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. The paper studies the relationship between land use, service interchange spacing and toll road performance. 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. A nomogram was made to find the optimum spacing between interchanges, taking account of toll road user interests and operator/developer interests.

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 [1,2].

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.

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, numbers of families, vehicle ownership numbers, 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 [3,4]. 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 as can be seen in Figure 2 below.

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.

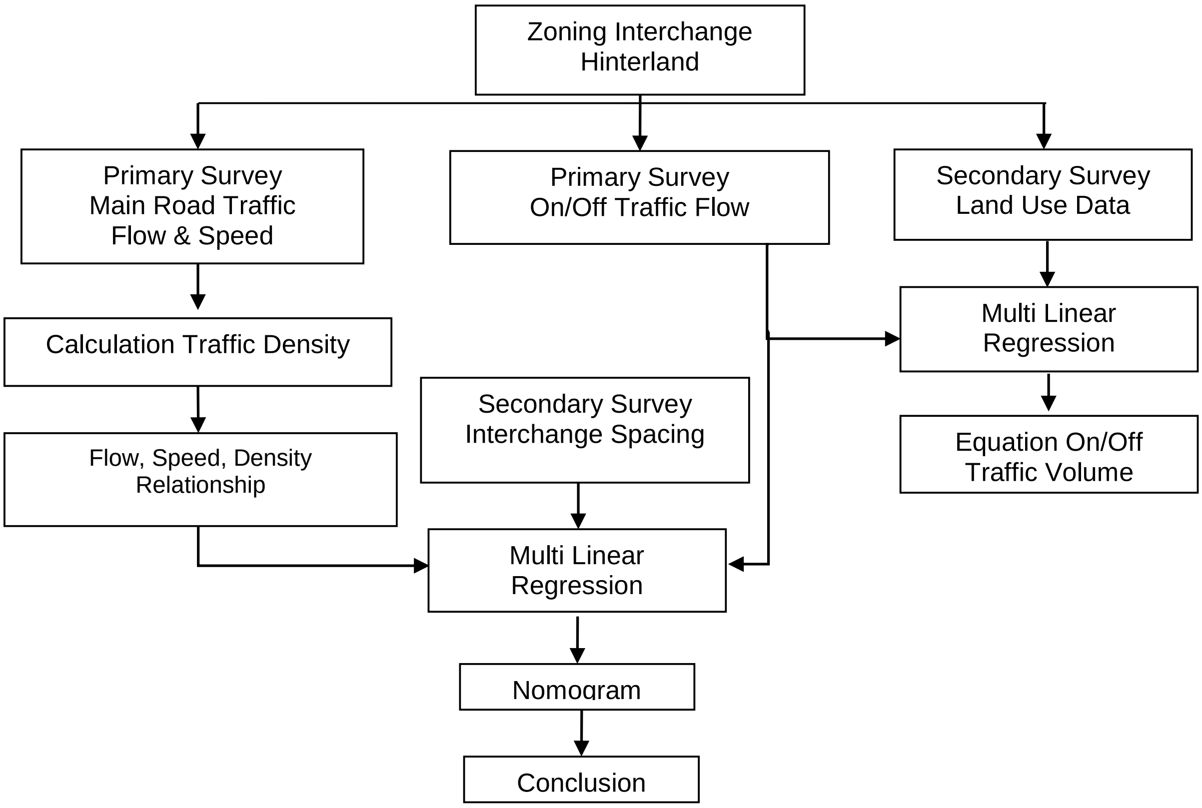

Fig. 1. Flow Chart of Research Process

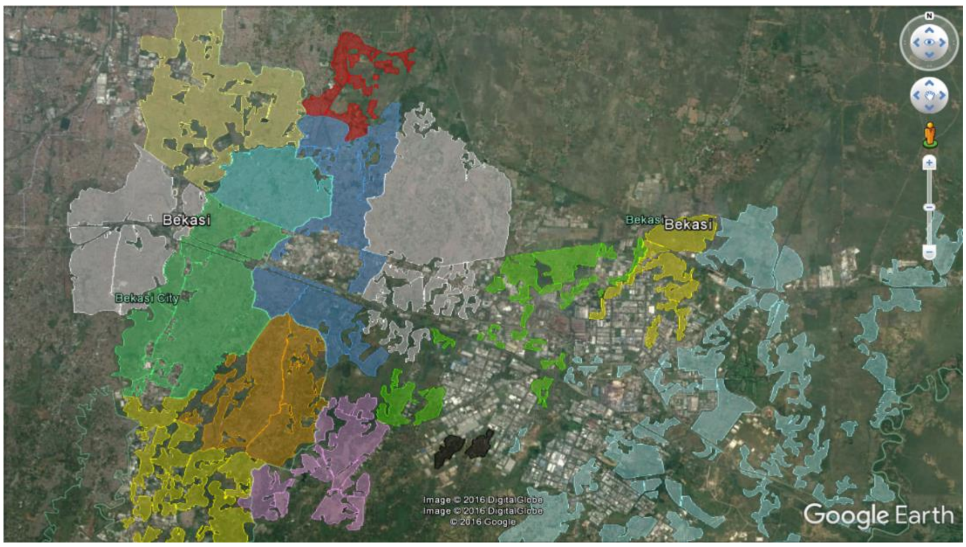

Fig. 2. Calculation of Residential Area

4. Data Analysis

Table 1 and Table 2 below present on/off ramp traffic flow as a dependent variable and some of the land use parameters as independent variables.

Table 1. On Ramp Traffic Volume and Land Use Parameters

Interchange	Traffic Volume [PCU/h]	Population [thousand]	Number of Family	Vehicle Ownership [PCU]	Residential Area [ha]	Industrial Area [ha]	Wetland Area [ha]	GDRP [Bio. Idr]
	Y	X1	X2	X3	X4	X5	X6	X7
Bekasi Brt	1985	698	200414	160729	8638	1869	252	20062
Bekasi Tmr	698	642	151216	156087	4261	147	1239	7440
Tambun	1610	488	118676	68348	8245	343	688	7299
Cibitung	555	529	155829	48743	3855	4883	3008	44267
Cikarang Brt	562	431	85537	80468	4170	2980	394	16968
Cibatu	412	215	63679	48655	1589	961	2468	7250
Cikarang Tmr	572	82	32375	20821	3826	1778	5337	44677
Karawang Brt	468	322	97108	29079	1832	572	5270	64464
Karawang Tmr	459	193	79087	17347	1704	2226	3755	23753

A Multi Linear Regression on the above matrices resulted in a formula for the relationship between ramp traffic volume and land use characteristics as shown in Equation (1) below:

$$Y = -61.36 + 0,21\ X4 \quad (1)$$

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:

$$Y = 531.93 + 0.136\ X5 \quad (2)$$

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 l 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.

Table 2. Off Ramp Traffic Volume and Land Use Parameters

Interchange	Traffic Volume [PCU/h]	Population [thousand]	Number of Family	Vehicle Ownership [PCU]	Residential Area [ha]	Industrial Area [ha]	Wetland Area [ha]	GDRP [Bio. IDR]
	Y	X1	X2	X3	X4	X5	X6	X7
Bekasi Brt	831	698	200414	160729	8638	1869	252	20062
Bekasi Tmr	419	642	151216	156087	4261	147	1239	7440
Tambun	423	488	118676	68348	8245	343	688	7299
Cibitung	1088	529	155829	48743	3855	4883	3008	44267
Cikarang Brt	1028	431	85537	80468	4170	2980	394	16968
Cibatu	753	215	63679	48655	1589	961	2468	7250
Cikarang Tmr	801	82	32375	20821	3826	1778	5337	44677
Karawang Brt	735	322	97108	29079	7732	572	5270	64464
Karawang Tmr	854	193	79087	17347	1775	2226	3755	23753

Main road traffic data was collected and compiled and then plotted in a graph to show the speed-density trendline as seen in Figure 3 below**.**

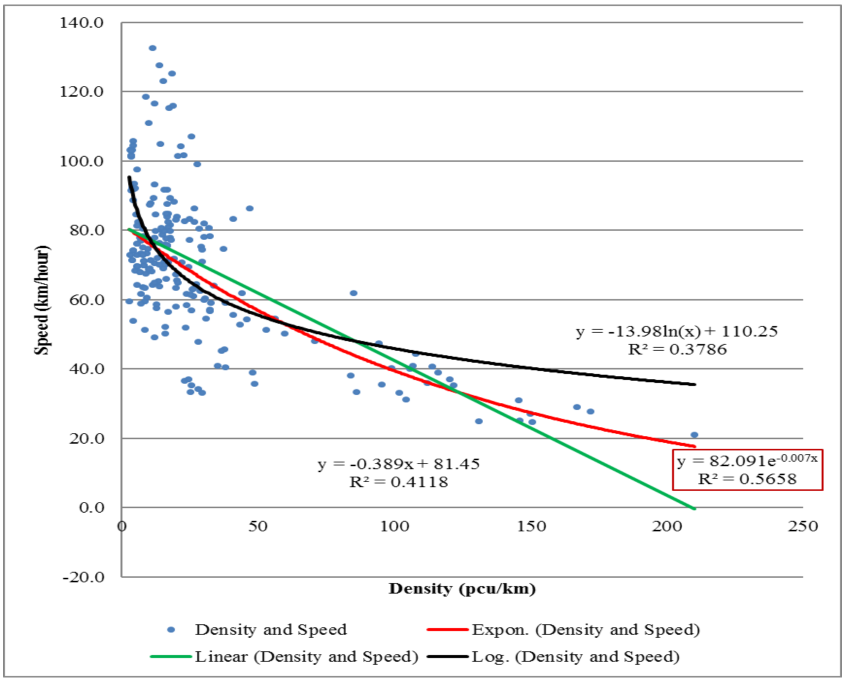

Fig. 3. Speed-Density Graph

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;

Accordingly, the data for 'On+Off' Ramp traffic volumes, Interchange spacing and Traffic Density were compiled as seen in Table 3 below.

Table 3. Density, 'On+Off' Traffic Volume and Interchange Spacing

Y Density [PCU/km]	X1 on+off [PCU/h]	X2 Interchange Spacing [m]	Y Density [PCU/km]	X1 on+off [PCU/h]	X2 Interchange Spacing [m]
195	3.867	3.628	72	2.072	7.121
104	3.862	3.628	120	1.947	7.121
43	3.523	3.628	111	2.929	7.121
90	3.789	3.628	124	2.311	7.121
122	3.679	3.628	28	1.122	3.522
171	3.844	3.628	26	2.530	3.522
201	3.751	3.628	43	1.810	3.522
206	3.575	3.628	61	1.389	3.522
70	1.453	4.348	26	498	3.522
70	1.272	4.348	41	427	3.522
80	1.462	4.348	85	612	3.522
118	1.143	4.348	47	932	3.522
85	1.229	4.348	48	1.074	10.400
108	1.289	4.348	68	1.374	10.400
124	1.785	4.348	66	1.376	10.400
99	1.347	4.348	96	1.236	10.400
94	1.151	3.305	41	1.234	10.400
110	1.305	3.305	83	1.222	10.400
153	1.099	3.305	98	1.836	10.400
132	493	3.305	105	1.790	10.400
139	782	3.305	25	1.140	7.450
167	888	3.305	20	2.539	7.450
138	1.016	3.305	12	1.858	7.450
133	907	3.305	25	1.514	7.450
81	1.532	4.740	9	963	7.450
93	1.780	4.740	17	600	7.450
67	2.047	4.740	17	998	7.450
56	1.658	4.740	11	1.680	7.450
47	2.488	4.740	118	2.716	13.430
43	2.753	4.740	47	2.097	13.430
53	3.305	4.740	24	1.947	13.430
54	2.667	4.740	28	1.704	13.430
123	1.388	7.121	54	1.766	13.430
105	1.670	7.121	24	1.090	13.430

Y Density [PCU/km]	X1 on+off [PCU/h]	X2 Interchange Spacing [m]	Y Density [PCU/km]	X1 on+off [PCU/h]	X2 Interchange Spacing [m]
105	1.670	7.121	24	1.090	13.430
92	1.999	7.121	33	1.586	13.430
99	1.412	7.121	31	1.480	13.430

(data traffic survey in peak hour period)

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:

$$Y = 8.564 + 0.021X1 - 0.003X2 \tag{6}$$

Where:
Y = Density (PCU/Km)
X1 = On+Off Traffic Volume (PCU/h)
X2 = Interchange Spacing (m)

Multiple Regression Coefficient (R) square adjustment is about 0.543 with F calculation is about 43.155, more than F table (3.20). Based on the above equation, a nomogram was prepared for practical usage as seen in Table 4 below.

Table 4. Nomogram Ramp Traffic Volume, Interchange Spacing and Density

On+Off Traffic Volume [pcu/h]	Interchange Spacing [km]											
	1	2	3	4	5	6	7	8	9	10	11	12
0	6	3										
600	18	15	12	9	6							
1200	31	28	25	22	19	16	13	10	7	4	1	
1800	43	40	37	34	31	28	25	22	19	16	13	10
2400	56	53	50	47	44	41	38	35	32	29	26	23
3000	69	66	63	60	57	54	51	48	45	42	39	36

As mentioned in the above paragraph, (R) square adjustment is about 0.543, which means there are other variables (45,7%) which affect the traffic density. To address this, another variable was added to the regression. Table 5 below shows the value of main road traffic volumes as an additional variable.

Table 5. Density, 'On+Off' Traffic Volume, Main Road Traffic Volume and Interchange Spacing

Y Density [PCU/km]	X1 on+off [PCU/h]	X2 Main Road [PCU/h]	X3 IC Spacing [m]	Y Density [PCU/km]	X1 on+off [PCU/h]	X2 Main Road [PCU/h]	X3 IC Spacing [m]
195	3.867	16.851	3.628	72	2.072	5.632	7.121
104	3.862	13.438	3.628	120	1.947	9.372	7.121
43	3.523	11.448	3.628	111	2.929	8.920	7.121
90	3.789	12.807	3.628	124	2.311	10.036	7.121
122	3.679	15.772	3.628	28	1.122	2.160	3.522
171	3.844	16.829	3.628	26	2.530	2.124	3.522
201	3.751	17.840	3.628	43	1.810	3.024	3.522
206	3.575	17.620	3.628	61	1.389	5.364	3.522
70	1.453	4.450	4.348	26	498	2.060	3.522
70	1.272	4.613	4.348	41	427	3.596	3.522
80	1.462	5.413	4.348	85	612	5.260	3.522
118	1.143	7.356	4.348	47	932	3.680	3.522
85	1.229	5.525	4.348	48	1.074	4.460	10.400
108	1.289	6.155	4.348	68	1.374	5.985	10.400
124	1.785	7.340	4.348	66	1.376	6.083	10.400
99	1.347	6.048	4.348	96	1.236	9.482	10.400
94	1.151	5.376	3.305	41	1.234	3.561	10.400
110	1.305	5.248	3.305	83	1.222	8.400	10.400
153	1.099	5.468	3.305	98	1.836	8.143	10.400
132	493	5.420	3.305	105	1.790	8.653	10.400
139	782	5.624	3.305	25	1.140	1.747	7.450
167	888	6.544	3.305	20	2.539	1.333	7.450
138	1.016	6.296	3.305	12	1.858	920	7.450
133	907	6.032	3.305	25	1.514	1.716	7.450
81	1.532	4.720	4.740	9	963	682	7.450
93	1.780	4.828	4.740	17	600	1.219	7.450
67	2.047	3.800	4.740	17	998	1.284	7.450
56	1.658	3.652	4.740	11	1.680	809	7.450
47	2.488	3.052	4.740	118	2.716	8.833	13.430
43	2.753	2.992	4.740	47	2.097	3.279	13.430
53	3.305	3.076	4.740	24	1.947	1.844	13.430
54	2.667	3.144	4.740	28	1.704	2.032	13.430
123	1.388	6.736	7.121	54	1.766	6.278	13.430
105	1.670	6.616	7.121	24	1.090	2.818	13.430
92	1.999	7.632	7.121	33	1.586	3.908	13.430
99	1.412	7.656	7.121	31	1.480	3.408	13.430

(data traffic survey in peak hour period)

The result of its regression is mentioned in Equation (7) below:

$$Y = -3.760 + 0.005X1 + 0.006X2 - 0.002X3 \quad (7)$$

Where:
Y = Density (PCU/km)
X1 = On+Off Traffic Volume (PCU/h)
X2 = Main Road Traffic Volume (PCU/h)
X3 = 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.

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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