TEST Engineering & Management

January-February 2020
ISSN: 0193-4120 Page No. 14043 - 14053

Improving Roundabout's Level of Service (A Case Study of Kecil Roundabout in Palangkaraya)

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Article Info
Volume 82
Page Number: 14043 - 14053
Publication Issue:
January-February 2020

Article History
Article Received*: 18 May 2019*
Revised*: 14 July 2019*
Accepted*: 22 December 2019*
Publication*: 26 February 2020*

Abstract:Kecil Roundabout is a signalized roundabout located in Palangkaraya. Traffic jams occur during the rush hour because the intersection is in the central education and office area and has become the main access for the community traveling for their daily activities. This study was done to analyze the performance of the existing roundabout and determine the most suitable type of intersection with life-cycle cost analysis (LCCA) suggested by IHCM (Indonesian Highway Capacity Manual). Primary data were obtained by a direct survey, including the traffic volume of the intersection, intersection and roundabout geometry, signal time, and saturation flow time slices. The methods used are the Indonesian Highway Capacity Manual (IHCM) 1997 and the saturation flow approach. The result of performance analysis on the existing intersection condition with the saturation flow method shows that the average delay is > 60s/pcu (service level F). Based on the scenario analysis, scenario 1 (a signalized roundabout) provides service level D, scenario 2 (intersection without roundabout) gives a service level almost reaching C, and scenario 3 (enlarged roundabout) has a degree of saturation (DS) < 0.8. The calculation with life-cycle cost analysis (LCCA) has the result that the best fitting type of intersection corresponding to the existing traffic volume is an elevated interchange.

Keywords:*Degree of saturation, Palangkaraya, Roundabout, Signal time, Traffic.*

I. INTRODUCTION

One of the cities in Indonesia that is creating a new impression is Palangkaraya, the capital of Central Borneo Province, whose development has grown in line with the increasing population and the increasing socio-economic activities of the community. Palangkaraya is now one of the most preferred cities to become the capital of Indonesia in the future [1]. According to data from BPS-Statistics Indonesia of Palangkaraya [2], the population of Palangkaraya City in 2015 amounted to 259,865, with a population growth rate of 3.08%. In line with this growth, the need for transportation is also increasing.

Palangkaraya City is well known as a city with many roundabouts, one of which is the "Kecil" Roundabout, named Kecil (small) because there is another large roundabout located in the center of Palangkaraya City. The Kecil roundabout is very

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important as a meeting point for the traffic flow from the four legs of the intersection, which are the primary arterial road (Imam Bonjol and RTA Milono Streets) and the inter-regional traffic flow as well as the primary collector road (G. Obos and Diponegoro Streets) [3].

Signalization of roundabouts was first experimented in 1959 in the United Kingdom (UK) to prevent circulating traffic from blocking traffic during peak periods [4]. Akcelik [5] presented the basic principles of roundabout metering signals. Akcelik [6] conducted case studies of signalized roundabouts in Australia, the UK, and the USA, and the results indicate that low cycle times give better intersection performance compared with the longer cycle times used in practice. Hummer et al. [7] conducted case studies of signalized roundabouts in the USA, and their results indicated that installing a metering signal on roundabouts with some demand combinations has the potential to reduce delay compared to an unmetered roundabout.

Amran [8] conducted a signalized roundabout case study in Jakarta, Indonesia. The result shows that an unsignalized roundabout is more effective than using a signalized roundabout and signalized intersection (without a roundabout). In a previous case study on Kecil Roundabout presented by Permana [3], the result proved that coordinating the signal with an intersection which is located close to Kecil Roundabout will reduce delays and queue lengths. In order to improve the service quality of the Kecil roundabout intersection, this study was carried out to analyze the performance of the existing roundabout and determine the most suitable intersection, with a life cycle cost analysis (LCCA) suggested by IHCM (Indonesian Highway Capacity Manual).

II. LITERATURE REVIEW

Roundabout

Roundabouts are circular intersections with specific design and traffic control features. These features include give-way control of all entering traffic, channelized approaches and appropriate geometric curvature to ensure that travel speeds on the circulatory roadway are typically less than 50 km/h [9].

The roundabout is most effective when used for crossing between roads with the same level of flow. A roundabout is valid for a degree of saturation less than 0.8–0.9. At higher traffic demands, the behavior of the traffic becomes more aggressive and there is a major risk that the weaving section will be blocked by drivers competing for the limited space in that section [10].

Signalized intersection

According to Khisty and Lall [11], a traffic light is an electrical device (with a timing system) that gives the right of way to one or more traffic flows so that this traffic flow can cross the intersection safely and efficiently. The signalized intersection is based on the concept of saturation flow and the saturation flow lane. The advantages of traffic signal control are: to increase capacity (thereby improving the level of service), to improve safety, and to provide for orderly movement through a complex situation [12].

Signalized roundabout

The use of roundabout metering signals is a cost-effective measure to avoid the need for a fully-signalized intersection treatment [13]. Roundabout metering signals are often installed on selected roundabout approaches and used usually on a part-time basis since they are required only when heavy demand conditions occur during peak periods [14]. Roundabout metering signals are

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used to create gaps in the circulating stream in order to solve the problem of excessive queuing and delays at approaches affected by highly directional flows [15].

A study of 20 signalized roundabouts has been carried out in London. It was found that signalization of “standard” roundabouts resulted in a 28 % decrease in crashes [16]. The two main signal controls of roundabouts are direct control and indirect control. Direct control rules both external and internal links in a roundabout while indirect control rules only the inflows to the roundabout. The roundabout can have either full or partial signal control and signals can be used either permanently or during peak times [17].

The presence of additional signals makes the traffic flow at the roundabout almost the same as a regular signal intersection because the vehicle flow is regulated by a traffic light, which is ultimately ineffective when the traffic density at the intersection is low and causes vehicles to stop at a certain phase even when the vehicle density occurring at the intersection approaches is very low. The signalized roundabout capacity is adapted from the calculated signalized intersection [18], so in Equation (1):

$$Q = s.u \qquad (1)$$

Notes:

Q = capacity (pcu/hour)
S = saturation flow (pcu/hour)
u = proportion of vehicle time to escape from the queue

Saturation flow based on time slice method
The time slice method is one of the methods of measuring the saturated flow at a signalized intersection developed by the Road Research Laboratory [19] listed in "Road Note 34, A Method of Measuring Saturation Flow at Traffic Signal". This method measures the average vehicle passing through the stop line during the green signal period and divides it by time (time slice) at smaller intervals (e.g. per 6 seconds).

Passenger carequivalent
Traffic flow for the analysis in this study has to be converted into pcu/hour by utilizing the passenger car equivalent following the Indonesian Highway Capacity Manual.

Level of service of signalized intersection
The service level criteria for the signalized intersection are shown in Table 1.

Tab 1. Level of service of signalized intersection

Service Level	Value of delay (sec/pcu)
A	≤ 5.0
B	5.1 – 15.0
C	15.1 – 25.0
D	25.1 – 40.0
E	40.0 – 60.0
F	> 60.0

Source: Directorate General of Land Transportation [20].

III. METHODS

Primary data were obtained from a direct survey, including traffic volume, the geometry of the roundabout, signal time, and saturation flow with the existing time slice. Secondary data were obtained from related institutions, including population data and a map of the study area. The location of the study area is the Kecil Roundabout in Palangkaraya City, as seen in Figure 1.

Fig. 1 Study location

Analysis of the existing Kecil Roundabout (signalized roundabout) is done using the saturation flow approach. Furthermore, a scenario improvement plan is done with three scenarios, including a signalized roundabout using the saturation flow approach, a signalized intersection (without roundabout) and an unsignalized roundabout using IHCM. Next, an analysis was done to check the subsequent life cycle cost analysis (LCCA) suggested by Directorate General of Land Transportation [10] for the best fitting type of intersection to accommodate existing traffic conditions.

IV. RESULT AND DISCUSSION

Traffic volumedata

The survey was conducted on Monday, October 5, 2016, for 9 hours at 6:00 am to 9:00 am and at 12:00 pm to 6:00 pm, by placing three cameras as a video recording device to record the pattern of traffic movement. The obtained peak hour is at 6:05 am - 07:05 am, as this is the time for travel to work and school. Table 2 shows the flow of traffic at the peak hour.

Tab 2. Distribution of Kecil roundabout traffic at peak hour

Vehicle Type	Traffic flow per approach (vehicle/hour)											
	A			B			C			D		
	LT	ST	RT	LT	ST	RT	LT	ST	RT	LT	ST	RT
LV	86	223	4	183	324	74	123	122	314	4	357	157
HV	1	0	0	1	18	2	5	0	5	0	18	2
MC	244	1273	6	369	685	190	273	685	661	6	844	520
vehicle/hour/												

Geometric data

From the survey results, geometric data were obtained as in Tables 3 and 4. Kecil Roundabout's existing geometric conditions can be seen in Figure 2.

Tab 3. Geometric data of intersection (existing)
Source: Permana [3]

Approach	Entry width (m)	Exit width (m)
A	8.5	13.2
B	12	12
C	8	12.7
D	7.5	10

Tab 4. Geometric data of roundabout (existing)

	Weaving section			
	AB	BC	CD	DA
Entry width 1	8.5	12	8	7.5
Entry width 2	20.3	13	12.7	23.8
Average width (e)	14.4	12.5	10.35	15.65
Width of weaving (w)	13	9	8	36.3
Length of weaving (L)	57.2	66.8	73.8	20.1

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Source: Permana [3]

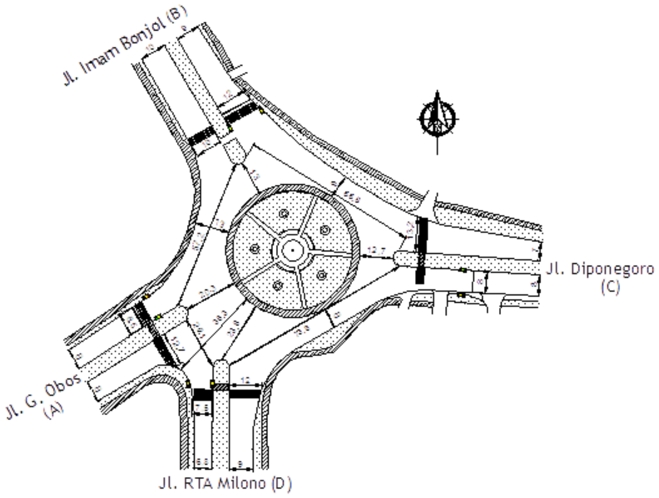

Fig. 2 Geometric of "Kecil" Roundabout intersection (existing)

Time signaldata

From the observation of the time signal data on the existing condition, the number of phases and cycle time are obtained. Kecil Roundabout has four phases with a total cycle time of 112 seconds. The time distribution of the intersection signal is shown in Table 5.

Tab 5. Intersection signal time data

Approach	Signal Time			All red	Cycle time
	Green	Red	Yellow		
A	21	88	3	4	112
B	21	88	3	4	112
C	21	88	3	4	112
D	21	88	3	4	112

Source: Permana [3]

Performance of existingroundaboutcondition

The performance of the existing condition (signalized roundabout) is analyzed using the saturation flow approach. This method has a stage of analysis that is almost the same as IHCM [10]. This method uses the average saturation flow and effective green time from the analysis of interval saturation flow. The results of the analysis of the interval saturation flow can be seen in Table 6, while the existing performance of Kecil Roundabout can be seen in Table 7.

Tab 6. Average interval saturation flow and effective green time

Intersect point	Intersect point location	Average interval saturation flow (pcu/hour)	Green time display (second)	Loss time additio (secon
A	G. Obos St.	3859	21	0.24
B	Imam Bonjol St.	4964	21	-2.39
C	Diponegoro St.	3846	21	1.25
D	RTA Milono St.	3743	21	-0.30

Source: Permana [3]

Tab 7. Kecil Roundabout performance - existing condition

Approach	S (pcu/hour)	Q (pcu/hour)	C (pcu/hour)	DS	QL (m)	D (sec/pcu)	Dintersection (sect/pcu)
A	3859	619	732	0.845	71	58.30	264.26
B	4964	857	825	1.039	120	161.71	
C	3846	896	764	1.172	335	377.25	
D	3743	818	692	1.183	339	403.78	

Source: Permana [3]

Table 7 shows that at peak hour, Kecil Roundabout's B, C, and D approaches have an average delay value > 60 sec/pcu (service level F). This means that the current intersection condition is theoretically not able to accommodate the existing traffic.

Improvement scenarioplanning

There are three improvement scenarios in this study. The planned scenarios are a signalized roundabout, a signalized intersection (without roundabout), and an enlargement of the roundabout. The performance analysis has been based on peak traffic conditions.

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Scenario 1. signalized roundabout
This scenario retained the existing conditions (signalized roundabout), with improvements including signal resetting, geometric changes, the application of left turns on red (LTOR), and heavy vehicle restrictions. Performance analysis was carried out using the saturation flow approach. The performance of each improvement can be seen in Tables 8, 10, 11, and 12.

Tab 8. Scenario 1a (reset the signal)

Approach	CT (second)	Phase Step	g (sec)	DS	QL (m)	D (sec/pcu)	Dintersection (sec/pcu)	LOS
A	130	1	22	0.927	91	83.50	75.22	F
B		4	24	0.927	83	75.91		
C		3	33	0.927	129	70.58		
D		2	31	0.927	128	73.33		

The planned geometric change is widening by minimizing the median and the green line on the side of the road as shown in Figure 3. For more details, the geometric data of the intersection plan can be seen in Table 9.

Tab 9. Enlargement of geometry

Approach	Existing	Planned
A	8.5	10.5
B	12	13
C	8	11
D	7.5	10.5

Tab 10. Scenario 1b (geometric changes)

Approach	CT (second)	Phase step	g (sec)	DS	QL (m)	D (sec/pcu)	Dintersection (sec/pcu)	LOS
A	91	1	15	0.790	47	46.58	43.48	E
B		4	18	0.790	49	42.87		
C		3	20	0.790	60	42.14		
D		2	18	0.790	58	43.26		

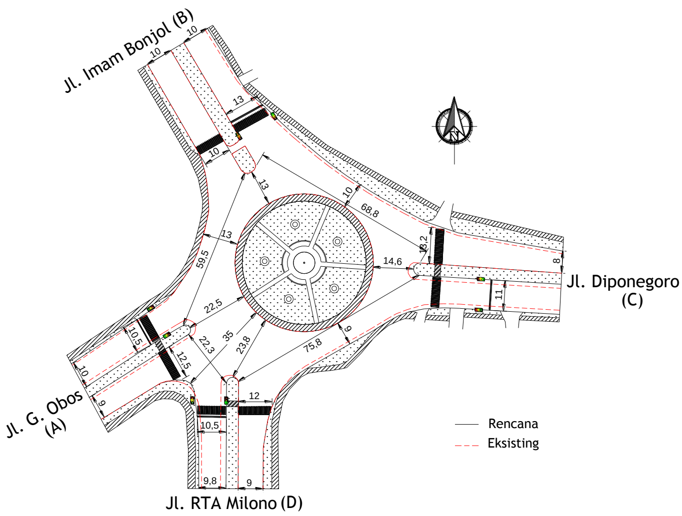

Fig. 3 Intersection Geometric (scenario plan 1)

Table 11. Scenario 1c (geometric changes & LTOR implementation)

Approach	CT (second)	Phase step	g (sec)	DS	QL (m)	D (sec/pcu)	Dintersection (sec/pcu)	LOS
A	90	1	16	0.784	53	46.58	38.77	D
B		4	17	0.784	47	44.90		
C		3	19	0.78	59	41.45		

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Approach	CT (second)	Phase step	g (sec)	DS	QL (m)	D (sec/pcu)	Dintersection (sec/pcu)	LOS
				4				
D		2	18	0.784	58	42.54		

Tab 12. Scenario 1d (geometric changes, LTOR implementation & heavy vehicle restriction)

Approach	CT (second)	Phases step	g (sec)	DS	QL (m)	D (sec/pcu)	Dintersection (sec/pcu)	LOS
A	87	1	16	0.778	51	44.86	37.64	D
B		4	15	0.778	44	43.96		
C		3	19	0.778	57	40.18		
D		2	17	0.778	54	41.49		

In the signalized roundabout scenarios, phase changes cannot be applied because this will cause complex traffic in the roundabout. The best improvement is scenario 1d (geometric change, LTOR application, and heavy vehicle restriction) with service level D.

Scenario 2. signalized intersection (without roundabout)

This scenario is without a roundabout so that the arrangement is with traffic signals only, and the improvements include signal resetting, geometric changes, phase changes, LTOR implementation, and heavy vehicle restriction. Performance analysis has been done using IHCM [10]. The performance of each improvement can be seen in Tables 13, 14, 15, 16, 17, 18, and 19.

Tab 13. Scenario 2a (reset the signal)

Approach	CT (second)	Phase step	g (sec)	DS	QL (m)	D (sec/pcu)	Dintersection (sec/pcu)	LOS
A	130	1	23	0.905	87	76.66	69.12	F
B		4	23	0.905	81	71.45		
C		3	35	0.905	124	64.13		
D		2	33	0.905	123	66.45		

Tab 14. Scenario 2b (geometric changes)

Approach	CT (second)	Phase step	g (sec)	DS	QL (m)	D (sec/pcu)	Dintersection (sec/pcu)	LOS
A	76	1	13	0.783	40	40.18	37.32	D
B		4	14	0.783	42	37.58		
C		3	17	0.783	51	35.71		
D		2	16	0.783	50	36.66		

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Tab 15. Scenario 2c (geometric changes & LTOR implementation)

Approach	CT (second)	Phase step	g (sec)	DS	QL (m)	D (sec/pcu)	Dintersection (sec/pcu)	LOS
A	75	1	13	0.777	46	40.46	31.72	D
B		4	12	0.777	40	39.63		
C		3	18	0.777	57	35.26		
D		2	16	0.777	49	35.89		

Tab 16. Scenario 2d (phase changes)

Approach	CT (second)	Phase step	g (sec)	DS	QL (m)	D (sec/pcu)	Dintersection (sec/pcu)	LOS
A	75	1	13	0.777	46	40.46	31.72	D
B		4	12	0.777	40	39.63		
C		3	18	0.777	57	35.26		
D		2	16	0.777	49	35.89		

Tab 17. Scenario 2e (phase & geometric changes)

Approach	CT (second)	Phase step	g (sec)	DS	QL (m)	D (sec/pcu)	Dintersection (sec/pcu)	LOS
A	81	3	13	0.809	43	44.24	31.44	D
B		1	35	0.809	52	27.83		
C		2	18	0.809	55	39.19		
D		1	35	0.614	54	21.50		

Tab 18. Scenario 2f (phase & geometric changes, LTOR implementation)

Approach	CT (second)	Phase step	g (sec)	DS	QL (m)	D (sec/pcu)	Dintersection (sec/pcu)	LOS
A	76	3	13	0.794	47	42.44	27.08	D
B		1	30	0.794	47	29.01		
C		2	18	0.794	58	36.85		
D		1	30	0.678	55	23.70		

Tab 19. Scenario 2g (phase & geometric changes, LTOR implementation, heavy vehicle restriction)

Approach	CT (second)	Phase step	g (sec)	DS	QL (m)	D (sec/pcu)	Dintersection (sec/pcu)	LOS
A	73	3	13	0.783	45	40.21	26.22	D
B		1	28	0.783	44	28.15		
C		2	17	0.783	56	35.11		
D		1	28	0.677	52	23.43		

In the signalized intersection scenarios (without roundabouts), the best improvement is scenario 2g (phase & geometric change, LTOR implementation, and heavy vehicle restriction), with service level D and nearly service level C.

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Scenario 3. enalargment of roundabout

This scenario is without signals so that the arrangement is with the roundabout, and improvements including geometric changes and heavy vehicle restriction. Performance analysis is conducted using IHCM [10]. The traffic flow is shown in Table 20. For each improvement, the performance can be seen in Tables 21, 23, and 24.

Tab 20. Traffic flow of the roundabout section

Weaving section	Weaving flow (pcu/hour)	Inbound stream flow (pcu/hour)	Weaving ratio
AB	2320	2949	0.787
BC	2141	2516	0.851
CD	1812	2250	0.806
DA	1858	2516	0.738

Tab 21. Scenario 3a (unsignalized roundabout)

Weaving section	C (pcu/hour)	DS	DT (sec/pcu)	QP (%)
AB	5758	0.512	2.40	6–14
BC	4888	0.515	2.41	6–14
CD	4159	0.541	2.54	7–15
DA	2793	0.901	8.23	27–58

Table 21 shows that the weaving DA has the lowest performance, the DS value of 0.901. Weaving AB, BC, and CD still have good performance, with DS values below 0.8. The planned geometry of the roundabout is intended to enlarge the width of entry, weaving width, and weaving length. For more details, the geometric data of the roundabout plan can be seen in Table 22.

Tab 22. Roundabout geometric data (plan)

	Weaving section			
	AB	BC	CD	DA
Entry width 1	8.5	12	8	10.5
Entry width 2	22.4	13	12.7	23.8
Average width (e)	15.45	12.5	10.35	17.15
Width of weaving (w)	13	10	9	35
Length of weaving(L)	58.4	66.8	73.8	22.3

Tab 23. Scenario 3b (roundabout with geometric changes)

Weaving part	C (pcu/hour)	DS	DT (sec/pcu)	QP (%)
AB	6134	0.481	2.25	6-12
BC	5004	0.503	2.36	6-13
CD	4304	0.523	2.45	6-14
DA	3315	0.759	4.69	16-36

Tab 24. Scenario 3c (roundabout with geometric changes & heavy vehicle restriction)

Weaving part	C (pcu/hour)	DS	DT (sec/pcu)	QP (%)
AB	6135	0.447	2.23	5-12
BC	5006	0.477	2.33	6-13
CD	4303	0.427	2.41	6-14
DA	3316	0.748	4.52	15-34

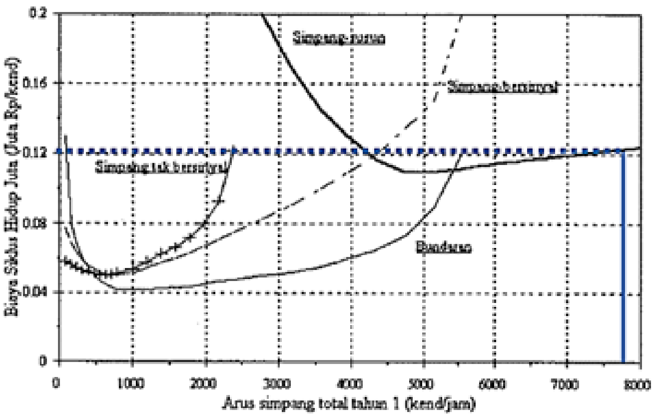

Fig. 4 Comparison of total cost of various intersections as a function of traffic flow. Source: Directorate General of Highways

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In the roundabout enlargement scenarios, the best improvement is scenario 3c (geometric changes to the roundabout and heavy vehicle restriction) with a degree of saturation (DS) less than 0.8 (DS) value suggested by IHCM [10].

Life Cycle Cost Analysis (LCCA)

Life cycle cost analysis (LCCA) can be used to determine the most economical type of road and intersection with a set of assumptions used by the Indonesian Directorate General of Highways, such as the lifetime, traffic growth rate, interest rate and purpose of road development. All relevant road user costs (vehicle operating cost, travel time cost, accident cost, pollution cost) and road construction costs (land acquisition cost, road construction cost, road maintenance and operation cost) have been calculated. The LCCA analysis calculates the total cost projected for year 1 (Net present value) for each plan as a function of the traffic flow [10]. Hereby the LCC analysis is presented: Given the inflow at each point of the intersection: 1) Point of intersection A (G. Obos Street) = 1837 vehicle/hour. Point of intersection B (Imam Bonjol Street) = 1846 vehicle/hour; 2) Point of intersection C (Diponegoro Street) = 2188 vehicle/hour; 3) Point of intersection D (R.T.A. Milono Street) = 1908 vehicle/hour; 4) Total incoming flow at intersection = 7779 vehicle/hour

Next, we illustrate the vertical line to touch the curve corresponding to the value of the total junction of the intersection as shown in Figure 4. It is found that the type of intersection corresponding to the total flow of the current intersection is an elevated interchange. An elevated interchange is a system where traffic between two or more roadways flows at different levels in the grade separated junctions [21]. According to Oregon Department of Transportation [22], elevated interchanges require major investment and may have a significant impact on the natural and built environments. They are the key elements of well-functioning access-controlled facilities. The decision to use an elevated interchange as a transportation solution requires careful and complete study, including traffic analysis, geometric design, and environmental impacts.

V. Conclusion

From the analysis and discussion, the following conclusions can be drawn: based on the analysis of the performance of the intersection in the existing condition with the saturation flow approach, obtained at peak hour, the B, C, and D approaches to Kecil Roundabout have an average delay value > 60 sec/pcu (service level F). This means that the current intersection condition is not able to accommodate the existing traffic flow.

Based on the best-planned scenario of improvement, scenario 1 (signalized roundabout) obtained service level D, scenario 2 (signalized intersection without roundabout) obtained service level D and almost reached service level C, and scenario 3 (enlargement of the roundabout) had a degree of saturation (DS) < 0.8. Heavy vehicle restrictions were applied to each scenario and had a positive role in reducing the degree of saturation and delays that occur.

Based on life-cycle cost analysis (LCCA), the best fitting type of intersection corresponding to the existing traffic flow is an elevated interchange. This needs to be taken into consideration for the future, as the traffic flow is increasing annually.

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