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Original Article

Development and application of the Weibull distribution-based vehicle survivorship models for a metropolis of a developing country

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Abstract

Vehicle survival rate models have been extensively built in developed countries and China in view of the availability of vehicle scrappage data, but many developing countries do not have those data. This paper intends to develop Weibull distribution-based models of vehicle survivorship for Metro Manila, Philippines, without using the vehicle scrappage data. The proposed computation procedure can capture the dynamics of average vehicle lifespan. Light-duty passenger vehicles are classified into two main categories: car (sedan, hatchback) and utility vehicle (SUV, van, minivan, pickup, wagon, Jeepney). The results highlighted that the average lifespan of the car decreased from 23.23 years in 2007 to 15.22 years in 2016, whereas the average lifespan of the UV was constant and equal to 14.18 years. Also, the developed models were applied to project the vehicle stocks, scrapped vehicles, and vehicle sales based on two designed scenarios: historical trend and limitation of the vehicle stocks.

Keywords: Weibull distribution, vehicle survival rate, scrapped vehicles, vehicle sales, vehicle stocks, Metro Manila

1. Introduction

Development of vehicle survival rate model is very simple for any countries having the scrapped vehicle data, the vehicle age distribution data, or the panel survival vehicle data. A vehicle survival ratio is indispensable to project the vehicle stock if a fleet of vehicle sales are known, and vice versa. It is informative to design policy for vehicle management. Furthermore, the vehicle stock and the vehicle age distribution data are used to predict road transport energy demand and mobile emission inventories for low-carbon scenario analysis to support proactive, efficient planning for a sustainable development (Azam, Othman, Begun, Abdullah, & Nor, 2016; Shabbir & Ahmad, 2010; Lee & Choi, 2016). Nakamoto, Nishijima, and Kagawa (2019) studied the impact

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of vehicle lifespan on CO_2 emission, and the results confirmed that an extension of vehicle lifespan was in line with a reduction in CO_2 emission. Also, the predicted fleet of vehicle sales can inform automakers to set a production target and motor vehicle distributors to develop market planning.

The development of vehicle survival rate models has been widely carried out in western countries since the 1950s, certainly on account of availability of the vehicle scrappage data (Chen & Niemeier, 2005; Kolli, Dupont-Kieffer, & Hivert, 2010; Parks, 1977; Walker, 1968). China has carried out vehicle scrappage standards since 1986 (Hao, Wang, Ouyang, & Cheng, 2011). Later on, the vehicle scrappage standards were revised in 1997, and the vehicle survival patterns have been studied after the year 2000 (Hao *et al*., 2011). Hao *et al*. (2011) studied the vehicle survival ratios in China using the available scrappage data while Yang, Yu, and Song (2005) developed the vehicle survival rate model of the light-duty passenger vehicle using the vehicle age distribution data. Chen and Lin (2006), Greene and Chen (1981), Lee and Choi (2016), and Nakamoto *et al*. (2019) have employed the vehicle scrappage data to develop the vehicle survival rates for 15 developed countries, South Korea, the USA, and the USA, respectively. Evident from the existing literature, all of the previous studies have been conducted in China and developed countries.

Rith, Fillone, Lopez, Soliman, and Biona (2018a) introduced a novel computation procedure to develop vehicle survival rate models using the fleets of new and renewed vehicles registered in the Land Transportation Office (LTO), Metro Manila because the scrapped vehicle data is not available. The developed vehicle survival rate models performed well for estimation of car and bus for the current year but not for the other past years, and it was supposed that the average vehicle lifespans of car and bus would be dynamic rather than static. Bento *et al*. (2016) confirmed that the average lifespan of passenger cars in the USA increased in terms of year, and ignoring the average vehicle lifespan changes would affect the output variables. Some studies have assumed the vehicle survival rates to project the energy consumption and emissions that would make their results less reliable, and those have been done by Shabbir and Ahmad (2010), Azam *et al*. (2016), and Ahanchian and Biona (2014) because the scrapped vehicle data may not be available in the country case studies.

Correspondingly, this study intends to develop vehicle survival rate models that can capture the dynamics of average vehicle lifespan without using the vehicle scrappage data, and the case study of Metro Manila, Philippines, was adopted. The data of light-duty passenger vehicles registered in the LTO were employed, and the LTO classifies the light-duty passenger vehicles into two main categories: car and utility vehicle (UV). Car is generally composed of sedan and hatchback. UV typically consists of cross utility vehicle (CUV), sport utility vehicle (SUV), minivan, van, pickup, wagon, Asian utility vehicle (AUV), and Jeepney. As compared to the car, the UV has a larger seating and luggage space and a higher chassis and consumes more fuel. A novel computation procedure was proposed, and the developed models were also applied to project the vehicle stocks, scrapped vehicles, and vehicle sales based on designed scenarios. To the best of our knowledge, no study is conducted to project the vehicle stocks, scrapped vehicles, and vehicle sales in Metro Manila.

The predicted output variables are informative for policymakers to design proactive policies, automakers and vehicle distributors to make planning, and officials at the Department of Finance to compute vehicular tax revenues before the coming year. The novel computation procedure proposed in this study is very informative to develop vehicle survival rate models for other countries having no scrapped vehicle data, and especially the dynamics of average vehicle lifespan can be addressed. The computation procedure is also possibly applied for other durable goods, such as the refrigerator, the heater, the cooler, etc. Correspondingly, this study provides a considerable contribution to fill the existing literature gap not only the proposed computation procedure but also the case study.

The remainder of the paper is structured as follows: Section 2 provides a brief description of the data source and the computation procedure, Section 3 discusses the model estimation results and applies the developed models, and Section 4 demonstrates the concluding thoughts and directions for future research.

2. Data Source and Methodology

The data of light-duty passenger vehicles were extracted from the Philippine Statistics Yearbooks (PSY) published from 2001 to 2017. Table 1 lists the distribution of the registered vehicles by year. The total vehicles refer to the vehicle stocks, while the total new vehicles refer to the total vehicle sales. The passenger vehicles are classified into two main categories: car and utility vehicle (UV). The data of registered vehicles are available from the year 2000 to 2016. The fleet of new vehicles registered before the year 2000 are not available in Metro Manila, and therefore the fleets of new cars and UVs can be approximated using the equations below, based on Rith *et al*. (2018a):

$$\text{New car fleet}_{\text{y}} = 0.227 + 0.759 \times \exp\left(\frac{\text{y}-2016}{7.320}\right) \quad (1)$$

$$\text{New UV fleet}_{\text{y}} = 0.401 + 0.616 \times \exp\left(\frac{\text{y}-2016}{3.702}\right) \quad (2)$$

where the index “y” represents a year.

A survivorship model of a durable good can be developed using various parametric approaches, e.g., beta, gamma, normal, lognormal, logistic, and exponential distribution functions (Bento, Roth, & Zuo, 2016; Kagawa *et al*., 2011; Kolli *et al*., 2010; Murakami, Oguchi, Tasaki, & Hashimoto 2010; Nakamoto *et al*., 2019). For the development of vehicle survival rate, Weibull and Beta distribution functions are the best parametric approaches (Kolli *et al*., 2010). Similarly, the Weibull distribution function is an efficient statistical distribution function to develop a survivorship rate model for any population groups (Pinder III *et al*., 1978). Correspondingly, the Weibull distribution function has been widely carried out to develop vehicle survivorship model in the previous studies (Hao *et al*., 2011). The Weibull distribution function is expressed below:

$$Vehicle\ Survial\ Rate_{Age,y} = exp\left(-\left(\frac{Age}{\lambda}\right)^{k}\right) \quad (3)$$

Table 1. Distribution of vehicle fleet by year.

Year	Car	UV
Total vehicles registered in LTO		
2016	601,628	1,097,222
2015	596,781	1,072,722
2014	568,383	982,732
2013	554,615	934,940
2012	543,343	902,904
2011	526,786	884,862
2010	511,211	835,585
2009	490,677	772,941
2008	489,673	747,068
2007	475,854	742,646
New vehicles registered in LTO		
2016	77,436	143,751
2015	65,460	122,161
2014	67,098	117,686
2013	52,363	97,023
2012	53,140	85,931
2011	48,516	84,654
2010	44,638	85,062
2009	36,042	67,998
2008	39,696	64,026
2007	35,413	60,021
2006	30,501	48,818
2005	32,105	48,344
2004	32,683	49,060
2003	23,024	68,760
2002	26,303	82,363
2001	24,347	60,716
2000	25,831	63,442

Vehicle stock = Total vehicles registered in LTO
Vehicle sales = New vehicles registered in LTO

where "k" and "λ" are the shape and scale parameter estimates, respectively, and "*Age*" defines the vehicle age. The scale parameter is an average vehicle lifespan. In our study, we modified the average vehicle lifespan to be an exponential function, as seen in Equation 4. The average vehicle lifespan becomes static if the "θ" estimate is equal to zero. The function of average vehicle lifespan can be any mathematic functions (i.e. exponential, logarithm, linear) attributed to vehicle scrappage and management policies, vehicle type and lifetime design, road and traffic characteristics, and driver behavior.

$$\lambda = \beta e^{\theta(y-2016)} \quad (4)$$

By substituting Equation 4 into Equation 3, the Weibull distribution-based vehicle survival rate model can capture the dynamics of an average vehicle lifespan as expressed in Equation 5. The vehicle stock of year *"y"* can be calculated using Equation 6. *"$Vehicle\ Sales_{y-Age}$"* refers to the fleet of new vehicles registered in the year of "*y* – *Age*."

$$Vehicle\ Survival\ Rate_{Age,y} = exp\left(-\left(\frac{Age}{\beta e^{\theta(y-2016)}}\right)^k\right) \quad (5)$$

$$Vehicle\ Stock_y = \sum_{Age=0}^{40} Vehicle\ Sales_{y-Age} \times Vehicle\ Survival\ Rate_{Age,y} \quad (6)$$

The parameters were estimated using the ordinary least square (OLS) method, as can be seen in Equation 7:

$$OLS = \sum_{y=2007}^{2016} \left|Vehicle\ Stock_y(actual) - Vehicle\ Stock_y(estimated)\right|^2 \quad (7)$$

where the period ranging from 2007 to 2016 was selected to estimate the models. The Solver tool of Data tab in Microsoft Excel was used to compute Equation 7.

3. Results and Discussion

3.1 Model estimation results

The developed vehicle survival rate models of car and UV of Metro Manila are demonstrated as Equations 8 and 9, respectively. The average lifespan of UV was static, while the average lifespan of car was dynamic. The positive sign of "θ" means that the average vehicle lifespan decreases with an increase in year "*y*." Based on Equations 8 and 9, the vehicle survival ratios of car and UV can be plotted in Figure 1.

$$Vehicle\ Survival\ Rate_{Age,y} = exp\left(-\left(\frac{Age}{15.215e^{0.047(y-2016)}}\right)^3\right) \quad (8)$$

$$Vehicle\ Survival\ Rate_{Age,y} = exp\left(-\left(\frac{Age}{14.184}\right)^3\right) \quad (9)$$

Vehicle scrappage rate is calculated by making a derivative of the vehicle survival rate with respect to the vehicle age (Hao *et al*., 2011). Cumulative vehicle scrappage rate is equal to one minus the vehicle survival rate (Rith *et al*., 2018a).

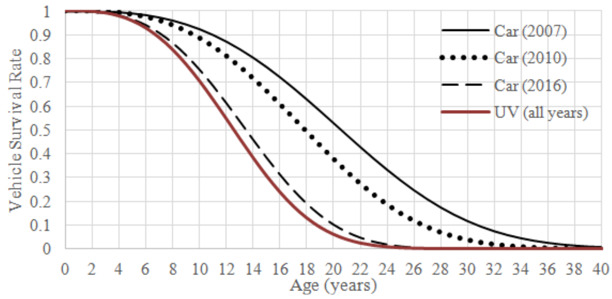

Figure 1. Vehicle survival rates.

3.2 Analysis of average vehicle lifespan

The average vehicle lifespans of car and UV are illustrated in Figure 2. The average lifespan of car noticeably decreased from 23.23 years in 2007 to 15.22 years in 2016, and the average lifespan of UV was fixed and equal to 14.18 years. The average lifespans of the passenger vehicles in Metro Manila were found quite higher than the average lifespans of the passenger vehicles in China (Hao *et al*., 2011) and the USA (Bento *et al*., 2016) because there is no implementation of a compulsory vehicle scrappage standard in Metro Manila.

The decrease in the average lifespan of car would be explained as follows. The Philippines has experienced a fast-

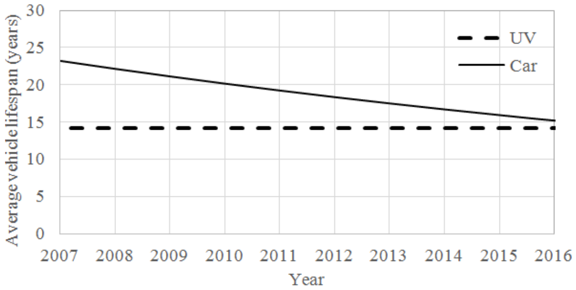

Figure 2. Average vehicle lifespans.

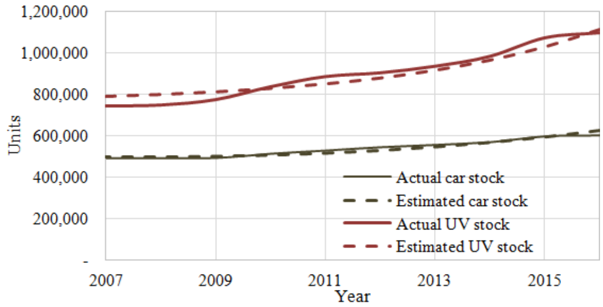

Figure 3. Estimated and actual vehicle stocks.

growing economy with an average annual economic growth of 6.8 % during the last three years (Trading Economic [TE], 2018). Economic growth is associated with an increase in household income. Generally speaking, people with higher income are more likely to acquire large vehicles with more seating and luggage capacity (Rith, Biona, Fillone, Doi, & Inoi, 2018b). Those vehicles must be minivans, SUVs, CUVs, pickups, and vans.

Another reason, the flooding susceptibility in Metro Manila might seduce people to shift from owning low chassis vehicles to high chassis vehicles to be less susceptible to flooding. Most of the high chassis passenger vehicles are CUVs, SUVs, pickups, minivans, and AUVs. According to a flood risk assessment in 2010 in Metro Manila, 746 barangays (communities) and 214 barangays were prone to high flood risk and very high flood risk, respectively (Pornasdoro, Silva, Munarriz, Estepa, & Capaque, 2014). This shall translate to that about 56.40% of Metro Manila is vulnerable to flooding. Consequently, people in Metro Manila are likely to sell their own cars to other regions and purchase new UVs.

The average UV lifespan was static, and it could be explained that UV is a better choice for people with high income because of its more comfort and larger seating and luggage capacity, as compared with car. Especially, UV is less vulnerable to flooding in light of its high chassis. It suggests that people owing UVs are less likely to shift to acquire cars.

3.3 Validation of the developed vehicle survival rate models

The developed vehicle survival rate models are used to estimate car and UV stocks and then compared with the actual ones. The estimated vehicle stocks compare well with the actual car and UV stocks, evident from Figure 3. The mean relative errors (MREs) of car and UV were 1.74 % and 3.53%, respectively. Therefore, the developed vehicle survival rate models in this study perform much better than the vehicle survival rate models developed by Rith *et al*. (2018a) in terms of MRE. With respect to this, the developed vehicle survival rate models were applied to estimate the scrapped vehicles from 2007 to 2016.

3.4 Model application examples

3.4.1 Estimated number of scrapped cars and UVs

The estimated fleets of scrapped cars and UVs are illustrated in Table 2. The estimated number of scrapped cars would increase from 37,644 units in 2007 to 44,626 units in 2016, and the number of scrapped UVs went up from 58,071 units in 2007 to 62,714 units in 2016. Therefore, the total scrapped vehicles were 107 thousand units in 2016.

3.4.2 Average lifetime vehicle usage

The average lifespans of car and UV in 2016 were 15.22 years and 14.18 years, respectively. The average vehicle kilometers traveled (VKT) of car and UV were 987 km and 967 km per month, respectively (Rith *et al*., 2018b). Therefore, the average lifetimes of car and UV were 180,266 km and 164,545 km, respectively. The vehicle lifetime is significant for comparative cost studies and lifecycle emissions of different vehicle types (Roosen, Marneffe, & Vereeck, 2015; Wee, Jong, & Nijland, 2011).

3.4.3 Projected vehicle stock and scrappage intensity

The developed vehicle survival rate models were applied to project the vehicle stocks and the fleets of scrapped cars and UVs from 2017 to 2025. For this designed scenario, we supposed there is no governmental intervention, and the registered new cars and UVs are based on the historical trend following Equations 1 and 2.

The projected stocks of cars and UVs are apparent in Figure 4. The car stocks will double from 663 thousand units in 2017 to 1,260 thousand units in 2025. Surprisingly, the projected UV stocks will skyrocket from 1.22 million units in 2017 up to 4.77 million units in 2025. The projected up-trend of UV stocks would be possible if the national economic growth remains constant, and there is no strategic intervention from the government.

Figure 5 illustrates the profiles of the projected fleets of scrapped cars and UVs. The scrapped cars and UVs would exponentially increase, and the car scrappage rate was found

Table 2. Estimated fleets of scrapped vehicles (units).

Year	Car	UV
2016	44,626	62,714
2015	42,436	61,509
2014	40,734	60,589
2013	39,448	59,887
2012	38,517	59,351
2011	37,889	58,942
2010	37,522	58,630
2009	37,379	58,391
2008	37,428	58,209
2007	37,644	58,071

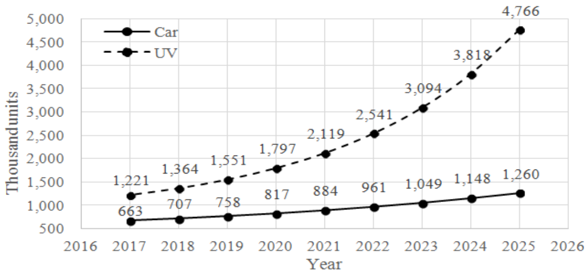

Figure 4. Projections of vehicle stocks based on the historical vehicle sales.

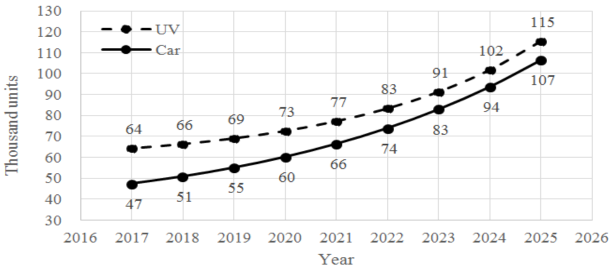

Figure 5. Projection of scrapped vehicles based on the historical vehicle sales.

higher than the UV scrappage rate. This certainly implied that the people in Metro Manila are likely to shift ownership of cars to UVs, which is a sign of less efficient energy consumption for passenger mobility using private vehicles because the UV's fuel economy is relatively lower.

3.4.4 Projection of scrapped vehicles and vehicle sales

Metro Manila faces a heavy traffic congestion, and about 50% of the roads already operate at a volume/capacity (V/C) ratios in excess of 0.8 (ALMEC, 2014). The light-duty passenger vehicle stock was 1.70 million units in 2016 (Philippine Statistics Authority [PSA], 2017). The projected vehicle stock will increase up to 2.61 million units in 2020 (see Figure 4), which might saturate the roads and reduce the effectiveness of the vehicular volume reduction scheme.

For this formulated scenario, we would like to restrain the car and UV stocks by 0.8 million units and 1.6 million units, respectively, from 2020. What are the predicted fleets of scrapped vehicles and vehicle sales of car and UV? Figure 6 illustrates the predicted vehicle sales. It is found that the UV sales will fall off from 257 thousand units in 2019 to 73 thousand units in 2021 and then slightly increase up to 96 thousand units in 2025, while the car sales will decline from 106 thousand units in 2019 to 60 thousand units in 2021 and then marginally increase up to 91 thousand units in 2025. The sharp decrease in vehicle sales in 2021 are caused by limited vehicle stocks in 2020. The predicted vehicle sales are very informative for transportation policymakers and practitioners to set a limited number of vehicle sales in terms of year to limit the vehicle stocks. Moreover, automakers and vehicle distributors can be informed beforehand to make production and marketing planning. Additionally, the Department of Finance can approximate the tax revenue from the predicted vehicle sales before the coming year.

Based on the predicted vehicle sales, the scrapped cars and UVs are plotted in Figure 7. The number of scrapped cars and UVs exponentially increases but marginally slower as compared with the scrapped vehicles based on the historical trend scenario, as visible from Figure 5.

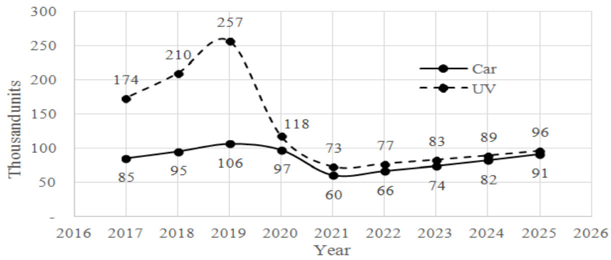

Figure 6. Estimated vehicle sales when vehicle stocks are limited.

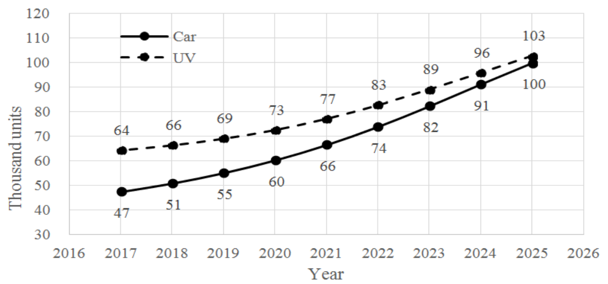

Figure 7. Estimated fleets of scrapped vehicles when vehicle stocks are limited.

4. Conclusions and Recommendations

This paper intends to develop and apply the Weibull distribution-based vehicle survival rate models without using the vehicle scrappage data. The results showed that the average lifespan of car decreased from 23.23 years in 2007 to 15.22 years in 2016, whereas the average lifespan of UV was fixed and equal to 14.18 years. The developed vehicle survival rate models were then used to estimate the vehicle stocks and compared with the actual vehicle stocks. The low MREs suggested that the proposed computation approach is valid and reliable. The developed vehicle survival rate models were applied to estimate the average lifetime usages of car and UV. Also, the developed models were carried out to project (1) the scrapped vehicles and vehicle stocks based on the historical trend of vehicle sales and (2) vehicle sales and scrapped vehicles if the vehicle stocks are constrained.

The projection of vehicle stocks, vehicle sales, and scrapped vehicles are indispensable for transportation planners to design proactive policies, automakers and vehicle distributors to make planning, and officials at the Department of Finance to compute tax revenue beforehand. The computation procedure of vehicle survivorship model can also be applied for other durable goods in the field of reliability engineering without using the product scrappage data. Importantly, the proposed computation approach can capture the dynamics of the average lifespan of a durable product.

Future research should focus on an analysis of the determinants of the dynamics of average vehicle lifespan, especially how socio-demographic characteristics and urban form attributes affect average vehicle lifetime. Also, further effort is required to compare various parametric approaches for the development of vehicle survivorship models based on the proposed computation procedure.

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