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A Mixture of Traffic Circle and Underpass to Increase Capacity of Intersection

Lambang Basri Said, Abdul Kadir Salim and Andi Alifuddin
Department of Civil Engineering, Faculty of Engineering, Indonesian Muslim University,
Jl. Urip Sumoharjo km 05, Makassar, Indonesia

Abstract: Degree of saturation happened in the observed intersection in Makassar is between 0.6 and 1.0 and it has low performance at the level of service score F (poorest) with high blocked frequency. This study is a design to develop the pattern of intersection handling to address the problem of comprehensive transportation. The system used simulation techniques for management and traffic engineering by implementing traffic circle and underpass as an alternative to improve intersection services. The study is designed in 2 years research at which in the first year it is more focused on traffic light design related to the operational time setting and cycle time setting as well as the number of optimum phase to be more increasing capacity and all at once measuring service performance from the implementation of traffic light. While in the second year is focused on designing of traffic circle and underpass as a key element in the analysis that research integrated with the traffic light in determining the performance and services level of technical/traffic engineering to measure cost savings and service levels, efficiency of time value and traffic delays as well as the difference in travel time for perspective use until 2025. The number of cycle obtained from optimum phase was 153 sec by green time of each approach that is North by 28 sec, South by 36 sec, West by 38 sec and East by 4 sec. This value was expected to be able to overcome queue from 6-160 vehicles and traffic delays by 18 until 54 sec of every vehicle while waiting for development of underpass and traffic circle finished. In a similar way, value of traffic delays and length of queue shows 11 sec per vehicle and 0.975 stop/vehicle. Effectiveness of intersection services can be increased to be better by developing underpass design. This is expected to decrease the degree of saturation from 1.0-0.2 at Perintis Kemerdekaan Street and 0.9-0.3 at Poros Maros Street.

Key words: Intersection, traffic light, traffic circle, underpass, degree of saturation, traffic delays

INTRODUCTION

Congestion is a major problem of transport activities in major cities (Arnott and Small, 1994) and has a major impact on the spatial and economic evelopment of cities and regions causes a reduction in investment of transport infrastructure (Banister, 2015; O'Mahony and Finlay, 2004). Congestion causes loss of vehicle operating costs were great and a lot of time wasted in traveling for weaving at the crossroads (Said, 2011). Many of the strategies have been developed to reduce congestion, some of which are focusing on improving the capacity of roads in terms of increasing number of lanes. One of method to solve this problem is proposing new overpasses and underpasses at the main road intersections and improving public transport (Kiunsi, 2013). Underpass may reduce traffic congestion at intersection whre other alternative have been exhausted (Dehnert and Prevedouros, 2004).

There are a lot of factors have caused congestion, one of them is the increase vehicles without followed by the development of new roads in the urban area. This situation occurred in many cities in Indonesia including Makassar. Administratively, Makassar is the provincial capital of South Celebes. The city area is 175.77 km^2 covering to 14 sub districts. The city is located at 0-700 m above sea level. According to the Central Statistics Agency (BPS) in 2012, the population of the Makassar people is 1.352.135 inhabitants and the growth rate is 1.56% each year. While the number of vehicles in South Sulawesi reaches up to 2.2 million units, at which 1.4 million of them is motorcycle and the remains are cars. Vehicle growth in South Sulawesi is 8-10% each year for four-wheeled motor vehicles and 13-14 each year for two-wheeled motor vehicles. On the other hand, the number of vehicles in Makasssar reaches up to seven hundred thousand units. The tendency of volume improvement to use highway is getting higher, so that, it

Corresponding Author: Lambang Basri Said, Department of Civil Engineering, Faculty of Engineering, Indonesian Muslim University, Jl. Urip Sumoharjo km 05, Makassar, Indonesia

is feared that the road network which its improvement is extremely low will not be able to accommodate the movement of community, goods and service well in the future. High movement demand will encourage a trend of transportation facilities and infrastructure needs.

Condition of vehicle movement pattern in Makassar continuously increasing has been implicated in the high vehicle density which encumbers road network. This condition also affects on the decrease of the performance of the road network, especially, at primary and secondary arterial network as strategic networks in Makassar such as Perintis Kemerdekaan Street, Poros Maros Street, Tol Reformasi Street and Bandara Sultan Hasanuddin Street.

Junction condition of this road network has significantly faced low performance and there is a long queue with high frequency. The use of signalized intersection today is not effective anymore to manage high volume of traffic flow. The indicator is seen from the cycle time of traffic light which cannot manage the movement of traffic light coming from several directions.

For that reason, this affects on the long delays of vehicles, especially from the direction of those streets. Actually, several alternatives have been performed such as the change of direction movement and junction shape. They are expected to be able to increase capacity of the junction but those are temporary alternatives and do not give significant contribution towards the increase of intersection capacity.

Traffic management with traffic circle and underpass system is needed in this case as an alternative to increase intersection capacity and services at that intersection. So, that it is expected to be able to give a contribution towards the enhancement of mobility and community productivity which is actually positively related to the economic growth of Makassar in specific and South Celebes in general.

A couple of researches on intersection have been performed previously. All of them focus on single traffic management such as separate traffic light and fly over or underpass as well as management of intersection and traffic circle. The result of the research shows that the development of intersection capacity is in the range of 20-50% from the previous capacity. Base on this situation this research is conducted to analysis of the effect of a traffic circle and underpass design at the intersection of Perintis Kemerdekaan Street, Poros Maros Street, Tol Reformasi Street and Bandara Sultan Hasanuddin Street. The main problem of this activity will be measured by the following things. How far any increase of capacity utilization of a traffic circle and underpass at intersection towards the intersection performance.

How the level of technical feasibility/engineering and traffic management by using several criteria as well as an analysis material, namely intersection capacity enhancement, Cost saving of Vehicle Operating (VOC), efficiency of time value, traffic delays and the difference in travel time. How to optimally determine the operational time and cycle time of traffic at each arm of junction.

MATERIALS AND METHODS

This study was undertaken in Makassar for 2 years. It starts from designing stage, survey data collection which is needed (both primary and secondary) and macro map from a related institution in Makassar. This study was done in Makassar at the intersection area of circle traffic and underpass at junction of Perintis Kemerdekaan Street, Poros Maros Street, Tol Reformasi Street and Bandara Sultan Hasanuddin Street.

In this study site, the most congested traffic flow happened in Sunday (busy day) for that reason a direct observation was performed by collecting data related to the traffic characteristic, namely traffic volumes, vehicle speed, the width of the road effectiveness as well as performing processing and analyzing data. Data collection was done through calculating each type of vehicle group in the every period of observation which is 15 min during an hour. Performance stages of this research process will be described in the following explanation.

First stage, limitation of research area: The location of research is in Makassar, comprising an approach area of intersection Perintis Kemerdekaan Street, Poros Maros Street, Tol Reformasi Street and Bandara Sultan Hasanuddin Street which is approximately 100 m at each junction arm.

Second stagem, survey: Better description of object characteristics observed can be obtained from relevant information with research purposes and objectives. Further information can be obtained from field review and interviewing related side. Type of data related to this research can be described as follows.

A research to collect primary data can be done by conducting a direct survey at field. It was carried out to know how much the volume of vehicle passing intersection, travel time in particular distance and approach area. In addition, measurement for geometrical intersection was done for planning orientation of a traffic circle and underpass.

Secondary data involves laws, government regulation and Ministerial Decree of Transportation relating to

transportation policy, map, residents, growth of vehicle and master plan of the road network. Data that have been collected are placed in the table to ease the process. Some of variables needed are traffic volumes, length of the queue and queue possibility, saturation flow, travel time, traffic delays and assessing intersection performance as a basis of designing of a traffic circle and underpass. Several methods used to obtain needed data were as follows. Observation, it was done through an observation and systematical statement towards symptom and phenomena observed based on direct observation.

Interview having an interview with related sides, namely operational management of transportation service manager and all public transportation drivers. Documentation, using documentation in the form of photos and notes related to the research.

Third stage data analysis: The research formulates and identifies problem related to the wisdom of traffic organizing, policy that has been done and together with that, literature reviews related to the field was done. Questionnaire it is a data collection technique by giving a set of question proposed proportionally to respondents in this case is road users from any kind of community.

The second-year research would be done by integrating the design of traffic circle plus underpass with field data collection and secondary data through the related institution both local and provincial government. Field data were getting from 2 ways, manual and counting collection.

RESULTS AND DISCUSSION

Traffic volume characteristics: The result of survey of traffic volumes in 2014 at the study site is presented in Table 1. Table 1 showed the highest and the lowest volumes of traffic by 8,359 pcu/h and 2.976 pcu/h, respectively while the average value is 5.371 pcu/h. According to the maximum values it can be seen that the highest volume reached is 10, 3012 pcu/h while the lowest is 4.327 pcu/h and the average value is 7,407 pcu/h. On the other hand, the highest volume of the minimum value is 6,844 pcu/h while the lowest is 822 pcu/h and the average value is 2,945 pcu/h.

Traffic speed characteristics: The result of traffic speed survey on those four samples of road were presented in Table 2. The characteristics show that according to free flow speed, the highest road is 30.21 km/h and the lowest is 16.25 km/h while the average speed is 24.48 km/h.

Table 1: Traffic volume at the road around study site

	Volume (pcu/h)		
Street arms	Average	Minimum	Maximum
Perintis Kemerdekaan	7.166	822	10.302
Poros Maros	8.359	6.844	10.247
Tol Reformasi	2.976	1.502	4.751
Bandara Sultan Hasanuddin	2.982	2.611	4.327
Average volume	5.371	2.945	7.407
Lowest average	2.976	822	4.327
Highest average	8.359	6.844	10.302

Table 2: Traffic speeds at the roads at the study sites

Street arms	Traffic free flow speed (km/h)
Perintis Kemerdekaan	21.44
Poros Maros	30.01
Tol Reformasi	30.21
Bandara Sultan Hasanuddin	16.25
Average speed	24.48
Lowest speed	16.25
Highest speed	30.21

Table 3: Traffic capacity, degree of saturation and level of services. Road arounds the study site

Street arm	Capacity (pcu/h)	Degree of comparison	Level of services
Perintis Kemerdekaan	5.880	1.46	F
Poros Maros	4.277	1.62	F
Tol Reformasi	3.666	1.22	F
Bandara Sultan Hasanuddin	5.880	1.38	F
Average	4.926	1.42	F
Lowest	3.666	1.22	F
Highest	5.880	1.62	F

Road capacity characteristic: Capacity of 4 samples of road is presented in Table 3. According to the Table 3, it can be seen that the highest traffic capacity at the road at study site is 5,880 pcu/h and the lowest capacity is 3.666 pcu/h while the average capacity is 4.926 pcu/h.

Degree of saturation of traffic: The analysis result showing the value of degree of saturation from those four roads which also the sample of road of this study are presented in Table 3. Acording to the Table 3, it can be seen that the highest value of degree of saturation is 1.62 while the lowest value is 1.22 and the average value is 1.42.

Level of road services: Further analysis of the results shows the value of level services at those four roads becoming the sample of this research is presented in Table 3. It showed that the level of services of all roads surveyed in the study site.

Traffic composition: Traffic compositions of those 4 samples of road were presented in Table 4. According to the result it can be seen that composition of traffic vehicle based on the average value is motorcycle with the

Table 4: Traffic compositions at the study site

	Traffic composition											
	Motorcycle		Public transportation		Private cars		Pick up		Heavy vehicle		Non-motorized vehicles	
Street arms	Amount	Percentage	Amount	Percentage	Amount	Percentage	Amount	Percentage	Amount	Percentage	Amount	Percentage
Perintis Kemerdekaan Street	20.825	70.06	2.437	8.20	4.995	16.81	749	2.52	301	1.01	416	1.40
Poros Maros Street	18.903	63.33	3.066	10.27	5.041	16.89	741	2.48	707	2.37	1.392	4.66
Tol Reformasi Street	11.211	66.11	1.307	7.71	2.681	15.81	395	2.33	1.364	8.04	0	0.00
Bandara Sultan Hasanuddin Street	11.671	66.76	533	3.05	4.570	26.14	709	4.06	0	0.00	0	0.00
Average	15.653	64.80	1.264	8.40	2.496	16.70	409	2.90	328	2.50	642	4.70
Lowest	11.211	51.90	389.0	3.00	798.000	11.10	154	2.10	0	0.00	0	0.00
Highest	20.825	71.70	3.066	14.90	5.041	26.10	1.238	10.00	1.364	12.00	1.515	11.10

Table 5: Number of phase and signal time at the study site

	Signal time (sec)				
Phases	Green	Yellow	Red	Cycle time (sec)	All red time (sec)
I (PS)	28	3	120	2	153
II (MU)	36	3	112	2	
III (TB)	38	3	110	2	
IV (BT)	44	3	104	2	

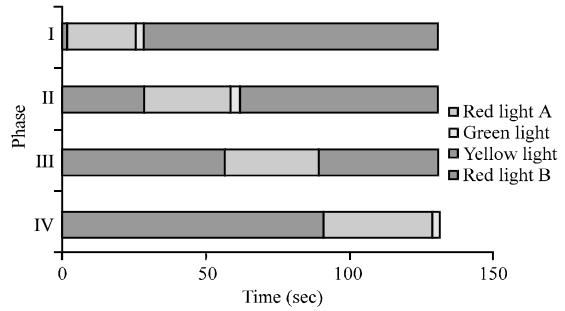

Fig. 1: Phase and time signal of each indication are fitted for the color

highest value by 64.8%, followed by private car of 16.7%, public transportation by 8.4%, van by 5.4% and the remains are non-motorized vehicle by 4.7%. The last result of the first year-research of traffic light showed a cycle time of traffic lights by 153 seconds for four phases. Signal time of every road approach shows that green traffic light time stays for 28-44 sec and red traffic light time by 104-120 sec. Description about the signal time can be presented as in Table 5 and Fig. 1.

Further research in the second year is related to the development of a traffic circle and underpass predicted will result in a four-fold increase in the capacity while the degree of saturation drastically decreases. That phenomenon can be in Table 6. In 2015, capacity increased from 5,354.4 pcu/h-22,542.03 pcu/h when there was traffic circle and it increases again until 24,094 pcu/h, since, underpass is built. Those increases still give good performance until 2024 L.

The result of the calculation above shows that there is change of travel time and vehicle speeds in every arm of the junction. The arm of Jl. Perintis Kemerdekaan in 2014 has traffic delays of 0.2331-0.8150 h and the travel time is 1.5159-2.8148 h. Traffic delays and travel time will experience a significant change in 2024 by travel time of 0.4182 until 1.3295 h after underpass development.

That change is influenced by the decrease of vehicle growth but it does not support by intersection capacity enhancement. As it previously described that the condition of traffic movements in 2024 at the intersection Tol Sutami-Poros Maros Street will experience a stable condition in which DS is >1.00. For that reason, through the scenario of underpass development there is significant development towards intersection performance enhancement, so that, traffic delays can be minimized. The calculation of projecting data showed that after the underpass is being built, speed rate can be maintained and exact travel time also experiences drastic enhancement. Degree of saturation was reduced from 0.19-0.04 in 2015 and from 0.64-0.14 in 2025 (Table 6).

The result showed that if there is nothing to do, intersection performance condition in 2024 will experience a significant decrease and level of services is at the level of F or DS>1.00 (poor service condition). But if the shape of the intersection is changed, intersection capacity that has been planned by the infrastructure department of South Sulawesi will have extremely high value of level of services that is in the level of D and A. It means that the condition of traffic movement after development of the underpass will be stable. However, traffic movements in the arm of Tol Sutami Street is only be able to manage traffic management until the end of 2023. Meanwhile in 2024 traffic movement condition experience a decrease again in the level of services at the level of F with DS>1.00 and follow traffic movements at the arm of Poros Maros Street in 2019 fall in F degree (Table 6).

The combination of a traffic circle and underpass may reduce the congestion in Makassar through two mechanisms. First, traffic circle may improve expedite the travel while second, the underpass play as an alternative route. Some strategy to reduce congestion is conducted

Table 6: Projection of intersection performance at the study site from 2014-2024

				Do nothing		Traffic circle		Combination	
Years (a)	Volume (b)	Increasing factors (c)	Exponential values (d = (1+c) n)	Volume (e)	Capacity (f)	DS (g = b/f)	Capacity (h)	DS (i = b/h)	Capacity (j)	DS (k = b/h)
2014	1022	-	-	1154	5,354.40	0.19	22,542.03	0.05	24,094.8	0.04
2015	1154	0.129057	1.129057	1303	5,354.40	0.22	22,542.03	0.05	24,094.8	0.04
2016	1303	0.129057	1.129057	1471	5,354.40	0.24	22,542.03	0.06	24,094.8	0.05
2017	1471	0.129057	1.129057	1661	5,354.40	0.27	22,542.03	0.07	24,094.8	0.05
2018	1661	0.129057	1.129057	1875	5,354.40	0.31	22,542.03	0.07	24,094.8	0.07
2019	1875	0.129057	1.129057	2117	5,354.40	0.35	22,542.03	0.08	24,094.8	0.08
2020	2117	0.129057	1.129057	2390	5,354.40	0.40	22,542.03	0.09	24,094.8	0.09
2021	2390	0.129057	1.129057	2699	5,354.40	0.45	22,542.03	0.11	24,094.8	0.10
2022	2699	0.129057	1.129057	3047	5,354.40	0.51	22,542.03	0.12	24,094.8	0.11
2023	3047	0.129057	1.129057	3440	5,354.40	0.57	22,542.03	0.14	24,094.8	0.13
2024	3440	0.129057	1.129057	3884	5,354.40	0.64	22,542.03	0.15	24,094.8	0.14

by applying to a combination of the corridor system and circulatory system. System corridor a major route that is end to end (or it could be circular but still on the main track) while the circulatory system is the route twisting required as a feeder of the corridor system (Sukarto, 2006).

Performance change with underpass development scenario positively affects on the decrease of vehicle delays which also affects the decrease of travel time. Speeds change as an influence of travel time reduction gets saved of Vehicle Operating Cost (VOC) and efficiency of time value.

The underpass is one of the proposed structures support. Additionally, the traffic circle addition increases intersection capacity. Traffic light is still needed with circle time of 70-160 sec, following the improvement pattern of physical development related to the planning stage. Development of a traffic circle and underpass at the intersection also affects on the decrease of delay time and travel time and increase vehicle speed as the value of NVK is under 0.5 and level of services is 0.44. The result of the research shows the decrease of degree of saturation phenomenon from 1.0-0.31 at Perintis Kemerdekaan Street and 0.9-0.38 at Poros Maros Street.

CONCLUSION

A study on practical strategies for reducing congestion and increasing mobility in Chicago City showed that the queue jumper concept for this report involves jumping one lane of traffic per direction instead of two lanes per direction and involves both an overpass and an underpass at each interchange (Staley, 2012). Moreover, Dehnert and Prevedouros (2004) stated that underpasses with low-clearance can reduce traffic congestion at intersections.

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