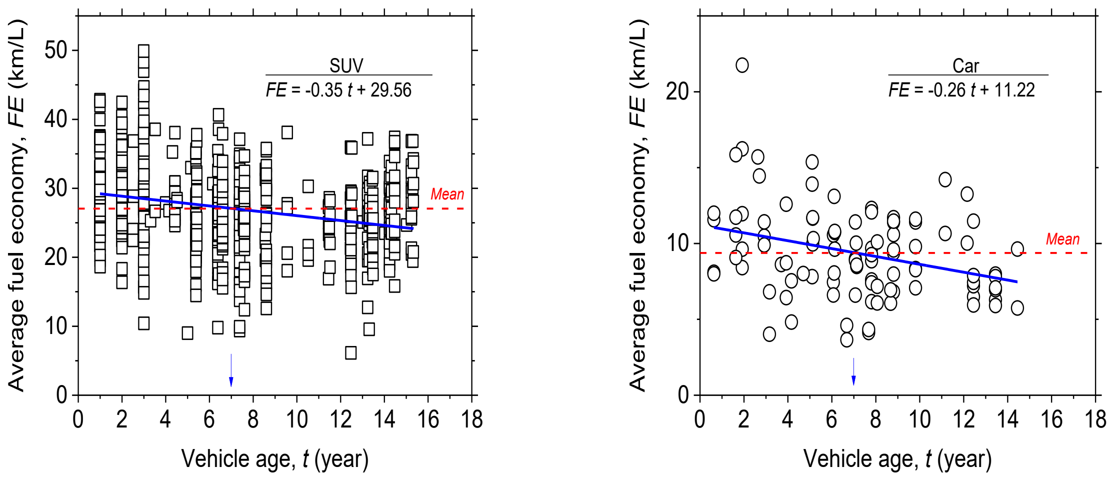


FIGURE 1. Average fuel consumption per unit vehicle fleet: (a) car, (b) SUV, (c) van.

FUEL ECONOMY

Figure 2 displays the plot of average fuel economy against vehicle age. It can be seen that the oldest car and SUV in the fleet are almost 15 years and 16 years old, respectively. The government Vehicle Service Termination Guideline (2015) referred to by the fleet management outlines that the minimum usage period for a saloon car and four-wheel drive is seven and twelve years after purchase, respectively. The guideline specifies that any vehicle that has reached the minimum age of economic use can be recommended to be withdrawn from its service. Statistical analysis of the fleet data showed that 57.2% of the cars and 24.4% of the SUVs exceed the stipulated service lifespan. It is known that proper asset maintenance is intended to preserve and extend life expectancy. This finding demonstrates that the fleet vehicles are well-maintained, resulting in extended service life.

According to the Malaysian Treasury Circular: Management Procedures for Government Movable Assets (2007), all movable assets should be competently utilised and efficiently managed to: (i) reduce waste, (ii) save costs, (iii) achieve lifespan, (iv) prevent abuse and (v) avoid loss. Therefore, the third objective of the circular is achieved. However, the second objective of the circular is uncertain. This is because the total cost includes the cost of purchase, operation and maintenance. Even though cost saving is implemented by expanding the vehicle service age, the amount of savings needs to be reweighed against the operating costs that are expected to increase with the increasing vehicle age.



(a)

(b)

FIGURE 2. Average fuel economy against vehicle age: (a) cars, (b) SUVs.

To distinguish between these two possibilities, costs related to fuel consumption need to take into account the fuel economy factor. Fuel economy defines the distance that can be reached by a vehicle with a total of 1 litre of fuel. Overall, fuel economy for cars is ranging from 4 km/L to 18 km/L. Whereas for SUVs fuel economy ranges between 5 km/L to 50 km/L. It is apparent from this plot that the range of fuel economy is quite large, especially for SUVs. Nevertheless, the low boundary of the fuel economy for both vehicle types is comparable. The results may be related to idling vehicle operation, which usually occurs during daily operating hours. Distance measurement based on odometer reading is inaccurate for the idle condition because odometers mainly work by assuming the distance travelled is equal to the number of wheel rotations times the tire circumference. Based on the same explanation, distance travelled measurement through odometer reading for a non-idle condition is therefore reliable. Therefore, later discussion will focus on the higher fuel economy range in the plot, in particular where most of the data is scattered.

While the data are widely scattered, the correlation between fuel economy and vehicle age reveals a remarkable result. An inverse linear correlation trend can be observed for both vehicle types. Initially, the fuel economy was relatively low before a rapid rise in two to three years of service. A similar trend was reported in the fuel consumption of a tractor fleet (Farid Eltom et al. 2014). Overall, the average fuel economy is relatively higher at a lower vehicle age than at a higher age. The results of the correlational analysis are presented in the same figure. Meanwhile, the dotted red line in the graph indicates the mean fuel economy for the studied period. Cars recorded a mean fuel economy of 9.38 km/L, whereas SUVs recorded a mean fuel economy of 27.05 km/L. It is noteworthy that the fuel economy of cars is comparatively low. Variations in the technical specification of both vehicle types including engine capacity, speed rate and the resulting power could be the reason for the fuel consumption rate difference (Farid Eltom et al. 2014). An improvement in fuel economy can be achieved by minimizing vehicle weight through size and accessory reduction (Lutsey & Sperling 2005). Besides, it was found that the decrement rate for cars is -0.26 while it is -0.35 for SUVs. As mentioned in the previous section, SUVs recorded a fairly consistent fuel consumption regardless of their age. However, the fuel economy degradation for SUVs is much higher compared to cars.

To reflect the operating cost implication on the fuel commitment, the average fuel economy is compared to the mean fuel economy line. The mean was considered a fair measure of the average fuel required for the entire sample, which covers the idle and non-idle conditions. Another important finding was that both lines intersect each other at a particular service age. With respect to the mean, it was found that the car fuel economy falls below the mean at seven years of vehicle age. It coincides with the minimum age limit suggested in the Vehicle Service Termination Guideline (2015). Surprisingly, SUVs recorded the same figure. This finding was unexpected and thus suggests seven years as the start of a decline in the passenger vehicle fuel economy.

CONCLUSION

The present study was designed to determine the effect of vehicle age on the economic aspect of the total fuel consumed by a passenger vehicle fleet. The age of passenger vehicles that have the best fuel consumption is not proved by this dataset. However, instead of fuel consumption which is strongly affected by vehicle demand among the vehicle fleet users, fuel economy is a better parameter to reflect the minimum age of ownership transfer. The results of this investigation show that a decrement in fuel economy below the mean starts at seven years of service for all passenger vehicle types. This figure is therefore suggested as the minimum age of economic use of a passenger vehicle intended for urban use, which can be recommended to be withdrawn from its service. This figure is in line with the government vehicle service termination guideline for cars but earlier for SUVs. These findings contribute in several ways to our understanding of the useful service life of a passenger vehicle ownership period. More importantly, this study establishes a quantitative framework and provides a basis for the establishment of a national ELV definition.

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