

Land Use, Service Interchange Spacing and Performance of Toll Roads: A Model and Case Study on Jakarta to Cikampek Toll Road, Indonesia

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Abstract. An on/off ramp traffic flow and land use relationship model was developed. For the case study, data on land use development surrounding the Jakarta-Cikampek Toll Road was collected, and traffic surveys were conducted at 9 on/off ramps and in the main road between the service interchanges. The main road traffic flow parameter relationships such as speed and density, speed and flow, flow and density relations were modeled. An overall model relating toll road performance to service interchange spacing was then established. Using SPSS software, a multiple linear regression was run to determine the relationship among those parameters. There are some research findings i.e.: residential areas influence on ramp traffic volume, industrial areas influence off ramp traffic volume. On ramp and off ramp traffic volume together with main road traffic volume and interchange spacing affect to traffic density. A nomogram was made to find the optimum spacing between interchanges, taking account of toll road user interests and operator/developer interests. This paper reviews our previous work [1], in which the studies of the relationship between land uses; service interchange spacing and toll road performance is done.

1. Introduction

The Jakarta–Cikampek Toll Road is one of the oldest toll roads in Indonesia. Its length is about 72 km which encompasses several administrative territories i.e.: East Jakarta City, Bekasi City, Bekasi Regency, Karawang Regency, and Purwakarta Regency. Opened in 1985, the highway links Jakarta with cities to its east in the province of West Java. Since 2005, this toll road also connects Bandung and Jakarta via the separate Cipularang Toll Road; the interchange to Bandung was built before the Dawuan Exit. This toll road is also part of Asian Highway Corridor Network. The toll road is operated by PT Jasa Marga Tbk. In June 2015, Cikampek-Palimanan Toll Road was opened, which connects Jakarta and Cirebon via toll road.

Originally, the whole length consists of 4 lanes 2 ways divided (i.e. 2 carriageways of 2 lanes each). Due to rapid land use development, the Toll Road has been widened to 8 lanes 2 ways now (2 carriageways of 4 lanes each). There are now 13 service interchanges and 3 system interchanges, much more than the 11 service interchanges and 1 system interchange at the opening stage. Currently, the level of service enjoyed by users of the Jakarta-Cikampek Toll Road (i.e. the traffic volume/capacity ratio) is reduced especially during peak hours. It is suggested that this decline in level of service may be caused by the additional service interchanges that have changed the interchange

spacing over time. Relationship between land use and transportation system has several times discussed [2,3].

It is currently difficult to decide whether to give permission or rejection when there is a request from local governments and/or developers to add a further interchange connection to a toll road without clear rules and an understanding of the impacts. The Indonesian Government Regulations on Toll Roads states that the minimum spacing between interchanges is about 5 km for interurban toll roads and 2 km for urban toll roads. There is often a debate about when land use has been developed sufficiently to reclassify it from rural to urban, even though toll was designed as an inter-urban toll road originally. To assist with resolution of these issues and formulation of clear policy and regulation to guide future planning decisions, a study to analyze the factors affecting toll road performance due to development of land use and reduction in service interchange spacing is required. This paper sets out the methodology and results of that study [1].

2. Methodology

In conducting the case study, first of all interchange hinterland zones were investigated and land use data was collected, including as population, numbers of families, vehicle ownership, residential areas, industrial areas, wetland areas, and gross domestic regional product. These data were compiled together with on/off ramp traffic volume data which were collected from primary surveys and a matrix consisting of the various variables was set up. Using Statistical Product and Service Solutions (SPSS) software, multi linear regression was run to produce an on/off traffic volume equation. Based on traffic volume and speed data collected from the primary survey, the traffic density was calculated using the general equation: $D = V/S$ where “D” is Density, “V” is Volume and “S” is speed. A table consisting of traffic volume data from minute to minute together with speed and density was established, and a speed vs density graph was derived. The traffic stream model was chosen from 4 models i.e. Greenshields Model, Greenberg Model, Underwood Model, or Bell Model. Mathematical models of volume-speed-density relationships were built [4,5]. Finally, a multi linear regression was processed to find the relationship between interchange spacing, on/off traffic volume and traffic density. The flow chart of research process can be seen at Figure 1 below.

3. Collecting Data and Survey

A secondary survey was undertaken by collecting data from related institutions, for example the Statistic Bureau Office, for collecting population data, family data, gross domestic regional product data, and the Provincial Income Bureau Office for collecting vehicle ownership data. Data on residential areas, wetland areas and industrial areas were calculated using a Google Map Application.

A traffic volume survey was conducted on each of the on ramps and the off ramps along Jakarta-Cikampek Toll Road. A traffic volume survey was also conducted on the main road in between the two interchanges. Beside traffic volume, a traffic speed survey was also conducted. The traffic survey used Video Image Processing Technology, which was measured three times on a weekday. The measuring times were 04.00 – 06.00, 08.00 – 10.00 and 12.00 – 14.00. Calculation of traffic volume and speed was undertaken in the office so that it could be repeated to ensure accuracy.

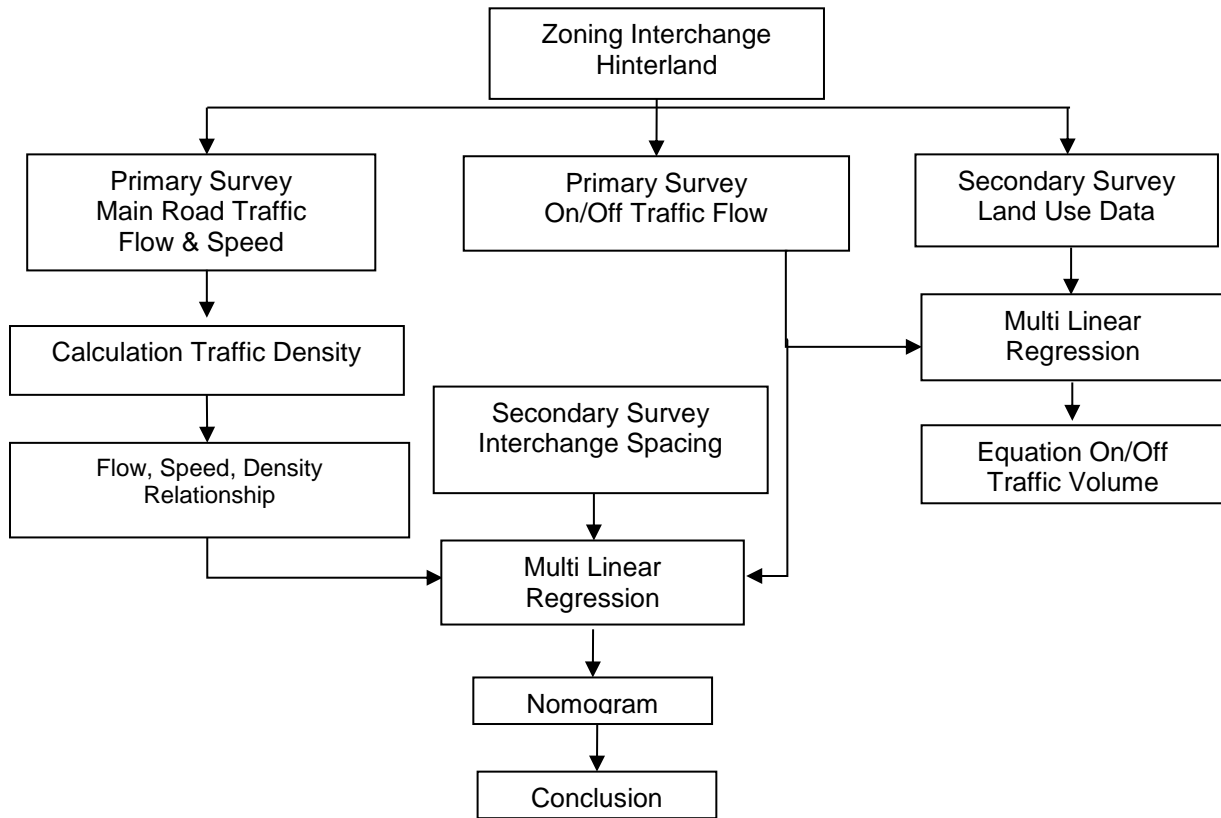


Figure 1 Flow Chart of Research Process

4. Data Analysis

Two tables were set up to present on/off ramp traffic flow as a dependent variable and some of the land use parameters as independent variables. A Multi Linear Regression on the first matrix resulted in a formula for the relationship between ramp traffic volume and land use characteristics as shown in Equation (1) below:

$$Y = -61.36 + 0.21 X_4 \quad (1)$$

Where:

Y = On Ramp Traffic Volume (PCU/h)

X₄ = Residential Area (ha)

While off ramp traffic volume versus land use relationship is mentioned in Equation (2) as follow:

$$Y = 531.93 + 0.136 X_5 \quad (2)$$

Where:

Y = Off Ramp Traffic Volume (PCU/h)

X₅ = Industrial Area (ha)

The Multiple Regression Coefficient (R) square adjustment is about 0.882 for the On Ramp Model, with F calculation is about 60.76 1 more than F table (6.30). While Multiple Regression Coefficient (R) square adjustment for Off Ramp Model is about 0.761 with F calculation is about 26.475 more than F table (5.41). From the above equations, it can be concluded that only the residential area influences on ramp traffic volume while the industrial area influences off ramp traffic volumes.

Main road traffic data was collected and compiled and then plotted in a graph to show the speed-density trendline as seen in Figure 2 below.

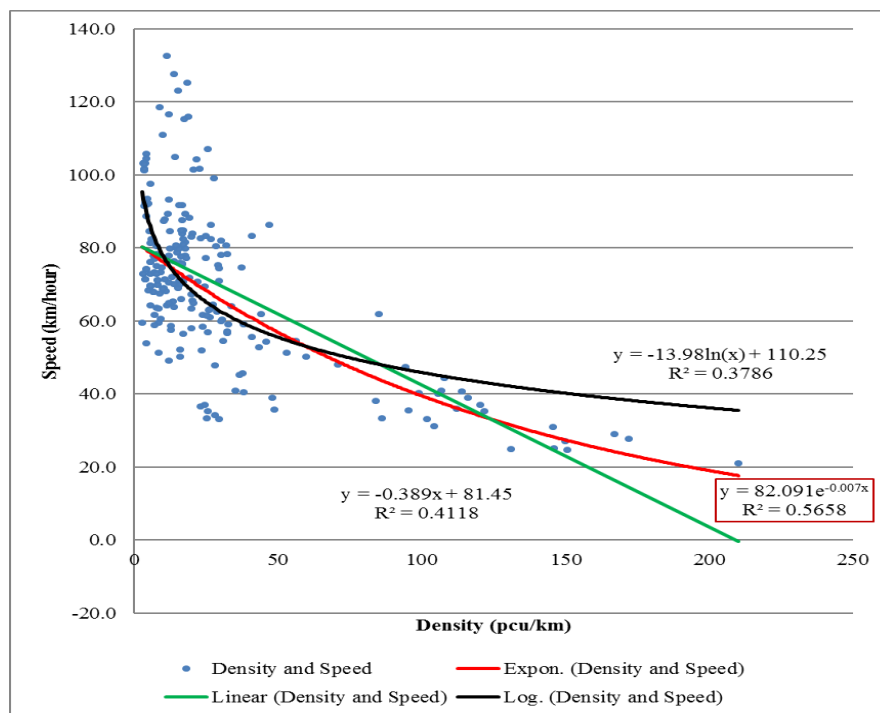


Figure 2 Speed-Density Graphs

Base on the graph it was seen that Underwood Model was the most appropriate model (the biggest R²). Therefore, the volume-speed-density relationship formula which was developed further was based upon the Underwood Model. Based on this model we established the equations for speed – density relationship as shown below in Equation (3); volume – density in Equation (4); and volume – speed in Equation (5) as follows:

$$S = 89.168 \times e^{\frac{-D}{238.2}} \quad (3)$$

$$V = D \times 89.168 \times e^{\frac{-D}{238.2}} \quad (4)$$

$$V = S \times 238.2 \times \ln \frac{89.168}{S} \quad (5)$$

Where:

S = Speed; D = Density; V = Volume

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Accordingly, the data for ‘On+Off’ Ramp Traffic Volumes, Main Road Traffic Volume, Interchange Spacing and Traffic Density were compiled. A Multi Linear Regression analysis using SPSS software was then run to find a formula for the relationship. The result is given in Equation (6) below:

$$Y = -3.760 + 0.005X_1 + 0.006X_2 - 0.002X_3 \quad (6)$$

Where:

Y = Density (PCU/km)

X_1 = On+Off Traffic Volume (PCU/h)

X_2 = Main Road Traffic Volume (PCU/h)

X_3 = Interchange Spacing (m)

Multiple Regression Coefficient (R) square adjustment becomes 0.888 with F calculation is about 188.466, more than F table (3.20), so we can have much more confidence in the accuracy of this derived equation. Based on the above equation, nomograms were prepared for practical usage. Two examples of the nomogram can be seen in Table 1 and Table 2 below.

Table 1 Nomogram of Ramp Traffic Volume, Main Road Traffic Volume, Interchange Spacing and Density Relationship for Service Interchange Spacing of 1 km

ON+OFF (PCU/h)	MAIN ROAD TRAFFIC VOLUME (PCU/h)								
	0	2000	4000	6000	8000	10000	12000	14000	16000
0		6	18	30	42	54	66	78	90
600		9	21	33	45	57	69	81	93
1200		12	24	36	48	60	72	84	96
1800	3	15	27	39	51	63	75	87	99
2400	6	18	30	42	54	66	78	90	102
3000	9	21	33	45	57	69	81	93	105

Table 2 Nomogram of Ramp Traffic Volume, Main Road Traffic Volume, Interchange Spacing and Density Relationship for Service Interchange Spacing of 2 km

ON+OFF (PCU/h)	MAIN ROAD TRAFFIC VOLUME (PCU/h)								
	0	2000	4000	6000	8000	10000	12000	14000	16000
0		4	16	28	40	52	64	76	88
600		7	19	31	43	55	67	79	91
1200		10	22	34	46	58	70	82	94
1800	1	13	25	37	49	61	73	85	97
2400	4	16	28	40	52	64	76	88	100
3000	7	19	31	43	55	67	79	91	103

Table 1 is the nomogram for service interchange with 1 km spacing and Table 2 for 2 km spacing. In case the spacing is about 1 km, main road traffic volume is about 12,000 PCU/h and 'on+off' ramp traffic volume is about 2,400 PCU/h so the main road traffic density will be 78 PCU/km. Another example of using nomogram: if the spacing is about 2 km, main road traffic volume is about 12,000 PCU/h and 'on+off' ramp traffic volume is about 2,400 PCU/h, the main road traffic density will be 76 PCU/km.

5. Conclusion and Recommendation

In this paper, the relationship between land use types, on/off ramp traffic volumes, interchange spacing and traffic density on the main toll road was demonstrated. A practical nomogram has been developed for controlling minimum interchange spacing when an additional interchange is required due to increased development. This can be used for the special requirements now faced in the Jakarta-Cikampek Toll Road. For wider usage on other Indonesian toll roads, it is recommended to undertake further research on more toll roads including inter urban toll roads, urban toll roads, and more roads on islands outside Java Island.

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