

Impact on The Existence of New Toll Road Section Due to Mode Choice Between Transportation Mode Using Modal Split Methods (Case Study: Tulungagung-Surabaya)

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Abstract. The Java-trans highway is almost connected from west to the east of Java Island and now, there is a new section that will be built, those are Kertosono-Kediri section and Kediri-Tulungagung section. The Impact from these construction in the future will shorten the travel time. Tulungagung-Surabaya buses which use the highway only take 3-3,5 hours of travel time with route combinations between national and highway roads. This research aims to find the model of mode choice proportion between bus, non-toll bus, cars, and train due to Tulungagung-Surabaya's highways in 2023. The travel attributes used in this research are travel time and travel cost between bus, non-toll bus, cars, and train. Then, the model could predict the mode choice proportion in the future, after the construction finished. The method for modelling is modal split which uses power function (α) and deterrence function (β). Mode choice model that is used is a modal split with power function (α) with NMAE values 0,5284 which is close to 0. The interpretation of NMAE value is the smaller the value the better the model, because the model would represent the existing condition in which the model could predict future condition.

Keywords: modal split, mode choice, NMAE

1. Introduction

One of the land connections to Surabaya city and another city is toll-road. Toll road which connects Surabaya city is now connected from Jakarta, Malang, Madura, and Situbondo. According to the media [1] in 2023 the toll road from Tulungagung to Surabaya will be open. Today, the section construction from Kertosono to Kediri is in progress. Soon, the section will continue from Kediri to Tulungagung. The existence of a new section from Kertosono to Tulungagung directly would change the pattern of mode choice [2].

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There are a lot of options to go to Surabaya from Tulungagung. For example, there are 2 types of buses which use toll roads and non-toll roads. Between those 2 options are given choices about travel time and travel cost. Bus that uses a toll road just needs 3-3.5 hours to do one trip from Tulungagung to Surabaya. Otherwise, buses that do not use toll-roads need about 3.5-4 hours or one trip from Tulungagung to Surabaya. Especially after Tulungagung to Surabaya is fully connected with a toll-road. Every transportation mode will go faster than before. The differentiation of travel time, travel distance, and travel cost would change the mode choice between transportation modes. In this research, the subject for this mode choice purpose are bus, private car, and train.

Mode choice is a part of decision making in transportation modelling that inflicts a lot of identifications, such as a relevant mode transportation performance, appropriate mode choice, level of service, and evaluation of mode performance [3]. The owner or developer focuses on travel cost and time [4].

The main problem in this research is the existence of a toll road new section between Kertosono to Tulungagung as a new competition that causes a different mode choice between bus, car, and train. The aspect of mode choice that is used in this research is the differentiation between travel cost and travel time. This research aims to get a model for mode choice between bus, car, and train after a new section of Kertosono-Tulungagung finishes in 2023RD.

2. Material and Methods

This section contains work steps that would be used to guide this research. This section aims to make this research go well, systematically, and could reach the goals.

2.1. Time and Location

This research is located in Gayatri's Bus Station and Tulungagung Train Stop in Tulungagung district. This research is done in a couple days (weekdays and weekend) for doing a survey. Because of pandemic COVID-19, the survey uses google form.

Table 1. Scenarios which use for Stated Preferences survey

SCENARIOS	
X1	If economic bus or non-toll bus still exist and did not use toll-road
X2	If trains still exist without travel time and travel cost changes.
X3	VIP bus or toll bus use combination routes like Tulungagung-Kertosono not using toll-road and Kertosono-Surabaya using toll road.
X4	If VIP bus or toll bus use combination routes like Tulungagung-Kediri not using toll-road and Kediri-Surabaya using toll road.
X5	If VIP bus or toll bus directly goes from Tulungagung to Surabaya using toll road.
X6	If cars use combination routes like Tulungagung-Kertosono not using toll-road and Kertosono-Surabaya using toll road.
X7	If cars use combination routes like Tulungagung-Kediri not using toll-road and Kediri-Surabaya using toll roads.
X8	If a car directly goes from Tulungagung to Surabaya using a toll road.

2.2. Research Survey

In this research, the method of survey is stated and revealed preferences. Revealed preferences and Stated preferences are included in the Discrete Choice Experimental (DCE) method. The preparation of the DCE should be carried out in 3 phases. The first phase is conducting a literature review and survey at the research site which aims to obtain the variables on the questionnaire that have been used in the past in the analysis of mode selection. The second phase is to conduct interviews with experts in mode selection analysis with the aim of controlling the feasibility of the questionnaire. The last phase is conducting an interview experiment with respondents with the aim of adjusting the variables that have

been used with field conditions [5]. Stated preferences methods made based on hypotheses which adjusted with transportation users [6]. Hypothesis made based on determined generalised cost according to mode route. Attributes which are used in hypothesis construction are based on travel cost, travel time, and variation of route. All the scenarios based on years of 2023rd after a new section of toll road was already built. The following table which is used for the scenario for stated preferences method is shown on Table 1.

2.3. Analysis of Data

Collected data which was obtained from the stated preferences survey is being processed and then being analysed using statistical methods. This research uses modal split with power and difference function to get a model of Tulungagung-Surabaya mode choice proportion between modes.

2.3.1. Deciding Mode Transportation Generalised Cost. Cost determination is based on type of mode. For passenger car, the generalised cost are toll road cost, vehicle operation cost, and value of time. Otherwise, for public transportation, generalised cost which used are ticket cost and value of time. If written in the form of formula is as follows:

$$\text{Generalised cost} = a_0 + a_1x_1 + a_2x_2$$

With,

- a_0 = toll cost (Rp)
- a_1 = vehicle operation cost (Rp/km)
- x_1 = travel distance (km)
- a_2 = value of time (Rp/hours)
- x_2 = travel time (hours)

For public transport generalised cost is as follows:

$$\text{Generalised cost} = a_0 + a_1x_1$$

With,

- a_0 = ticket cost (Rp)
- a_1 = value of time (Rp/hours)
- x_1 = travel time (minutes)

2.3.2. Mode Choice Using Mode Split Methods. Mode choice model in this research is using modal split with two different kind of function that is power function (α) and difference function (β) which is written in this form of formula [7]:

Power function (α)

$$P_{Mode1} = \frac{C_{Mode1}^{-\alpha_{Mode1}}}{C_{Mode1}^{-\alpha_{Mode1}} + C_{Mode2}^{-\alpha_{Mode2}} + C_{Mode3}^{-\alpha_{Mode3}} + C_{Mode4}^{-\alpha_{Mode4}}}$$

Deterrence function (β)

$$P_{Mode1} = \frac{EXP(-\beta_{Mode1} \cdot C_{Mode1})}{EXP(-\beta_{Mode1} \cdot C_{Mode1}) + EXP(-\beta_{Mode2} \cdot C_{Mode2}) + EXP(-\beta_{Mode3} \cdot C_{Mode3}) + EXP(-\beta_{Mode4} \cdot C_{Mode4})}$$

In the beginning of analysis is using assumption of the power function, $\alpha = 1$ and the deterrence function, $\beta = 0,00001$. Then, the proportion value of mode choice with those assumption is minus by the proportion of existing mode choice, in this case the value of proportion of existing mode choice is got from survey. The deviation value between model assumption and existing is absolute. Then, add up

all the values of the deviation and find the average. This average value we call it MAE indicator, then the MAE value divides with the average of existing mode choice proportion. The result is NMAE. NMAE is an error indicator of the model. The smaller the value, the model can be said to be close to the existing condition. To get the model close to the existing condition, the function value should be calibrated to get the minimum value of NMAE.

The calibration is using a tool from Excel which is named Excel Solver. The method in excel solver that is used is GRG Nonlinear. The steps to use the excel solver are:

1. Load the excel solver by Option > File > Add-In > Add-In Excel > To > Add-In Solver then tick the Add-in Solver option.
2. Open the excel solver by clicking Data > Excel Solver, then the excel solver window should appear.
3. Choosing the NMAE and put it in the “Set Objective” column.
4. Choosing “Min ” or minimal parameters to get the smallest possibilities of NMAE value.
5. Choosing the function value (power or deterrence function) and put it in the “By Changing Variable Cells” column that soon will change by itself because of the analysis. In this step, the function values are calibrated.
6. Choosing “GRG Nonlinear” method of solving in the “Solving Method” column.
7. Final step, click on the “Solve” to find the calibrated value of difference or power function,
8. After the analysis completed, the function value will be changed and the value will be used in the model or the value has been calibrated.

3. Result and Discussion

3.1. Number of Samples

Defining the number of samples in this research is using the Slovin formula. The population being used is the population of public transportation users in Tulungagung. The number of samples is based on average daily passenger [7] but in this research is used average annual passenger which give the same result like average daily passenger.

The average of annual passenger number of public transportation users in Tulungagung are 2.417.401. *e* value or error value is 10% and the number of samples are:

$$n = \frac{N}{1 + Ne^2} = \frac{2417401}{1 + 2417401(0.1)^2} = 100 \text{ sample}$$

From Slovin formula we got 100 minimum samples. But, in this research we used 200 samples, in case to avoid invalidity.

Table 2. Generalised cost of Tulungagung-Surabaya route

O-D	Distance to Toll Gate (km)	Toll Road Distance (km)	Bus Ticket	Toll Cost Car	Travel time (hours)	
					Car	Bus
Tulungagung-Surabaya	4.5	152.65	IDR 50,000	IDR 149,007	2.02	2.06
Value of Time		Vehicle Operational Cost	VoT x Distances		Generalised Cost	
Car	Bus		Car	Bus	Car	Bus
IDR 18,269	IDR 20,471	IDR 2,780	IDR 36,915	IDR 42,132	IDR 623,000	IDR 93,000

3.2. Generalised Cost of Tulungagung-Surabaya Route

In the years of 2023rd, after all the sections connected, calculation of generalised cost is shown in the Table 2. The generalised cost calculation divided into 3 calculation scenarios, i.e., GC Tulungagung-

Surabaya, Tulungagung-Kertosono-Surabaya, and Tulungagung-Kediri-Surabaya. Travel speed assumption is 60 km/hours.

Table 3. Generalised cost of Tulungagung-Kertosono-Surabaya route

O-D	Distance to Toll Gate (km)	Toll Road Distance (km)	Bus Ticket	Toll Cost		Travel time (hours)	
				Car	Car	Car	Bus
Tulungagung-Kertosono-Surabaya	64.6	80.75	Rp30,000	Rp85,060	2.62	3.16	
Value of Time		Vehicle Operational Cost	VoT x Distances		Generalised Cost		
Car	Bus		Car	Bus	Car	Express Bus	
Rp18,269	Rp20,471	Rp2,780	Rp47,945	Rp64,744	Rp538,000	Rp95,000	

Table 4. Generalised cost of Train and Non-Toll Bus

O-D	Travel Distances (km)	Train Ticket	Travel Time (Hours)	Value of Time	Generalised Cost
			Train		
Tulungagung-Surabaya (Train)	143	IDR 18,000	5.11	IDR 9,320	IDR 66,000
O-D	Travel Distances (km)	Bus Ticket	Travel Time (Hours)	Value of Time	Generalised Cost
			Bus		
Tulungagung-Surabaya (non-toll bus)	145.35	IDR 25,000	3.63	IDR 20,471	IDR 100,000

3.3. Characteristic of Transportation User

The characteristics of Tulungagung-Surabaya transportation users are obtained from a survey. We got 201 respondents and the characteristic are divided into sex, age, last education, job, salary, trip purposes, and vehicle ownership.

Sex characteristic of transportation user is dominated by female with 111 people and another 90 people is male. Then, age characteristic is dominated by 21-30 years old with 149 people or 74% and the smallest user is 41-50 years old with 6 people or 6%. The last user education is dominated by bachelor degree with 102 people or 51% and the smallest user is master degree job with 7 people or 3% from total data. The job background is dominated by a student with 85 people or 42% and the smallest user is professional job with 4 people of 2% from total data. Then, the user characteristic about salary is dominated by user with un-salary user or jobless with 63 people or 31% and the smallest user is 6-8 million rupiah per month with 7 people or 4% from total data Next is about the purpose of the trip. It is dominated by family or social purpose with 65 people or 32% and the smallest respondent is about business trip with 14 people or 7% from total data.

3.4. Mode Choice Using Modal Split

In the beginning of the mode choice analysis is data grouping. The purpose of data grouping is for determining the total of origin-destination respondents. But, in this research, we do not use origin destination as a grouping method, because there is too much origin and destination that makes the data would not group. This research uses travel distance from home to the mode location and from the drop point to final destination. The data is categorical and makes it into the average value of distance. The distance and average are shown in Table 5 below.

Table 5. Data grouping categories

Distance Categories	Average
Less than 3 km	3 km
3-5 km	4 km
5-7 km	6 km
7-10 km	8.5 km
10-12 km	11 km
More than 12 km	12 km

The next analysis is calculating extra cost that will add into the generalised cost in every mode. This additional cost is a cost for doing a trip from home to the mode location and from the drop point to final destination.

The value of time being used is the value of time of the motorcycle. Because, from the survey result, the most vehicle that has been used for a trip from home to the mode location and from the drop point to final destination is a motorcycle. Travel speed assumption is about 40 km/hours then from it, we got the travel time. Then, the generalised cost is travel time times value of time.

Table 6. Extra cost for generalised cost

Categories of distance from origin to mode location (A)	Categories of distance from the drop point to destination (B)	Average of (A)	VoT (Rp/minutes)	Travel time (minutes)	VoT x tt (A)	Average of (B)	Travel time (minutes)	VoT x tt (B)
10-12 km	10-12 km	11	221.51	16.5	IDR 3,655	11	16.5	IDR 3,655
10-12 km	5-7 km	11	221.51	16.5	IDR 3,655	6	9	IDR 1,994
10-12 km	7-10 km	11	221.51	16.5	IDR 3,655	8.5	12.75	IDR 2,824
10-12 km	Less than 3 km	11	221.51	16.5	IDR 3,655	3	4.5	IDR 997
3-5 km	10-12 km	4	221.51	6	IDR 1,329	11	16.5	IDR 3,655
3-5 km	3-5 km	4	221.51	6	IDR 1,329	4	6	IDR 1,329
3-5 km	5-7 km	4	221.51	6	IDR 1,329	6	9	IDR 1,994
3-5 km	7-10 km	4	221.51	6	IDR 1,329	8.5	12.75	IDR 2,824
3-5 km	Less than 3 km	4	221.51	6	IDR 1,329	3	4.5	IDR 997
3-5 km	More than 12 km	4	221.51	6	IDR 1,329	12	18	IDR 3,987
5-7 km	10-12 km	6	221.51	9	IDR 1,994	11	16.5	IDR 3,655
5-7 km	3-5 km	6	221.51	9	IDR 1,994	4	6	IDR 1,329
5-7 km	5-7 km	6	221.51	9	IDR 1,994	6	9	IDR 1,994
5-7 km	7-10 km	6	221.51	9	IDR 1,994	8.5	12.75	IDR 2,824
5-7 km	Less than 3 km	6	221.51	9	IDR 1,994	3	4.5	IDR 997
5-7 km	More than 12 km	6	221.51	9	IDR 1,994	12	18	IDR 3,987
7-10 km	10-12 km	8.5	221.51	12.75	IDR 2,824	11	16.5	IDR 3,655
7-10 km	3-5 km	8.5	221.51	12.75	IDR 2,824	4	6	IDR 1,329
7-10 km	5-7 km	8.5	221.51	12.75	IDR 2,824	6	9	IDR 1,994
7-10 km	7-10 km	8.5	221.51	12.75	IDR 2,824	8.5	12.75	IDR 2,824
7-10 km	More than 12 km	8.5	221.51	12.75	IDR 2,824	12	18	IDR 3,987
Less than 3 km	10-12 km	3	221.51	4.5	IDR 997	11	16.5	IDR 3,655
Less than 3 km	3-5 km	3	221.51	4.5	IDR 997	4	6	IDR 1,329
Less than 3 km	5-7 km	3	221.51	4.5	IDR 997	6	9	IDR 1,994
Less than 3 km	7-10 km	3	221.51	4.5	IDR 997	8.5	12.75	IDR 2,824
Less than 3 km	Less than 3 km	3	221.51	4.5	IDR 997	3	4.5	IDR 997
More than 12 km	10-12 km	12	221.51	18	IDR 3,987	11	16.5	IDR 3,655
More than 12 km	3-5 km	12	221.51	18	IDR 3,987	4	6	IDR 1,329
More than 12 km	5-7 km	12	221.51	18	IDR 3,987	6	9	IDR 1,994
More than 12 km	7-10 km	12	221.51	18	IDR 3,987	8.5	12.75	IDR 2,824
More than 12 km	Less than 3 km	12	221.51	18	IDR 3,987	3	4.5	IDR 997
More than 12 km	More than 12 km	12	221.51	18	IDR 3,987	12	18	IDR 3,987

The extra cost could be a factor for a mode choice. Research in Barcelona stated if extra cost influences the mode choice. When travel cost for car increase, there is a probability for rail based transportation increase by a passenger than a car [8]

The extra cost above will be added into the generalized cost in every scenario. For example, the 3rd scenarios said “If toll-bus uses combination route Tulungagung to Kertosono without toll road and Kertosono to Surabaya uses toll road”, then the generalised cost used is generalised cost for Tulungagung-Kertosono-Surabaya like Table 3 above. Then, add the extra cost for each group data. Details about the calculation are shown below.

- The average origin to the mode location (A) = 11 km
- VoT = IDR 222/minute
- Average travel time (40 km/jam) = 16.5 minutes
- VoT x travel time (A) = IDR 3,655
- The average distance from drop point to destination (B) = 6 km
- Average travel time (40 km/jam) = 9 minutes
- VoT x travel time (B) = IDR 1,994

According to table 3, the generalised cost of every mode is shown below.

- Generalised cost toll bus = IDR 95,000
- Generalised cost non-toll bus = IDR 100,000
- Generalised cost car = IDR 538,000
- Generalised cost train = IDR 66,000

With extra cost, the final generalised cost is shown below

- Generalised cost toll bus + extra cost = IDR 100,649
- Generalised cost non-toll bus + extra cost = IDR 105,649
- Generalised cost car + extra cost = IDR 543,649
- Generalised cost train + extra cost = IDR 71,649

Calculation on the above is just for one data in one scenario. There are 201 respondents times 8 scenarios, so there are 1500 results from a calculation like the above.

The value of generalised cost + extra cost on the above later will be used to determine the model of mode choice. First, we need to determine the value of power (α) and difference (β) function. Use assumption with the power function (α) is 1 and the difference function (β) is 0.0001. The reason behind this assumption that there is no effect from the differentiation of generalised cost. Then, the model is shown below.

1. Power function (α)

$$P_{tollbus} = \frac{GC_{tollbus}^{-\alpha_{tollbus}}}{(GC_{tollbus}^{-\alpha_{tollbus}} + GC_{nontollbus}^{-\alpha_{nontollbus}} + GC_{car}^{-\alpha_{car}} + GC_{train}^{-\alpha_{train}})}$$

$$P_{tollbus} = \frac{Rp\ 100,649^{-1}}{(IDR\ 100,649^{-1} + IDR\ 105,649^{-1} + IDR\ 543,649^{-1} + IDR\ 71,649^{-1})} = 0.11772 = 11.7\%$$

2. Deterrence function (β)

$$P_{tollbus} = \frac{EXP(-\beta_{tollbus}.GC_{tollbus})}{EXP(-\beta_{tollbus}.GC_{tollbus}) + EXP(-\beta_{nontollbus}.GC_{nontollbus}) + EXP(-\beta_{car}.GC_{car}) + EXP(-\beta_{train}.GC_{train})}$$

$$P_{tollbus} = \frac{EXP(-0.00001.IDR\ 100,649)}{EXP(-0.00001.IDR\ 100,649) + EXP(-0.00001.IDR\ 105,649) + EXP(-0.00001.IDR\ 543,649) + EXP(-0.00001.IDR\ 71,649)} = 0.3030$$

After the value of the two functions found, those function should be calibrated so that the model should be fit with the existing condition. In this research, the calibration method uses Normalised Mean Absolute Error or NMAE. Then, step for calibrating is shown below:

1. Change the existing mode choice number form into percentage.
2. Subtract the proportion of existing mode choice with the model proportion, (β)=0,0001 and (α)=1. The result should be an absolute number.
3. All of the result from that subtraction is added and find the mean, it is called MAE.
4. Calculate the average of existing mode choice proportion.

5. Determine the NMAE value by dividing the MAE with the average number of existing mode choice proportion.

The proportion value from two functions is calibrated so that the model should resemble the existing condition. The calibration analysis is using excel solver, as mentioned above.

For the calibration of power function (α)

- Mean Absolute Error (MAE) (α) = 0.1321
- Mean $|y - \hat{y}|$ (α) = 0.2500
- NMAE power function (α) = 0.5284

For the calibration of deterrence function (β):

- Mean Absolute Error (MAE) (β) = 0.1793
- Mean $|y - \hat{y}|$ (β) = 0.1346
- NMAE deterrence function (β) = 1.3328

From the calibration calculation, we have to choose the smallest NMAE value, because the value closer to 0, the better model. The NMAE from power function value (0.5284) above is the smallest one. So, we can get a conclusion if the power function is more resemble the existing condition, then a difference function. So, the mode choice model for Tulungagung to Surabaya due to toll road are:

$$PBus\ Patas = \frac{GCBusPatas^{-0.01987}}{(GCBusPatas^{-0.01987} + GCBus\ NonTol^{-3.07143} + GCMP^{-0.03891} + GCKA^{-0.00032})}$$

$$PBus\ NonTol = \frac{GCBus\ NonTol^{-3.07143}}{(GCBusPatas^{-0.01987} + GCBus\ NonTol^{-3.07143} + GCMP^{-0.03891} + GCKA^{-0.00032})}$$

$$PMP = \frac{GCMP^{-0.03891}}{(GCBusPatas^{-0.01987} + GCBus\ NonTol^{-3.07143} + GCMP^{-0.03891} + GCKA^{-0.00032})}$$

$$PBKeretaApi = \frac{GCKA^{-0.00032}}{(GCBusPatas^{-0.01987} + GCBus\ NonTol^{-3.07143} + GCMP^{-0.03891} + GCKA^{-0.00032})}$$

4. Conclusions

- a. The socio-economy characteristics of respondents for the Tulungagung-Surabaya route are dominated by female sex with a percentage of 55%, ages between 21-30 years with a percentage of 74%, the last education is D4/Bachelor with a percentage of 51%, the type of work is a student with a percentage of 42%, dominated by people who have no income, because the average student with a percentage of 31%, the purpose of traveling is for family/social needs with a percentage of 32%, and as many as 93% of mode users surveyed own a motorized vehicle. Transportation mode that been used are travel time and travel cost. The socio-economy condition is just for how is the user characteristic and not affected the model.
- b. The model obtained is using the power function with given NMAE value of 0.5284 with the following equation:

$$PBus\ Patas = \frac{GCBusPatas^{-0.01987}}{(GCBusPatas^{-0.01987} + GCBus\ NonTol^{-3.07143} + GCMP^{-0.03891} + GCKA^{-0.00032})}$$

$$PBus\ NonTol = \frac{GCBus\ NonTol^{-3.07143}}{(GCBusPatas^{-0.01987} + GCBus\ NonTol^{-3.07143} + GCMP^{-0.03891} + GCKA^{-0.00032})}$$

$$PMP = \frac{GCMP^{-0.03891}}{(GCBusPatas^{-0.01987} + GCBus\ NonTol^{-3.07143} + GCMP^{-0.03891} + GCKA^{-0.00032})}$$

$$PBKeretaApi = \frac{GCKA^{-0.00032}}{(GCBusPatas^{-0.01987} + GCBus\ NonTol^{-3.07143} + GCMP^{-0.03891} + GCKA^{-0.00032})}$$

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