A Study on the Financial Effect of Promoting Autonomous Emergency Breaking for Elderly Drivers

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Abstract: Gradually, the number of traffic accidents caused by elderly drivers is increasing. In order to decrease the number of traffic accidents by elderly drivers, it is effective to promote the Advanced Driver Assistance Systems for the elderly drivers. Therefore, we focus on promoting the Advanced Driver Assistance Systems for elderly drivers especially Autonomous Emergency Breaking. The purpose of this research is to uncover the financial benefit by subsidy policy. We performed a financial Cost-Benefit analysis. In order to analyze, we assumed parameters of this calculation by taking questionnaire, referring to previous study. As a result, the present study has demonstrated that financial effect by promoting AEB approach. We found that the subsidy of 40,000 JPY or below gives the policy become surplus (We define AEB price as 100,000 JPY).

Keywords: Subsidy policy, Elderly drivers, Cost-Benefit analysis, Traffic accident

1. INTRODUCTION

The number of collision accidents caused by elderly drivers has shown an increasing trend, and it is currently considered as one of the most pressing social issues in Japan. According to the Voluntary Automobile Insurance (2012), Cabinet Office (2008,2012)and Jing JING (2004), the financial loss caused by the collision accidents by these elderly drivers is estimated to be about 300 billion JPY. Furthermore, the share of elderly drivers will increase in the coming years. As can be seen in Figure 1, the age pyramid for the Japanese population shows a concentration in the age group 65-69 compared with the other age groups. For that reason, the number of traffic accidents caused by elderly drivers will indubitably increase with respect to the current situation. For this reason the society should not neglect this issue, but rather focus on a solid approach to solve this problem.

For the past few years, topics related to automated vehicle technologies and their implementation are being discussed worldwide. According to the SAE (2016), automated vehicle technology can be divided into six levels (level 0, 1, 2, 3, 4 and 5). The detail information of each levels is shown by Table 1. Currently level 2 is implemented worldwide. The representative systems on level 2 are classified as follows; Autonomous Emergency Braking (AEB), Lane Keeping Assist System (LKAS), and Adaptive Cruise Control (ACC). These systems are defined as Advanced Driver Assistance Systems (ADAS), and have two main advantages with regard to elderly drivers. The first advantage is the decrease of driving fatigue by the use of these systems. Secondly, traffic accidents will significantly decrease if these Advanced Driver Assistance Systems are implemented. In order to decrease the number of traffic accidents caused by elderly drivers, it is necessary to promote the Advanced Driver

Assistance Systems with the focus on elderly drivers.

Few Japanese prefectures have focused on implementing subsidy policy approaches for encouraging the use of Advanced Driver Assistance Systems for elderly drivers. Kagawa prefecture, for example, carries out the subsidy policy for elderly drivers that purchase an Advanced Safety Vehicle (ASV). Kagawa prefecture has a budget of 30,000 JPY allotted to the subsidy for Advanced Driver Assistance Systems for elderly drivers (2016). Toyota city has also implemented a subsidy policy for this matter. Through this policy, elderly drivers can apply for subsidy in the case they purchase a car with an ACC or AEB system. When both AEB and ACC are purchased, the purchaser will receive a subsidy of 30,000 JPY. In the case the elderly driver decides to purchase only AEB, s/he will receive a subsidy of 20,000 JPY (2016). Subsidy policies as discussed above prove to be effective approaches towards encouraging and promoting Advanced Driver Assistance Systems. However, there have not been any cost-benefit analyses modelled with the above-mentioned subsidy policies included as one of the criterions. The clarification of the financial benefit compared with the policy costs is necessary if we wish to pursue the promotion of Advanced Driver Assistance Systems.

In this research, we have investigated the financial benefit of promoting Autonomous Emergency Brake (AEB) with regards to the Japanese society. The purpose of this research is to discover the financial benefit of subsidy policies in Japan through the use of mathematical calculations.

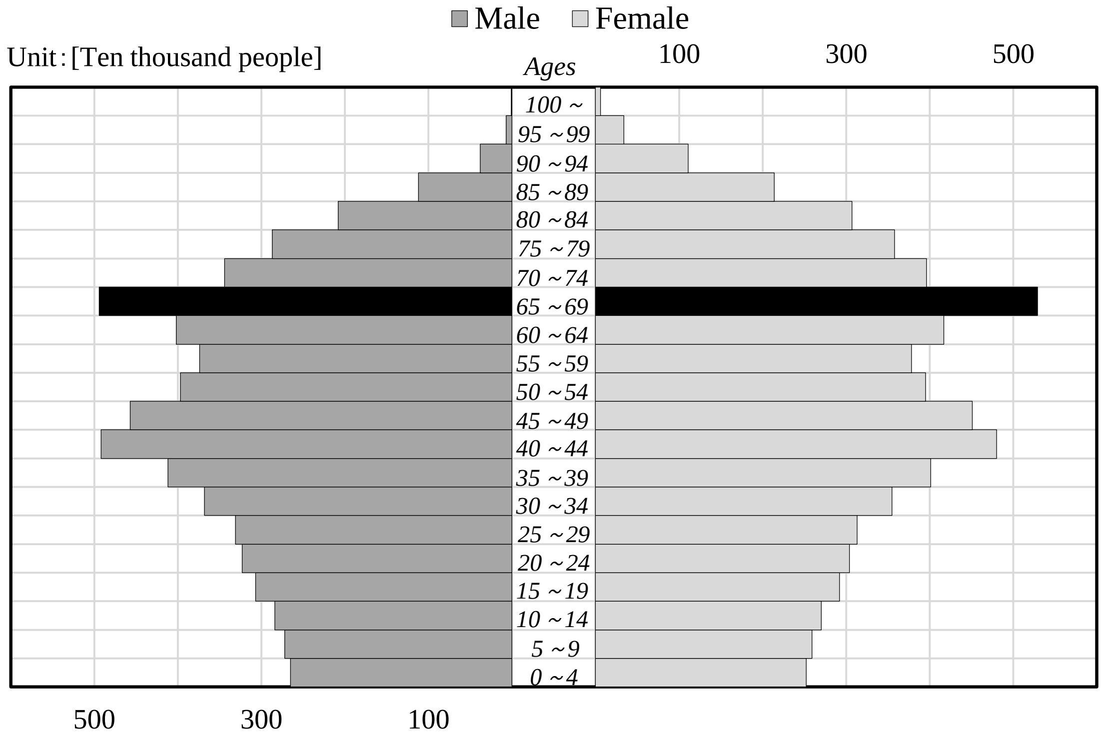

Figure1 Age pyramid in Japan (2016)

Table 1 Each autonomous car driving levels by SAE (2016)

Level	Name	Narrative definition	DDT*[1]		DDT fallback	ODD*[3]
			Sustained lateral and longitudinal vehicle motion control	OEDR*[2]		
Driver performs part or all of the DDT						
0	No Driving Automation	The performance by the driver of the entire DDT, even when enhanced by active safety systems	Driver	Driver	Driver	n/a
1	Driver Assistance	The sustained and ODD-specific execution by a driving automation system of either the lateral or the longitudinal vehicle motion control subtask of the DDT (but not both simultaneously) with the expectation that the driver performs the reminder of the DDT.	Driver and System	Driver	Driver	Limited
2	Partial Driving Automation	The sustained and ODD-specific execution by a driving automation system of both the lateral and longitudinal vehicle motion control subtasks of the DDT with the expectation that the driver completes OEDR subtask and supervises the driving automation system	System	Driver	Driver	Limited
ADS("System") performs the entire DDT (while engaged)						
3	Conditioned Driving Automation	The sustained and ODD-specific performance by an ADS of the entire DDT with the expectation that the DDT fallback-ready user is receptive to ADS-issued requests to intervene , as well as DDT performance-relevant system failures in other vehicle systems, and will respond appropriately.	System	System	fallback-ready user (becomes the driver during fallback)	Limited
4	High Driving Automation	The sustained and ODD-specific performance by an ADS of the entire DDT and DDT fallback without any expectation that a user will respond to intervene.	System	System	System	Limited
5	Full Driving Automation	The sustained and unconditional (i.e. not ODD-specific) performance by an ADS of the entire DDT and DDT fallback without any expectation that a user will respond to intervene.	System	Driver	Driver	Unlimited

*[1] The meaning of DDT is Dynamic Driving Task
*[2] The meaning of OEDR is Object and Event Detection and Response
*[3] The meaning of ODD is Operational Design Domain

2. DATA COLLECTION OF ELDERLY DRIVERS IN JAPAN

2.1 Financial loss caused by collision accidents

The financial loss caused by collision accidents is divided into three categories. These are human wounded and casualties (Human loss), material loss, and non-monetary loss. Financial loss related to human wounded and casualties includes inter alia treatment costs, consolation costs and lost profits. Material loss includes the amount that has to be paid for all physical damage (e.g. car accident, guardrail, facilities). Non-monetary loss encompasses the loss of life value (e.g. death-related costs, sequela, traumas and disorders). Damage such as human wounded and casualties and material loss can be calculated directly. For non-monetary loss, however, that is not possible. In order to calculate non-monetary losses, Cabinet Office and Jing JING use the Contingent Valuation Method and Standard Gamble Method for estimating the non-monetary loss of per victim (Unit: 100 million JPY/victim). The non-monetary loss per victim data according to Cabinet Office and Jing JING is averaged in Table 1. By multiplying the average non-monetary loss per victim by the number of elderly drivers, the total non-monetary financial loss can be obtained. The number of victims hit by elderly drivers, and the total amount of non-monetary loss are displayed in Tables 2 and 3. The total financial loss caused by the collision accidents is shown in Table 4.

Table 2 The non-monetary loss per victim (100 million JPY / victim)

Investigation	Deaths	Sequela	Injury
Cabinet Office in 2007	2.26	0.836	—
Cabinet Office in 2012	2.13	0.648	0.002
Jing JING	2.66	1.105	0.145
Average	2.35	0.863	0.074

Table 3 The number of victims hit by elderly drivers in 2012 (in persons)

The age of person who made the accident	The number of **deaths** in victim	The number of **sequela** in victim	The number of **injury** in victim	Total of victim
70 ~ 74	1	431	13,328	13,760
75 ~ 79	4	251	8,547	8,802
80 and over	2	164	5,449	5,615
Total	7	846	27,324	28,177

Table 4 Non-monetary loss in categories for 2012 (hundred million JPY)

Things	Non-monetary loss
Deaths	16
Sequela	730
Injury	2,022
Total	2,769

Table 5 The total loss in 2012 (hundred million JPY)

Type of loss	Each nonmonetary loss
Human loss	189
Material loss	247
Nonmonetary loss	2,769
Total loss	3,196

2.2 Estimating the number of future elderly drivers

The number of future elderly drivers can be predicted by multiplying the ownership rate of driver's licences by the elderly population in Japan. Equation (1) shows the corresponding formula. The elderly population in Japan is predicted by using the vital statistics from 2014 (the data divided to each age group). The data used in this research is based on the initial numbers acquired from the data obtained in 2014, as this provides us of the most recent data. This, however, means that death or other reasons that prevent this population from using the car is not considered in this research, assuming that they will continue driving the car as in 2014. In this way, data for the coming five years can be estimated (Table 5). In order to estimate the future driver's licence ownership rate, data from the past decade is used for the prediction equation. Equation (2) shows the prediction formula, Figure 2 displays the predicted data, and Table 6 encompasses the estimated results. In the equation (2), the outcome of the determination coefficient R^2 is 0.99.

$$W_T = O_T \times Q_T \tag{1}$$

where,

W_T : The number of 70 year-old elderly drivers at year T (in persons).

O_T : The ownership rate of driver's license at year T.

Q_T : The number of the population consisting of 70 year-olds at year T.

$$O_T = 0.0385\, T^{0.7105} \tag{2}$$

where,

O_T : The ownership rate of driver's license at year T.

T : Heisei T year (Heisei year 29 corresponds with year 2017).

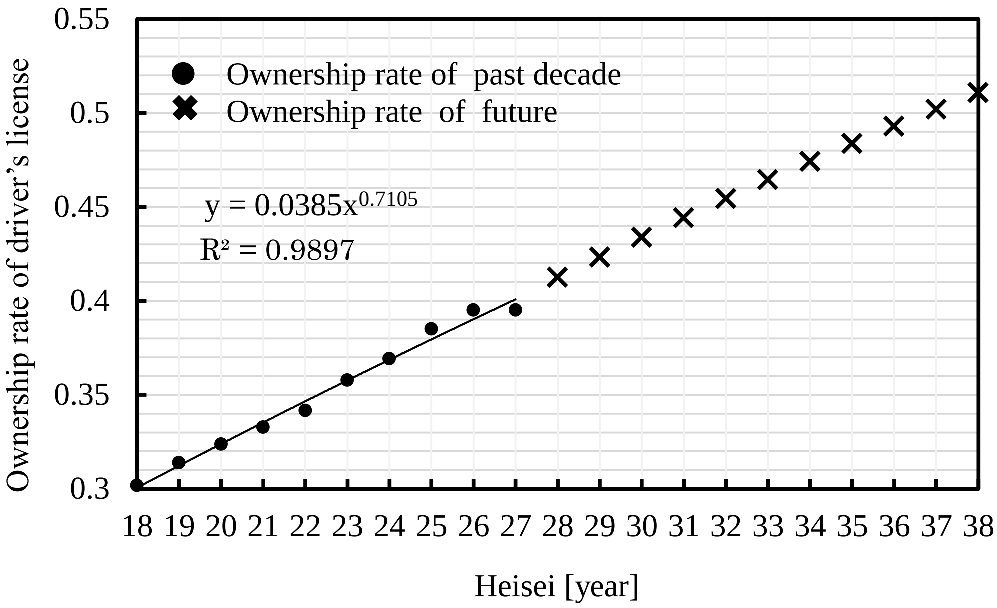

Figure 2 The predicted ownership rate of driver's license

Table 6 The number of 70 year-old people at year T.

Year	Number of 70 years old people
2017	2,076,000
2018	2,191,000
2019	2,214,000
2020	2,027,000
2021	1,887,000

Table 7 The estimated future ownership rate of driver's license

Year	Future ownership rate of driver's license
2017	0.421
2018	0.431
2019	0.442
2020	0.452
2021	0.462

3. QUESTIONNAIRE SURVEY FOR ELDERLY DRIVERS

In order to understand the relation between the amount of subsidy and the number of AEB purchasers, we conducted a questionnaire with 72 elderly drivers. The data results are shown and discussed below.

3.1 Data and Location

・Subject group: elderly drivers aged 70 or above.
・Date : December 9th through 11th, 16th through 18th, 25th 2015.
・Number of participants : 83 people
・Location : Hokkaido Traffic Safety Association Automobile School, Japan

3.2 Questions included in the conducted questionnaire

- If you would receive financial support (subsidy) for the purchase of a car with a Driver Assist System implemented, would you consider purchasing such a car?
- How much would you pay for a new car?
- How much would you pay for the Driver Assist Systems (please consider the price including the budget of the purchase of your new car)?

3.3 Questionnaire results

Question 1: 'If you would receive financial support (subsidy) for the purchase of a car with a Driver Assist System implemented, would you consider purchasing such a car?'

The result for this question is shown in Figure 3. As can been seen in Figure 3, the ratio of elderly drivers that are *positively considering* accounts for 43 per cent of the total responses, and the ratio of elderly drivers that are *little positively considering* encompasses 47 per cent. Therefore, if there is subsidy for the systems, 90 per cent of the total responders *consider positively* or a *little positively*. Because of this result, there is a possibility that the subsidy policy is an effective approach for the promotion of AEB.

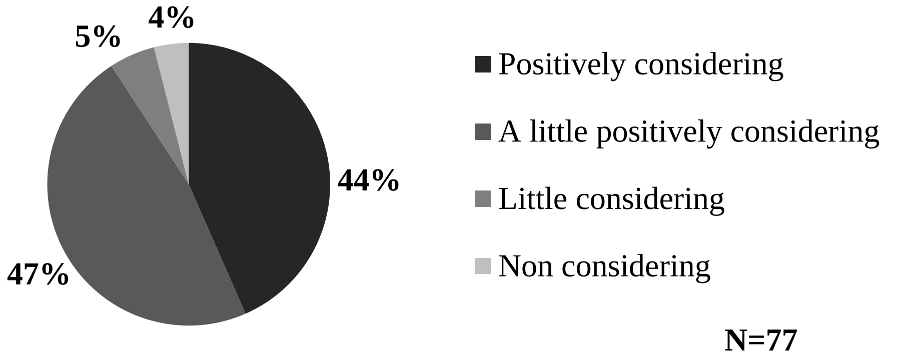

Figure 3 Awareness for purchasing the Advanced Driver Assistance Systems by the subsidy policy

Question 2: 'How much would you pay for a new car?'

The results corresponding to this question are shown in Figure 4. This figure shows that 80 per cent of the total responders will pay two million JPY for a new car at the maximum. For Figure 4, the vertical axis shows the ratio of answers (e.g.: if a person responds to the question with a budget of one million JPY, the price is also counted for one million JPY or below in the data). The horizontal axis displays the price the responder would pay at a maximum for a new car.

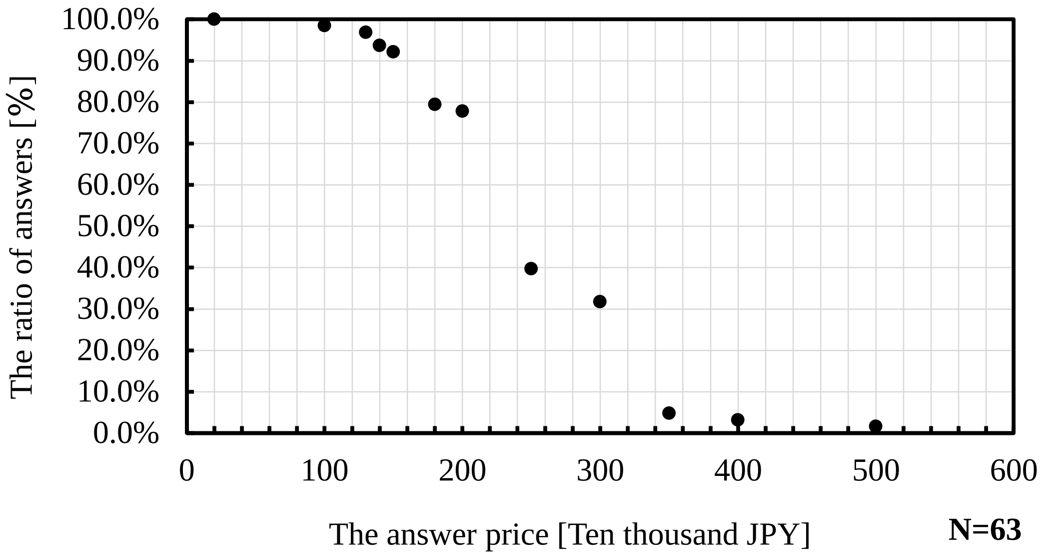

Figure 4 The maximum desirable price payment for purchasing a new car

Question 3: 'How much would you pay for the Driver Assist Systems (please consider the price including the budget of the purchase of your new car) ?

The results coming from this question are displayed in Figures 5 and 6. Figure 5 shows that 83 per cent of the total will pay 100,000 JPY for Advanced Driver Assistance Systems at maximum. In addition to this, a model for this question can be sketched, which is shown in Figure 6. This figure shows that the model is expressed through equation (3). The outcome of the determination coefficient R^2 is 0.97. This equation (3) shows a relationship between the purchasing ratio and AEB price ratio. Moreover, this equation is used for the cost-benefit analysis, which is discussed in the following section.

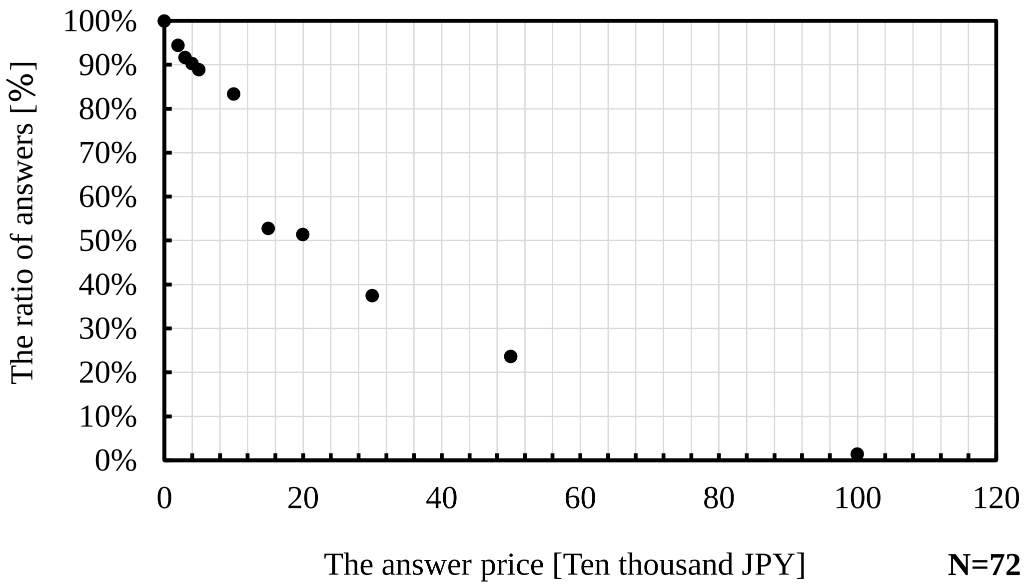

Figure 5 The maximum desirable price payment for Advanced Driver Assistance Systems

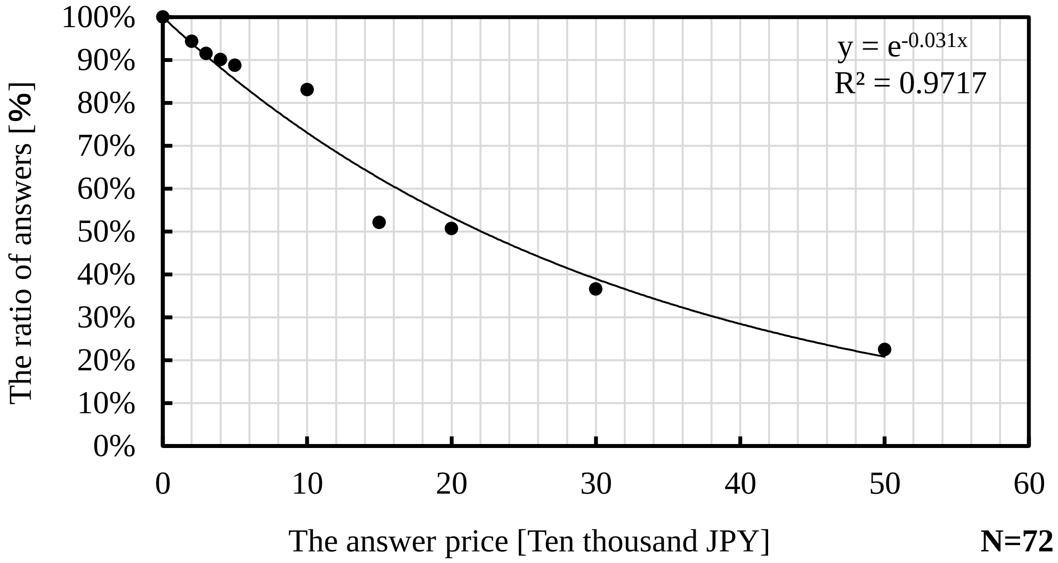

Figure 6 The equation for estimating the relationship between the purchasing ratio and AEB price ratio

$$P_m = e^{-0.031 \quad m} \tag{3}$$

where,

P_m : The purchasing ratio when the price is m Ten thousand JPY.

m : The price of systems (in this study, we define the system as AEB. The nominal price is 100,000 JPY. m is 0≦m≦10 [Ten thousand JPY])

4. COST-BENEFIT ANALYSIS OF THE POLICY

4.1 Policy contents prospected in this study

The subject group for this research consists of 70 year-old drivers that have the plan to purchase a new car, either with or without an AEB installation. AEB-focused subsidies will encourage the subjects to purchase an AEB-installed car, rather than a normal one. In this research, a policy period of five years from 2017 to 2021 is considered. By carrying out this policy for five years, the baby boomer will be enabled to purchase a car with an AEB-installation. In other words, pursuing such measures may encourage a decrease of the number of traffic accidents caused by elderly drivers (i.e. baby boomers). In this research, the price of the AEB installation is theoretically set on 100,000 JPY (ex: EyeSight ver.3 of Subaru Impreza price is 108,000JPY). The subsidy will encompass an amount varying from 0 to 100,000 JPY. In the case of receiving 0 JPY, it means that the purchaser will not receive a subsidy. The purpose of this analysis is to compare the subsidy cost with the financial benefits through the promotion of AEB. The costs and benefits resulting from the analysis are discussed below.

In this paper, the following terms are employed

- Cost: the cost is defined as the initial subsidy amount, multiplied by the number of eligible AEB purchasers (i.e. elderly drivers).
- Benefit: the benefit is defined as the number of collision accidents decreased after the purchase and use of AEB-installed cars.

4.2 Analysis Procedure

For the cost-benefit analysis as modelled in this research, the following steps are applied:

- Step 1 : Estimating the number of elderly drivers and new car purchases within this population for each year in the period 2017 to 2021.
- Step 2 : Estimating the number of 70 year-old AEB-installed car purchasers corresponding with subsidy-receivers as calculated in step 1.
- Step 3 : Calculating the AEB penetration ratio corresponding to subsidy-receivers.
- Step 4 : Estimating the collision accident reduction coefficient from data results from step 3.
- Step 5 : Gauging the cost and benefit.

4.3 Methods to estimate the financial benefit

Fildes (2015) has investigated the decreasing rate of collision accidents after the use of AEB-installed cars through the means of meta-analysis. This study shows that AEB can decrease the number of collision accidents by 38 per cent. This parameter of the 38 per cent decreasing rate is for this research defined as the parameter for the calculation. In order to estimate the collision accident reduction coefficient, the parameter of the 38 per cent decreasing rate is multiplied with the AEB penetration ratio corresponding to the various subsidies.

In order to estimate the benefit by subsidy policy, the (4) equation is applied.

$$B_{Tj} = \frac{D_T}{D_0} \times L_0 \times \alpha \times \beta_j \tag{4}$$

where,

B_{Tj} : Benefit of policy at year T when subsidy is j thousand JPY.

(2017≦T≦2021) , (0≦j≦100,000)

D_T : The number of elderly drivers at T year. *[1]

D_0 : The number of elderly drivers at 2012 year. *[1]

L_0 : The financial loss of traffic collision accident by elderly drivers at 2012 year. *[1]

α : The decrease rate of collision accident by using AEB. *[2] (α=0.38)

β_j : The penetration ratio when subsidy is j JPY. *[2]

*[1] We use $\frac{D_T}{D_0} \times L_0$ to calculate the financial loss of collision accidents at year T. The reason why data is based on the year 2012, is because this data provides us of the most recent detailed information. This part means that financial loss of collision accidents at year T depends on the number of elderly drivers.

*[2] $\alpha \times \beta_j$ is defined as the collision accident reduction coefficient. α changes by the penetration ratio, as β_j is set as a weighting coefficient for α.

4.4 Methods to estimate the number of elderly drivers per year

Japan Automobile Manufacturers Association (2014) show that 58 per cent of elderly drivers aged 75 or above have intention of replacing their car with another. Therefore it can be defined that 5.8 per cent of elderly drivers will replace their car with a new one per year. To estimate the number of subjects that receive the subsidy, and the number of AEB purchasers corresponding with this policy, the equation as shown below is employed.

$$U_T = (W_T - A_T) \times 0.058 \tag{5}$$

where,

U_T : The number of subjects on subsidy policy in year T (in persons).

W_T : The number of 70 years old elderly drivers in year T (in persons).

A_T : The number of people who already have an AEB-installed car in year T (in persons).

0.058 : The ratio of replacing the car with new car.

$$G_{Tj} = P_m \times U_T \tag{6}$$

where,

G_{Tj} : The number of AEB purchasers on j subsidy at year T (in persons).

P_m : The ratio of purchases when the price of AEB is m. ($0 \leqq m \leqq 100{,}000$)

U_T : The number of subjects on subsidy policy in year T (in persons).

m : The price of AEB for the subjects.

$m = 100{,}000 - j$ (The defined AEB price is 100,000 JPY. j is the corresponding subsidy.)

4.5 The analysis of subsidy costs and benefits

The subsidy cost is estimated by multiplying the amount of subsidy and the number of AEB purchasers (7). The analysis of the costs and benefits is calculated by using equation (8). A policy duration of 5 years from 2017 to 2021 is considered. In order to take the social discount rate into account, the costs and benefits are calculated.

$$C_{Tj} = j \times G_{Tj} \tag{7}$$

where,

C_{Tj} : The amount of policy cost on j subsidy in year T (hundred million JPY).

j : The subsidy for the subjects (JPY).

G_{Tj} : The number of AEB purchasers on j subsidy in year T (in persons).

$$E_j = \sum_{i=0}^{4} \frac{B_{ij} - C_{ij}}{(1+r)^i} \tag{8}$$

where,

E_j : The amount of the accumulation effect because of the policy on j subsidy (hundred million JPY).

i : The years following after the policy is applied.

r : The social discount rate (r = 0.04)

4.6 Results deriving from the cost-benefit analysis

We estimated the financial effect for each subsidy through calculation the cost and benefit corresponding to the subsidy policy. The financial effect on each subsidy is shown in Figure 7. As can be seen in this figure, it appears that the higher the subsidy amount provided from the government, the more B-C decreases. In this calculation, a subsidy of up until 40,000 JPY shows a financial surplus. When the subsidy exceeds 40,000 JPY, a financial deficit will arise. In this case, when elderly drivers are considering the purchase of a new car, these systems should be promoted for elderly drivers on a subsidy up until 40,000 JPY. When a subject is highly considering the purchase of a new car with an AEB installation, the subsidy policy can contribute to a better promotion of these systems with the focus on elderly drivers than is the case without such a subsidy policy. It is also important, however, to consider approaches to promote AEB rather than focusing on subsidy policies only.

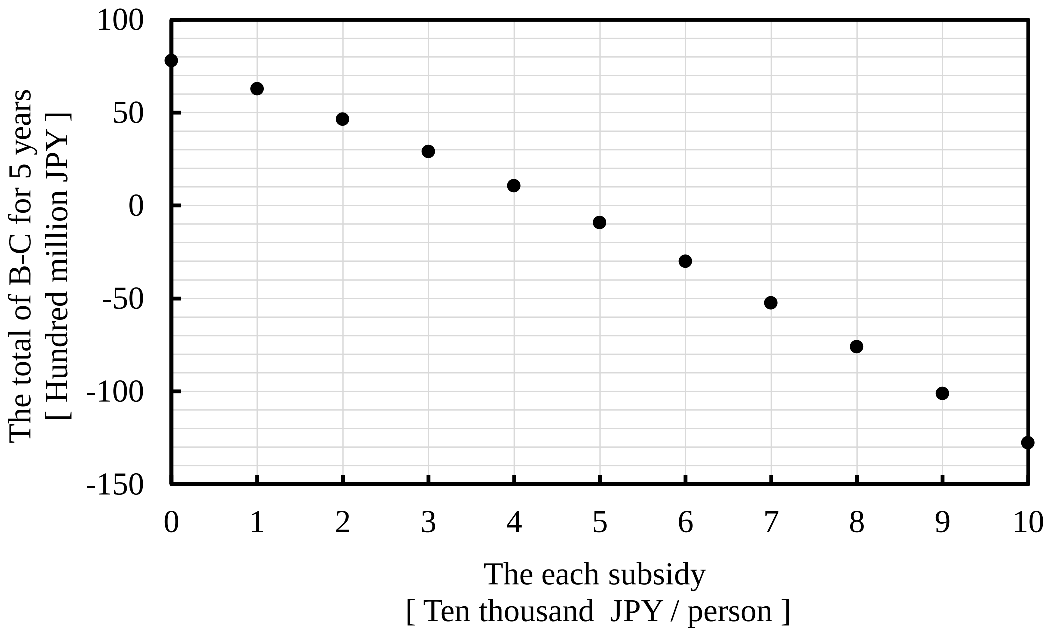

Figure 7 The calculation result for the subsidy policy for the period of five years

5. CONCLUSION

In this research, we have investigated the subsidy policy approach towards the promotion of AEB installed cars. As the result, the present study has demonstrated the financial effects of promoting subsidy-related AEB approaches. In the case of this study, especially when elderly drivers are considering purchasing a car with AEB installation, a subsidy of up until 40,000 JPY secures a financial surplus.

In this research, however, various parameters for this calculation are assumed. For example, the assumption was that the accident decrease rate due to the implementation of AEB installations according to Fildes (2015) could be applied for this calculation. In addition to this, the number of 70 year-old drivers for the coming five years is an estimated number based on previous collected data. In order to achieve a more accurate estimation in future research, it is necessary to improve these parameters.

This research has been conducted with the underlying motive that no previous research has covered this current social problem for the Japanese elderly population. This research, however, is not sufficient to solve this problem and requires further research on this topic. Two major improvement points can be drawn from this research. The first one concerns the accuracy of the calculations to estimate the number of elderly drivers using or considering the use of cars with AEB installation in the future. In this research, results derived and relied on one type of calculation. In order to evaluate this calculation, the use of different methods towards the calculations is necessary to increase the transparency, reliability, and replicability of this research. A second point of improvement regards the cost-benefit method. Assumed is that the financial benefits could compare with the costs directly theoretically, but it should be taken into consideration that in actual situations various financial benefit sorts are present. It is true, however, that some of the financial benefits can be compared with the costs, but there are many that are not and should not be compared with the costs (directly). In this calculation, this notion is neglected and all financial benefits are compared with the costs directly due to time restrictions. For the sake of strengthening these improvement points, thorough research on the circulation of money flows (i.e. in what way and to what extent certain costs and financial benefits can be compared) should be conducted. Understanding which financial benefits can be compared with the costs will enable highly transparent and reliable calculations.

6. REFERENCE

The General Insurance Association of Japan. (2012) Actual condition of traffic accident on the vehicle insurance data.

Cabinet Office of the Japanese Government. (2012), (2008) Report of the survey on Economic Analysis on the Damage and Loss of Road Traffic Accidents, March 2012, March 2008.

Jing JING, Hideo YAMANAKA, Eiji TAMURA. (2004) Measurement of Human Cost Of Trajfic Accidents Using CV And SG Survey Methods. INFRASTRUCTURE PLANNING REVIEW Vol. 21 (2004) P 137-144.

Matsushiro Eiichi. (2015) The countermeasure for the elderly drivers after Partial reform of the Road Traffic Act. Monthly periodical of traffic, October 2015, P4.

Fildes B, Keall M, Bos N, Lie A, Page Y, Pastor C, Pennisi L, Rizzi M, Thomas P, Tingvall C. (2015) Effectiveness of low speed autonomous emergency braking in real-world rear-end crashes. Accid Anal Prev. 2015 August.

Ministry of Internal Affairs and Communications. (2014) Population by Age (Single Year), Sex and Sex ratio - Total population, Japanese population. 2014 October 1.

Japan Automobile Manufacturers Association. (2014) Market Trend Survey: Passenger Vehicles.2014, P89.

Society of Automotive Engineers (SAE). (2016) autonomous car driving levels (SAE J3016). 2016 September.

Kagawa Prefecture Government. (2016) The subsidy policy for ASV purchaser of elderlydrivers."http://www.pref.kagawa.lg.jp/kurashi/koutsuu/asvfukyuu/index.htm#content". (in Japanese).

Toyota Prefecture Government. (2016) The elderly advanced safety vehicle buying expenses supplementary fund. (in Japanese).
Searson, D.

Ponte G, Hutchinson T, Anderson R, Lydon M. (2015) Emerging vehicle safety technologies and their potential benefits: discussion of expert opinions. Proceedings of the 2015 Australasian Road Safety Conference, 2015 / pp.1-11.

Metropolitan Police Department. (2015) Traffic Administration Section Statistics. The Traffic Accident Occurrence of elderly drivers. (in Japanese).