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by

Study on Emission Measurement of Vehicle on Road Based on Binomial Logit Model

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Abstract: This research attempts to evaluate emission measurement of on road vehicle. In this regard, the research develops failure probability model of vehicle emission test for passenger car which utilize binomial logit model. The model focuses on failure of CO and HC emission test for gasoline cars category and Opacity emission test for diesel-fuel cars category as dependent variables, while vehicle age, engine size, brand and type of the cars as independent variables. In order to implement the model, a survey to measure the vehicle emission was done to the two categories of passenger cars on road. Other information related to the characteristics of the cars sampling was collected in the survey. The survey was done at two main roads in Makassar City, one of the large cities in Indonesia. According to calculation result, the model gave good appearance. In further, the results showed that vehicle age became significant variable to determine the failure probability of vehicle emission test for CO and HC emission of gasoline cars category. As well as, engine size gave significant contribution to the failure of Opacity emission test for diesel-fuel cars category. The model provides good expectation to be tested in others cases and to develop failure model of vehicle emission test on macro scale in further studies.

Key Words: *Vehicle emission, CO, HC, binomial logit*

1. INTRODUCTION

Recently years, transportation sector is one of the bigger contributors to cause deterioration of environmental quality such as carbon dioxide and others air pollution, noise, water pollution, and physical encroachment in natural and cultural environment. Globally, motor vehicles emit 14% of fossil-fuel-based carbon dioxide, 50% to 60% of carbon monoxide and hydrocarbons, and about 30% of nitrogen oxides emissions (Hwang *et al.*, 2007). The emission reduction is one of main topics on discussion about solving problem to global warming and climate change issue. When a significant portion of the emission comes from transport sectors especially from vehicles, it is suggested that reduction of the emissions should be taken into consideration when road administrators control road traffic.

Address to the above concern, inspection and maintenance (I/M) program in order to controls air pollution from mobile source on road has been implemented (Simamora, 2006). The I/M program has been conducting in large cities in Indonesia such us Jabodetabek metropolitan area including Jakarta, Bogor, Depok, Tangerang, and Bekasi area (Sudarmanto *et al.*, 2007), Bandung, and Surabaya (Sudarmanto *et al.*, 2010). However, there have been ongoing debates related to effectiveness of the program in order to reduce the emissions (see, for example, Hubbard, 1997; Wasburn *et al.*, 2001; and Bin 2003).

Even though, some scholars had been elaborated the achievements results of the I/M program, in particular to grasp emission level of on road vehicle and test failure model of cars on vehicle emission test related to factors that caused of the failure. Sudarmanto *et al.* (2007) developed bivariate probit model in order to describe the failure of on-road emission measurement of passenger cars in Jakarta City, Indonesia. As well as, the model approach was used to motorcycles emission in Jakarta-Bandung-Surbaya, Indonesia (Sudarmanto *et al.*, 2010). Pujadas *et al.* (2004) also compare between experimental and calculated vehicle idle emission factors for Madrid fleet case. Another different approach model was developed by using logit and regression analysis models (Beydon *et al.*, 2006).

In order to contribute and to extend those researches, this paper attempts to grasp and to evaluate a result of a vehicle emission measurement as part of I/M program in Makassar City, Indonesia. In this regard, the paper develops binary logistic regression or binomial logit model approach to grasp the emission test failure of passenger car in idle condition on road.

The rest of this paper is organized as follows. Chapter 2 describes methodology of the research and development structure of the binomial logit model to test failure of vehicle emission test of passenger cars. Chapter 3 demonstrates the application of the model. The final chapter, Chapter 4 provides discussion about the result of the model implementation and conclusions.

2. METHODOLOGY AND MODEL STRUCTURE

2.1. Binomial logit model

Logistic regression model, it also called logit model, is one of models approaches to represent relationship between response (dependent) variable (Y) that categorical and one or more predictor variables (X) that not only categorical but also continual. When the dependent variable consist of two category, i.e. Y = 1 (success) and Y = 0 (fail), then binary logistic regression model could be applied, or it usually called binomial logit model.

Furthermore, the both categories of the dependent variable result in Y follow the Bernoulli distribution. The function of distribution probability of Y with parameter γ is stated as below:

$$P(Y = y) = \gamma^{y}(1-\gamma)^{1-y} \qquad (1)$$

Where $y = 0, 1$

Then, probabilities of each categories are $P(Y=1) = \gamma$ and $P(Y=0) = 1 - \gamma$ with $E(y) = \gamma$, for $0 \leq \gamma \leq 1$.

Generally, probability of the logistic regression that deal with *n* predictor variables could be formulated as follows.

$$P(y|x) = \frac{e^{-(\beta_0+\beta_1 x_1+\beta_2 x_2+...+\beta_n x_n)}}{1+e^{-(\beta_0+\beta_1 x_1+\beta_2 x_2+...+\beta_n x_n)}} \quad (2)$$

Where x_n is a vector of observed variables that represent relevant attributes to dependent variable, *Y*. β_n is parameter of x_n that should be estimated, and β_0 is a specific constant of the model.

2.2. Variable specification

Specification of variables that taking account in this research is divided into two categories, i.e. the failure result of emission test of cars as dependent variable, internal and external characteristics of cars as independent variables. There are two type of emission test result on assessment standard of vehicle emission, i.e. Y = 0 if the value emission of cars exceeds the standard value, it called test failure, and Y = 1 if the emission is still under the standard, it called test success or pass. Some characteristics of passenger cars related to operational capability, called internal characteristics, such as vehicle age, engine size capability, and travel distance that are indicated as determinant factors which contribute to concentration level of vehicle emission are introduced into the model as dependent variables. In order to consider external characteristics of the cars, two kinds of the characteristics, i.e. type of cars, and brand of cars are also included as variables in the model. The classification of each attitude and attribute of these variables are showed in Table 1.

Table 1 Categories of variables attitudes

Attitudes of Variables	Notation	Classifications
I. Dependent variables		
1. Assessment of emission test	Y_{Et}	Y = 0 if failure; Y = 1 if success
II. Internal attitude of car		
1. Vehicle age (years)	X_{Va}	a. ≤ 4 b. 5 – 8 c. 9 – 12 d. ≥ 13
2.Engine Size (cc)	X_{Es}	a. ≤ 1,000 b. 1,000 – 1,500 c. 1,500 – 2,000 d. ≥ 2,500
3. Travel Distance (km)	X_{Td}	-
III. External attitude of car		
1. Brand of cars	X_{Bc}	Gasoline car: Toyota; Suzuki; Daihatsu; Honda; Others Diesel-fuel car: Mitsubishi; Daihatsu; Toyota; Others
2. Type of cars	X_{Tc}	a. Sedan b. Non-sedan

2.3. Assessment Standard of Vehicle Emission

In order to assess a result of vehicle emission measurement is failure or pass, this research uses Indonesia Standard of vehicle emission that is launched on Traffic Regulation of Indonesia No. 22/2009. Table 2 shows the emission value standard of gasoline vehicle category, while Table 3 shows the standard of diesel fuel vehicle category.

Table 2 Gasoline vehicle emission standards in Indonesia

Classification of car	Car model (Year)	CO (%)	HC (ppm)
Carburetor car	Pre-1985	4.0	1000
	1986 - 1995	3.5	800
	1996 and newer	3.0	700
Injection Car	1986 - 1995	3.0	600
	1996 and newer	2.5	500

Source: Road Traffic Regulation of Indonesia No 22/2009

Table 3 Diesel fuel vehicle emission standards in Indonesia

Classification of car	Criterions	Max. Opacity (%)
Car model (Year)	Pre-1985	50
	1986 - 1996	45
	1997 and newer	40
Car Weight (Ton)	< 3.5	50
	> 3.5	60

Source: Road Traffic Regulation of Indonesia No 22/2009

2.4. Binomial logit model development for failure probability of vehicle emission test

According to the logit model approach where there are two results alternatives to happen as the mentioned above, the binomial logic model (BNL) was applied. In order to distinguish contribution of internal and external characteristics of cars, the model is divided into two models variation. The first model, Model-1, considers only internal characteristics of the cars, and the second model, Model-2, considers the both characteristics of the cars, internal and external. Regarding to Equation (2) and specification of variables in Table 1, the probability of test failure of vehicle emission for the both various models, $P_1(y|x)$ and $P_2(y|x)$, in term of the binomial logic model can be expressed as follows equation:

$$P_1(y|x) = \frac{e^{-(\beta_0+\beta_1 x_{Va}+\beta_2 x_{Es}+\beta_3 x_{Td})}}{1+e^{-(\beta_0+\beta_1 x_{Va}+\beta_2 x_{Es}+\beta_3 x_{Td})}} \tag{3}$$

$$P_2(y|x) = \frac{e^{-(\beta_0+\beta_1 x_{Va}+\beta_2 x_{Es}+\beta_3 x_{Td}+\beta_4 x_{Bc}+\beta_5 x_{Tc})}}{1+e^{-(\beta_0+\beta_1 x_{Va}+\beta_2 x_{Es}+\beta_3 x_{Td}+\beta_4 x_{Bc}+\beta_5 x_{Tc})}} \tag{4}$$

Where β_0 is constant of the model, $\beta_1 \ldots \beta_n$ are parameters of each variable that mentioned in the Table 1 respectively.

2.5. Parameters estimation of the binomial logit model

This research adopted maximum *likelihood* theory in order to estimate the parameter values of the binomial logit model. The procedure to estimate maximum *likelihood* value involves development of a joint probability density function of the observed sample, called the *likelihood function*, through estimation of parameter values which maximize the *likelihood function*. The *likelihood function* in case T observation face j alternatives result is defined as follows (Koppelman and Bhat, 2006):

$$L(\beta) = \prod_{\forall_t \in T} \prod_{\forall_j \in j} \left(P_{jt}(\beta)\right)^{\delta_{jt}} \tag{5}$$

Where δ_{jt} is chose indicator (=1 if j is happen by observation t and 0, otherwise) and P_{jt} is the probability when the observation t give event j. The solution in order to maximize the *log-likelihood function* is the second derivation of the function with respect to β. In this research, the parameters values of the model are estimated by using statistical package software, i.e. SPSS Version 12.0.

3. APPLICATION OF MODEL

3.1 Implementation of survey

A survey to measure emission level of vehicle on site was conducted at two main roads, Sudirman Street and Alauddin Street, in Makassar City, one of large cities in Indonesia (One of the biggest countries in Asian Developing Countries) as showed by Figure 1. The survey used vehicle emission test equipments in order to measure CO and HC emission level of gasoline passenger car category, and Opacity emission level of diesel-fuel passenger car category. Other information of car characteristics for the both categories was collected in the survey by using interview method approach to user or owner of the cars sampling. The information include vehicle age, engine size, travel distance, brand and type of car. Table 4 shows the number of passenger car sampling that chose randomly during the survey.

Table 4 Number of sampling

Classification of car		Survey location (Street)		Number of data
		Alauddin	Sudirman	
Gasoline car	Non-sedan	191	125	316
	Sedan	47	18	65
Diesel-fuel car	Non-sedan	32	67	99
	Sedan	25	27	52
Total		295	237	532

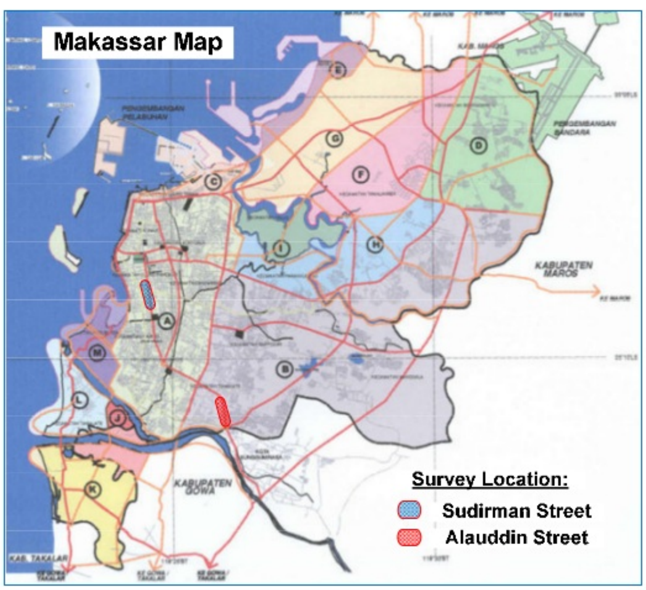

Figure 1 Survey location of vehicle emission test

The number of car sample at the both locations for gasoline car category is about 381 passenger car that include 316 and 65 passenger cars of non-sedan and sedan car type respectively. For the diesel-fuel car category, there are 99 passenger cars of non-sedan car type and 52 passenger cars of sedan car type.

3.2 Results of the Survey

The survey results to emission level measurement of CO and HC emission on gasoline car category and Opacity emission on diesel-fuel car category are described by Figure 2, Figure 3, and Figure 4 respectively. In addition, failure assessment results of vehicle emission test related to vehicle age and engine size characteristics of the both cars categories by using the Indonesia's Emission Standard are showed in Figure 5 and Figure 6 respectively.

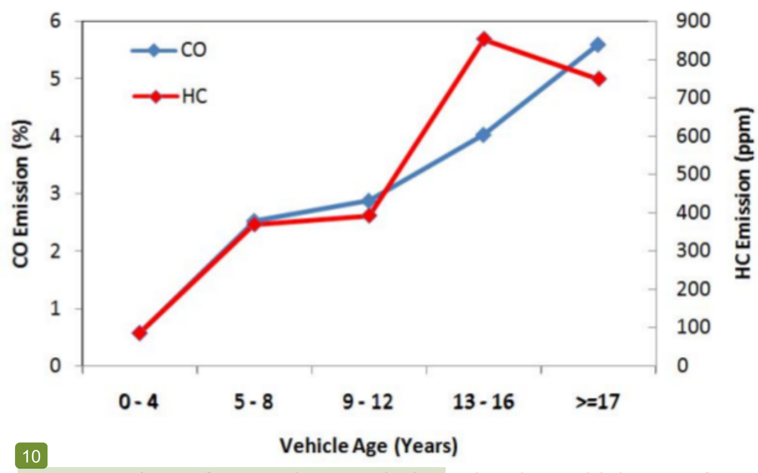

Figure 2 Average values of CO and HC emission related to vehicle age of gasoline car

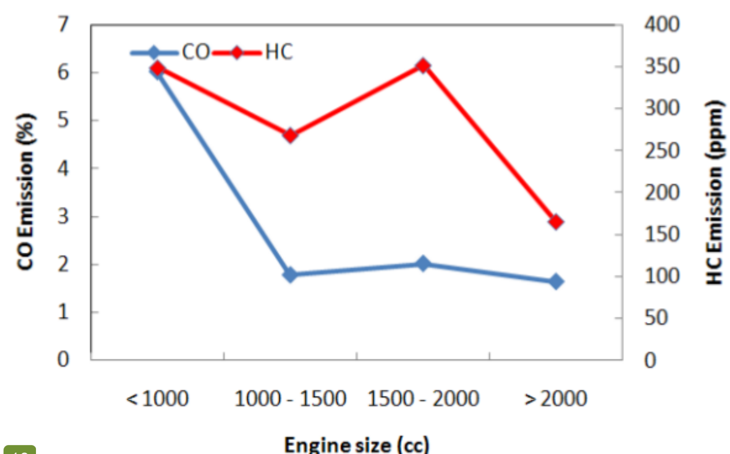

Figure 3 Average values of CO and HC emission related to engine size of gasoline car

Figure 2 shows that concentration of CO and HC emission of gasoline cars increase according to increasing of vehicle age of the cars. However, the concentration level of HC emission decreases slightly when the vehicle age of the cars is equal or more than seventeen years.

Figure 3 describes that generally increasing of engine size capacity decrease level of CO and HC emission, yet the both types of emission are slightly increasing on the cars which have engine size 1,500-2,000 cc.

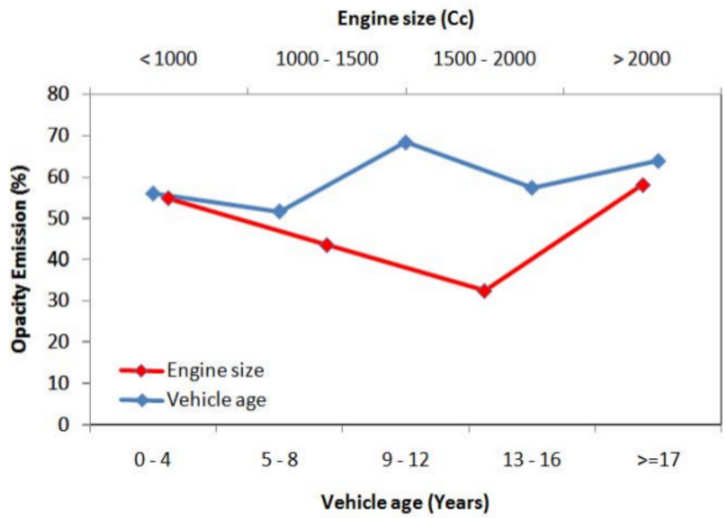

Figure 4 Average values of Opacity emission related to age and engine size of diesel-fuel car

Figure 4 shows that the concentration of Opacity emission increase generally to follow rise of vehicle age of diesel-fuel cars. In contrary, level of the emission decrease according to increasing of engine size capacity of the cars, except for the cars with engine size are more than 2,000 cc.

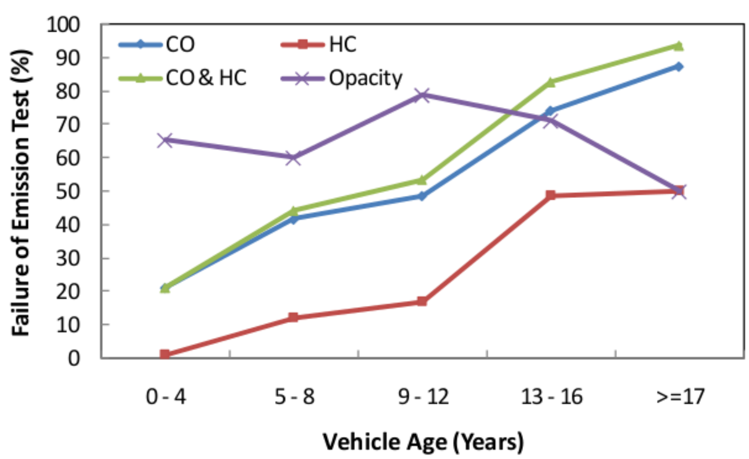

Figure 5 Failure of CO, HC and Opacity emission test related to vehicle age of car

Figure 5 shows general trend that failure of CO, HC, and the both emission test of gasoline cars category to standard value of the emissions rise to follow increasing of vehicle age of the cars. Number of CO emission test failure of the cars is higher than failure of HC emission test. It means that CO is more significant than HC emission to determine a gasoline cars pass or failure of emission test. In other view, the Figure shows that number of Opacity emission test failure of diesel-fuel cars fluctuate in increasing of vehicle age of the cars.

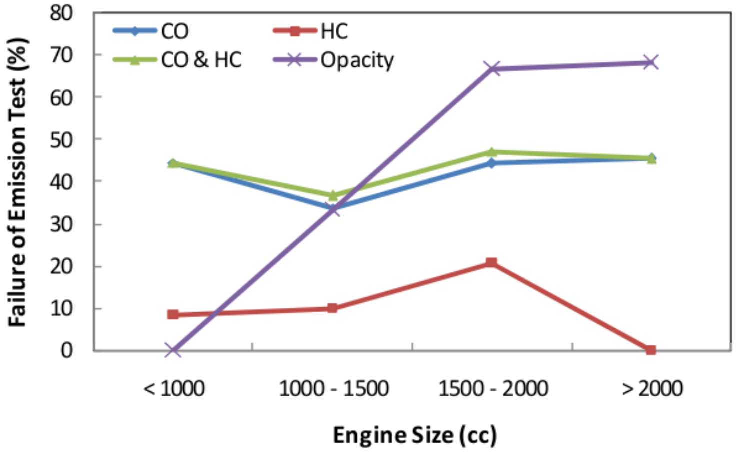

Figure 6 Failure of CO, HC and Opacity emission test related to engine size of car

Figure 6 shows contrary trend of the vehicle emission test failure related to engine size capacity of the both cars categories. The Figure shows that number of cars of failure on CO, HC, and the both emission test are fluctuation in increasing of engine size capacity of gasoline car category, while the number of the failure to Opacity emission test of diesel-fuel cars category incline according to increasing of the car engine size. Even though, CO emission also becomes determiner in failure of emission test of gasoline passenger car category in comparing to HC emission.

3.3. Parameter Estimation and Model Validation

Calibration and validation of the binomial logit model in order to estimate the parameters values of the logit model for failure probability of emission test were done with consider results of testing in view of statistics. There were two kinds of statistical test which were conducted, i.e. significant test (i.e. *p* value) in order to evaluate contribution of each variable itself to the model and goodness of fit statistic test in order to validate the values of the parameters model. Table 5, Table 6, Table 7, and Table 8 show the parameters values of the failure model of vehicle emission test on test failure of CO, HC, CO and HC, and Opacity emissions respectively.

Table 5 Parameter values of gasoline car category for test failure of CO

Variable	Symbols	Parameters of Model 1		Parameters of Model 2	
		Value	*p*(value)	Value	*p*(value)
Vehicle age (X_{Va})	β_1	-0.218	0.000	-0.221	0.000
Engine size (X_{Es})	β_2	0.001	0.160	0.001	0.134
Travel distance X_{Td}	β_3	0.000	0.143	0.000	0.165
Type of car (X_{Tc})	β_4	-	-	-0.338	0.544
Brand of car (X_{Bc})	β_5	-	-	-0.016	0.927
Constant	β_0	1.494	0.116	1.683	0.130
Number of data	n	191		191	
Hit ratio (%)		81.7		81.7	
Likelihood ratio	ρ^2	0.187		0.189	

Table 6 Parameter values of gasoline car category for test failure of HC

Variable	Symbols	Parameters of Model 1		Parameters of Model 2	
		Value	p(value)	Value	p(value)
Vehicle age (X_{Va})	β_1	-0.242	0.000	-0.249	0.000
Engine size (X_{Es})	β_2	0.000	0.801	0.001	0.132
Travel distance X_{Td}	β_3	0.000	0.068	0.000	0.536
Type of car (X_{Tc})	β_4	-	-	-0.812	0.357
Brand of car (X_{Bc})	β_5	-	-	0.068	0.792
Constant	β_0	4.097	0.002	4.200	0.010
Number of data	n	191		191	
Hit ratio (%)		87.4		88.0	
Likelihood ratio	ρ^2	0.258		0.268	

Table 7 Parameter values of gasoline car category for test failure of CO and HC

Variable	Symbols	Parameters of Model 1		Parameters of Model 2	
		Value	p(value)	Value	p(value)
Vehicle age (X_{Va})	β_1	-0.271	0.000	-0.279	0.000
Engine size (X_{Es})	β_2	0.001	0.067	0.001	0.052
Travel distance X_{Td}	β_3	0.000	0.225	0.000	0.241
Type of car (X_{Tc})	β_4	-	-	-0.544	0.332
Brand of car (X_{Bc})	β_5	-	-	-0.088	0.613
Constant	β_0	1.167	0.225	1.638	0.143
Number of data	n	191		191	
Hit ratio (%)		81.7		82.7	
Likelihood ratio	ρ^2	0.238		0.242	

Table 8 Parameter values of diesel-fuel car category for test failure of Opacity

Variable	Symbols	Parameters of Model 1		Parameters of Model 2	
		Value	p(value)	Value	p(value)
Vehicle age (X_{Va})	β_1	-0.014	0.789	-0.031	0.559
Engine size (X_{Es})	β_2	0.000	0.630	0.000	0.774
Travel distance X_{Td}	β_3	0.000	0.788	0.000	0.674
Type of car (X_{Tc})	β_4	-	-	-0.124	0.842
Brand of car (X_{Bc})	β_5	-	-	0.535	0.206
Constant	β_0	-0.837	0.679	-0.656	0.766
Number of data	n	86		86	
Hit ratio (%)		50.0		62.8	
Likelihood ratio	ρ^2	0.004		0.025	

Those Tables show the results of significant test of models variables by using p value test. The results show that vehicle age of the gasoline cars category influenced the model significantly on the all types of emission test failure, CO, HC, and the both emissions. This result is indicated by the p value of the variable less than 0.05 (it means significance level under 5%). However, the vehicle age is not significant to influence test failure on Opacity emission of diesel-fuel car category. As well as the others variables give p value more than 0.05 which means those variables is not enough significant to contribute to the models.

In order to validate of the parameter values of the models, goodness of fit statistic test was conducted by using two indicators, i.e. *log-likelihood* ratio index, ρ^2, and hit ratio. The *log-likelihood* ratio index is used to measure how well the model performance with its estimated parameter is compared to the model in which all the parameters are zero (which is usually equivalent to having no model at all). While, the "percent correctly predicted" methods or usually it is called hit ratio is the statistic method that calculated by indentifying for each sampled probability of test failure according to the estimated model, and determining whether or not this was the failure actually happen.

The result of both ratios as is showed by the Table 5 gives values 0.187 and 81.7% of ρ^2 and hit ratio respectively for Model-1 of test failure of CO emission, as well as 0.189 and 81.7% of ρ^2 and hit ratio respectively for Model-2 of the test failure of CO emission. Table 6 shows that ρ^2 and hit ratio of the Model-1 and Model-2 respectively are 0.258 and 87.4%, and 0.268 and 88.0% for the test failure of HC emission test. Table 7 gives ρ^2 and hit ratio of the Model-1 and Model-2 respectively about 0.238 and 81.7%, and 0.242 and 82.7% for the test failure of CO and HC emission test. Table 8 shows that ρ^2 and hit ratio of the Model-1 and Model-2 respectively are 0.004 and 50.0%, and 0.025 and 62.8% for the test failure of Opacity emission test of diesel-fuel cars category. Due to the ρ^2 values of gasoline cars category is more than 0.2 (minimum value to asses that model is good) except CO test failure which slightly down of 0.2, and the hit ratios have enough large percent correctly to predicted the test failure (more than 80%), thus the binomial logit model which is used to represent the phenomena of test failure of vehicle emission test has good appearance. In other side, the ρ^2 of the both models of diesel-fuel cars category indicate small values that means the models are not enough to predict the test failure of Opacity emission. Fortunately, the hit ratio of the models is enough significant (more than 60%) in particular on Model-2 of diesel-fuel cars category.

Comprehensively, Model-2 that considered all types of variables is slightly better than Model-1 on the both cars categories and the all types of emission test.

4. DISCUSSIONS AND CONCLUSIONS

4.1 Discussions

According to the results of vehicle emission test survey and calculation of the binomial logit model emission test failure, some important points could be discussed as below.

Vehicle age of passenger car plays important role to concentration level of CO and HC emission of gasoline cars category. The results show that the increasing of vehicle age leads to the increasing of emission concentration for the both types of emissions. In further, the increasing of the vehicle age also arise the failure probability on vehicle emission test. In other side, characteristic of engine size capacity shows significant contribution to increasing of number of diesel-fuel cars that failure in Opacity emission test. However, the variable is un-significantly to show the influence of the emission test failure on the binomial logit model.

Those phenomena could lead to encourage important role for government in order to control the emission level of air pollution as part of inspection and maintenance (I/M) program. The government should restrict number of cars that may operate on road, particularly to the age of cars, as well as constraining in using of passenger cars that have large engine size capacity.

4.2 Conclusions

In this paper, the authors have developed a model to describe the emission test failure of on road vehicle. The model is derived from binomial logit model assumptions, where some factors such us vehicle age, engine size, travel distance, brand and type of cars are introduced as independent variables in order to construct the model. In this regard, failure of emission test comparing to Emission Standard of Indonesia become dependent variable. There are four types of emission test result that are considered as dependent variables in this research, i.e. CO emission, HC emission, the both emission (CO and HC) for gasoline cars category, and Opacity emission for diesel-fuel cars category.

The model was applied to passenger cars on road at two main roads in Makassar City, Indonesia. A survey was conducted in order to measure vehicle emission and characteristics of the cars. The survey measured CO and HC emission for gasoline cars category, as well as Opacity emission for diesel-fuel cars category. Information related to vehicle age, engine size, and others characteristics of the both cars categories were also collected in the survey. By using the binomial logit model approach, the failure probability model of vehicle emission test of passenger cars on road was represented with good appearance. The results show that vehicle age becomes significant variable to determine the failure of vehicle emission of gasoline passenger car category. As well as, engine size is more significant to contribute on increasing number of diesel-fuel car category on test failure of Opacity emission test.

In brief, the model with estimated parameters can be tested further by applying to others situations, and also can be expected to provide a basis in order to find more advanced and expanded models in macro scale in further studies.

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