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An Analysis of the Economic Value of Left – Turn System at the Intersection for Urban Environmental Benefit

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ABSTRACT

Background: Congestion is a major problem of transport activities in major cities including big cities in Indonesia. Congestion occurs when the capacity of the road is fixed, but the number of road users has increased continuously, resulting in longer travel time. There are a lot of factors have caused congestion, some of them are gridiron intersection and the increase of two-wheeled vehicles. Deceleration of vehicle speed at the intersection is the main cause of lost time in travelling. **Objective:** The objectives of this study are to analyze the efficiency of vehicle operating costs and travel time by developing geometric widening. **Methods:** This study was performed at Makassar City, South Celebes. The sampling technique in this study was accidental sampling, direct field observation, survey, and in-depth interviews of 80 (eighty) respondents. The study sites were 4 (four) arm of intersections as follows Veteran Utara (VU) Street; Veteran Selatan (VS) Street; Sungai Saddang (SS) Street; and Sungai Saddang Baru (SSB) Street. Data analysis was performed with a traffic evaluation device with an advanced microanalysis analyzing lane by lane with a recurrent approximation method to obtain capacity and performance statistics such as delay, the degree of saturation, and service levels. **Results:** This study showed that without any actions (do nothing) the intersection performance in 2025 will experience high degree of saturation (DS) of all the arms, fell at 0.9 and severe degradation in which level of service fall in F level with DS>1 (poorest service conditions). When geometric widening is developed at intersections, level of service will be of a very high that increasing at the level of A and C. **Conclusion:** In the analysis of the left - turn system with geometric improvements (super elevation), increased time and cost efficiency, and thus more benefit in VOC in order to accelerate the movement of goods and people.

INTRODUCTION

Congestion is a major problem of transport activities in major cities (Arnot & Small, 1994). According Wohl and Hendrickson (1984), congestion occurs when the capacity of the road is fixed, but the number of road users increase continuously, resulting in longer travel time. Traffic congestion causing great expense and inconvenience for many businesses and companies, especially companies that require high levels of transport activity per unit of production. Since the mid-1990s until today, economic activity has falters. In addition, the impact of congestion also causes a reduction in investment of transport infrastructure (O'Mahony & 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). A study conducted in the United States shows that congestion causes

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shrinkage of the market area and reduces the "agglomeration economies" of companies operating in major urban areas, thus increasing the cost of production (Weisbrod *et al.*, 2003).

There are a lot of factors have caused congestion, some of them are gridiron intersection and the increase of two-wheeled vehicles at a rate of 13% to 14% per year and four-wheeled vehicle at a rate of 8% to 10% per year. This increased are ironically not supported by the development of new roads in the urban area. In Makassar City, South Celebes, from 2009 to 2014 data, the roads only increased by 0.01% kilometer per year (BPS, 2015), which ideally should increase from 10 to 15 kilometers per year.

Characters of road users are no longer suitable with gridiron roads due to the accelerated rate. Travel time and travel expenses, due to an increase in the number of vehicles moving inside contemporary cities nowadays, have caused lost in cost trip (Hippodamus). It has also caused long queue because of the interrupted velocities (freedom of movement) of vehicles as well as traffic behavior of road users resulting in dirty air concentration at intersections. In addition, the non-geometric shape of urban intersections has resulted in delays and permanent congestion. As a result, freedom of movement in the area to avoid congestion has turned into points of conflicts. Generally, a movement to the right shall not be done and is so disturbing due to the weaving resulted (Said, 2011). This is caused by the presence of crossing groups that require accretion phase and other settings. Installation of promoting media, such as rumble strips in the area of violations, are generally not recommended in relation to remove adhesions resulting in congestion. Finally, left-turn lanes can be included in this issue.

There are several concerns of improving safety effect of cross-section design i.e. lane widening, shoulder widening and left-turn. The aforementioned problems are the reason to examine the level of losses incurred, both financial loss and loss of travel time converted in vehicle operating costs, contamination and sustainability of the environment by analyzing the economic value of the sustainable environment toward left-turn system that does not cause conflict (no weaving) at intersections in urban areas. Therefore, intersections require decomposers such as geometric design, turning left or right (McCoy and Malone, 1989; Karlaftis and Golias 2002). Many studies about congestion relates with mathematic modelling (Thiagarajan *et al*., 2016), information system by using algorithm programming (Tan *et al*., 2013), and wireless ad hoc network (Rajesh and Gnanasekar, 2015). Moreover, studies in geometric design focus on safety to reduce roadway accident (McCoy and Malone, 1989; Karlaftis and Golias 2002). There is no information about relationship of geometric widening with vehicle volume and travel cost. Based on the above problems, this study intends to examine the level of losses incurred, both financial and travel time. The objectives of this study are to analyze the degree of saturation, level of services, efficiency of vehicle operating costs and travel time, with applied geometric widening intersection and left-turn system in Makassar. The objectives of this study are to analyze the efficiency of vehicle operating costs and travel time by developing geometric widening.

MATERIALS AND METHODS

Scope of Study:

The approach used in this study is quantitative descriptive, focusing on the formulation of research problems. The discussion in this study is the result of the processing of the data and was based on measurable variables. The study employed a mix between a quantitative, interpretive, purposive, and survey approach, interviews and in-depth interviews with respondents. This approach is based on direct observation at intersections. This study also used vector calculation in determining the geometric design of an intersection.

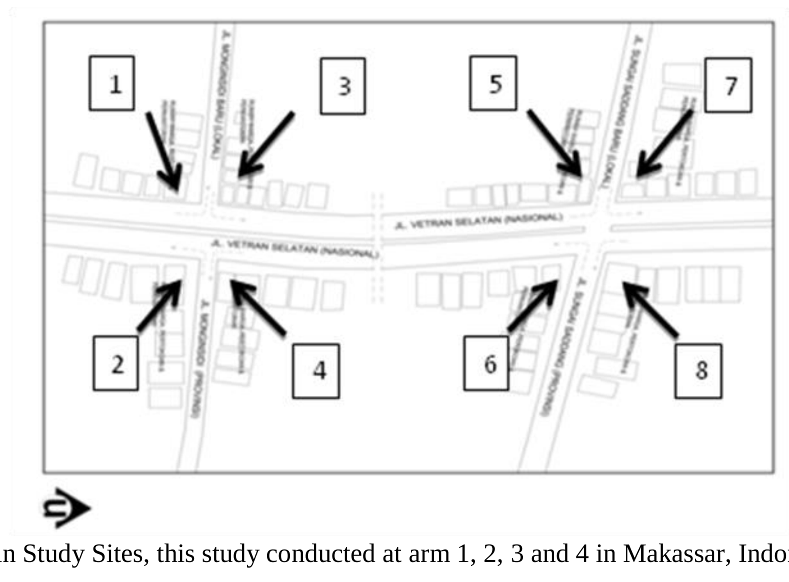

Fig. 1: Intersections in Study Sites, this study conducted at arm 1, 2, 3 and 4 in Makassar, Indonesia

The sampling technique in this study was accidental sampling, direct field observation, survey, and in-depth interviews of 80 (eighty) respondents. The study sites were 4 (four) arm of intersections as follows Veteran Utara (VU) Street; Veteran Selatan (VS) Street with Sungai Saddang (SS) Street - Sungai Saddang Baru (SSB) Street (Figure 1). There were three variables used in this study, as follows:

1. Fuel—the fuel used before and after congestion at intersections before turning.
2. Time—the length of time the vehicle stuck in traffic jams at intersections before turning.
3. Convenience—the comfort referring to physical and non-physical effects due to congestion.

In addition, we examined the 8 (eight) variables supporting and inhibiting losses and time.

Data Collection:

a) Intersection Data

A basic configuration of intersections, related to the number of sections and volume.

b) Geometric Data

Intersection geometric data show the geometric condition of the road studied, including approaches, lane configuration approaches, and lane condition.

c) Traffic Volume

It is defined as the number of vehicles that pass a point of road (transverse) in one time written in point/hour/lane, divided into three classes of vehicles, namely low vehicle, heavy vehicle, and motorcycle.

d) Speed

Speed is defined as the total distance traveled divided by the total time it took to travel that particular distance in km/hour m/sec.

e) Movement Data

The data are based on the movement of vehicles, which is determined by the direction—be it left, straight, and right that include space and queues of vehicles.

f) Priority

Priority setting is done by setting the opposing movements for every move selected. If the movement from the opposite direction has been determined on each selected movement, the program will identify and treat it as a challenged movement. At a signaled intersection, the challenged movement must be in the same phase with the reviewed movement.

g) Gap Acceptance Data

Gap acceptances the process of entry of vehicles from minor flows through a gap to major pathways that include data on follow up headway and critical gap.

h) Phase and Time Data

Phase and time data is the data to be included in the program to be processed and evaluated on the influence of the phase time-delay occurring at the intersection.

Performance Measures at Intersection:

Performance measures in general in the analysis of signalized intersections that can be expected are:

a) Capacity

Saturation flow (s) is the maximum number of vehicles that can run. The proportion of green time (g) with the cycle time (c) is called the green time ratio (u). Capacity (Q) has the same unit with saturated flow, i.e. vehicles/hour.

b) Degree of Saturation

Degree of saturation (x) is the ratio of inflows (q) compared with a capacity.

c) Delay

Delay is the average vehicle delay during the current specified period, including delay after the end of the period.

d) Level of Services

Based on Sidra Intersection 5.1 User Guide, in measuring the level of service, method of delay and degree of saturation must be used. This method uses the average delay and the degree of saturation as the basis for setting the level of service.

Data Analysis:

Analysis can be performed with a traffic evaluation device with an advanced microanalysis analyzing lane by lane with a recurrent approximation method to obtain capacity and performance statistics such as delay, the degree of saturation, and service levels. This analysis evaluates the signalized intersection. The calculation is performed for two conditions, namely the existing linear condition and turning conditions at intersections. The results of the analysis are in the form of intersection performance parameters such as capacity, degree of saturation, delays, and service levels. Results of analysis for these two conditions are then compared to determine the effect of the geometric arrangement of traffic light at the intersections.

Determining the value of variables for intersection performance measures is done using an analytical method based on Manual Highway Capacity Indonesia in 1997 that includes the analysis of traffic characteristics, density, type and width of approaches, basic saturation flow and flow rate, the determination of adjustment factor value, and analysis of traffic behavior.

RESULT AND DISCUSSION

Analysis on Intersection Performance:

From the results of the analysis, during do nothing moment, degree of saturation (DS) of all the roads, and the sections of the intersection were at 0.9, and this would bring such bad effect toward road service level performance, environmental stability, and public health conditions both for short term and long term. With the high degree of saturation, level of service (LS) exceeding 0.85 (F), means that the intersections studied were in over-saturated condition that would cause long queues at peak traffic conditions up to 500 meters.

Table 1 showed that, if no actions were taken (do nothing) then intersection performance in 2025 will experience severe degradation in which TP will be at F level with DS > 1 (poorest service conditions). However, if geometric widening is developed at intersections, LS will be of a very high service that increasing at the level of A and C. This meant that the movement of the traffic after geometric widening will be stable. However, the movement of traffic on the arm of VS Street will just be able to cope with the movement of traffic until the end of the study in 2024 and 2025 in which LS will be back on F level with DS > 1. The movement of traffic on the arm of VU Street and SS Street in 2025 will also be the same, in which LS will be fall on F level with DS > 1.

Table 1: Recapitulation one the Scenario of Intersection Performance in 2025

Street	Do Nothing				Geometric Widening			
	Volume (vehicles/hour)	Capacity (vehicles/hour)	DS	LS	Volume (vehicles/hour)	Capacity (vehicles/hour)	DS	LS
SSB	16,360	5,403	3.03	F	8,645	18,471	0.56	C
VS	15,992	5,354	2.98	F	11,218	22,434	0.50	A
SS	11,076	5,188	1.48	F	12,505	14,269	0.88	E
VU	8,674	5,405	1.61	F	9,794	8,648	1.01	F

Note: DS = degree of saturation; LS = level of service; A = very high service; C = moderate service, E = poor service, F = poorest service

Travel Time Efficiency:

In the initial year (2015), time efficiency at SSB Street was 0.15088. The value of that for each vehicle of Class I was IDR 1,550.66, Class II was IDR 3,141.59 while Class III was IDR 370.55 per hour. In 2025, projection data showed that the time efficiency was increased to 0.56586. Projection of growth in the time value can be calculated using an exponential equation by first determining growth factor (r) of the function of income per capita of the population. The results show a significant increase in the time value each year. The increase time efficiency values were as follows: Class I was IDR 18,343.10, Class II was IDR 37,162.64 while Class III was IDR 4,383.29 per hour (Table 2).

Table 2: Time Efficiency on the Arm of SSB Street

Year	Travel Time		Difference in Travel Time	Time Efficiency (IDR vehicle/hour)		
	Do Nothing	Develop Widening		Class I	Class IIA	Class IIB
2015	0.46382	0.31294	0.15088	1,550.66	3,141.59	370.55
2016	0.48274	0.31598	0.16676	1,922.54	3,895.02	459.41
2017	0.50438	0.31924	0.18514	2,394.30	4,850.79	572.14
2018	0.52935	0.32274	0.20660	2,997.03	6,071.91	716.17
2019	0.55841	0.32651	0.23190	3,773.49	7,644.99	901.72
2020	0.59263	0.33057	0.26206	4,783.41	9,691.07	1,143.05
2021	0.63347	0.33495	0.29852	6,112.05	12,382.85	1,460.54
2022	0.68296	0.33968	0.34327	7,883.99	15,972.76	1,883.97
2023	0.74410	0.34481	0.39929	10,286.83	20,840.86	2,458.15
2024	0.82144	0.35037	0.47108	13,613.52	27,580.64	3,253.10
2025	0.92226	0.35641	0.56586	18,343.10	37,162.64	4,383.29

Time efficiency at VS Street was 0.17057 in 2015. The value of that for each vehicle of Class I was IDR 1,753.07, Class II was IDR 3,551.68 while Class III was IDR 418.92 per hour. In 2025, projection data showed that the time efficiency was increased to 0.49392 The increase time efficiency values were as follows: Class I was IDR 16,011.20, Class II was IDR 8,454.02 while Class III was IDR 3,826.05 per hour (Table 3).

Table 3: Time Efficiency on the Arm of VS Street

Year	Travel Time		Difference in Travel Time	Time Efficiency (IDR vehicle/hour)		
	Do Nothing	Develop Widening		Class I	Class IIA	Class IIB
2015	0.65133	0.48076	0.17057	1,753.07	3,551.68	418.92
2016	0.67068	0.48451	0.18617	2,146.27	4,348.29	512.88
2017	0.69231	0.48852	0.20379	2,635.39	5,339.23	629.75
2018	0.71661	0.49281	0.22380	3,246.56	6,577.44	775.80
2019	0.74409	0.49740	0.24669	4,014.10	8,132.46	959.21
2020	0.77536	0.50233	0.27303	4,983.54	10,096.52	1,190.87
2021	0.81120	0.50761	0.30359	6,215.98	12,593.41	1,485.38
2022	0.85267	0.51329	0.33938	7,794.50	15,791.45	1.862.58
2023	0.90111	0.51940	0.38171	9,833.86	19,923.14	2,349.91
2024	0.95838	0.52599	0.43239	12,495.45	25,315.46	2,985.93
2025	1.02702	0.53310	0.49392	16,011.20	32,438.27	3,826.05

Time efficiency at VS Street was 0.03905 in 2015. The value of that for each vehicle of Class I was IDR 401.32, Class II was IDR 813.06 while Class III was IDR 95.90 per hour. In 2025, projected data showed that the time efficiency was increased to 0.12872. The increase time efficiency values were as follows: Class I was IDR 4,172.82, Class II was IDR 8,454.02 while Class III was IDR 997.14 per hour (Table 4).

Table 4: Time Efficiency on the Arm of SS Street

Year	Travel Time		Difference in Travel Time	Time Efficiency (IDR vehicle/hour)		
	Do Nothing	Develop Widening		Class I	Class IIA	Class IIB
2015	0.20641	0.16736	0.03905	401.32	813.06	95.90
2016	0.21283	0.16986	0.04298	495.47	1,003.81	118.40
2017	0.22003	0.17256	0.04747	613.94	1,243.83	146.71
2018	0.22815	0.17550	0.05265	763.83	1,547.49	182.52
2019	0.23737	0.17870	0.05867	954.62	1,934.04	228.12
2020	0.24789	0.18219	0.06570	1,199.18	2,429.51	286.56
2021	0.26002	0.18602	0.07400	1,515.14	3,069.63	362.06
2022	0.27413	0.19022	0.08390	1,927.05	3,904.15	460.49
2023	0.29071	0.19485	0.09586	2,469.70	5,003.55	590.16
2024	0.31047	0.19997	0.11050	3,193.43	6,469.81	763.11
2025	0.33437	0.20565	0.12872	4,172.82	8,454.02	997.14

Time efficiency at VU Street was 0.02033 in 2015. The value of that for each vehicle of Class I was IDR 208.91, Class II was IDR 423.25 while Class III was IDR 49.92 per hour. In 2025, projected data showed that the time efficiency was increased to 0.04249. The increase time efficiency values were as follows: Class I was IDR 1,377.39, Class II was IDR 2,790.55 while Class III was IDR 329.14 per hour (Table 5).

Table 5: Time Efficiency on the Arm of VU Street

Year	Travel Time		Difference in Travel Time	Time Efficiency (IDR vehicle/hour)		
	Do Nothing	Develop Widening		Class I	Class IIA	Class IIB
2015	0.15865	0.13832	0.02033	208.91	423.25	49.92
2016	0.16068	0.13893	0.02175	250.74	507.99	59.92
2017	0.16288	0.13958	0.02330	301.27	610.36	71.99
2018	0.16526	0.14028	0.02498	362.40	734.22	86.60
2019	0.16784	0.14101	0.02682	436.50	884.33	104.31
2020	0.17064	0.14179	0.02884	526,46	1,066.59	125.80
2021	0.17368	0.14263	0.03106	635,89	1,288.30	151.95
2022	0.17701	0.14351	0.03350	769,31	1,558.60	183.83
2023	0.18064	0.14445	0.03619	932,33	1,888.88	222.79
2024	0.18463	0.14546	0.03917	1,132.05	2,293.50	270.52
2025	0.18902	0.14653	0.04249	1,377.39	2,790.55	329.14

Efficiency can be seen clearly—in no geometric improvement, condition seems to be stagnant from year to year. However, after the improvement of the intersection, a trend towards decreasing the value of travel time limit happens. This meant that improvement directly influences traffic at the intersection. If geometric improvements were not done at intersections, continuous imbalanced use of roads due to congestion would occur all the time, according to the load of vehicle unit at the intersections.

From these results, it appeared that intersection geometric widening caused a reduction in delays and travel time at the same location of approach. With the geometric improvement, the time efficiency increased, in the interval of 0.82 % to 1.28 %. This meant that the movement of vehicles can be energized by obtained the opportunity to utilize the unused travel time efficiently. This opportunity might be beneficial because of the efficiency of rupiah for the class of vehicle periodically. This advantage was obtained with a larger nominal at beginning and end of a quarter in a period. During the period of transition, it has not yet brought substantial benefits although the overall value obtained annually is very satisfying. This value was created and obtained by the presence of corrective measures and geometric improvement at intersections.

Analyzing Speed:

The calculation result graphically showed that acceleration further increases in the middle of the period where speed driving on the roads may reach two times larger and higher in value; when no geometric improvement was done, this tends to slow down due to congestion. Meanwhile, geometric improvement may certainly help to reduce congestion in all arms (Figure 2):

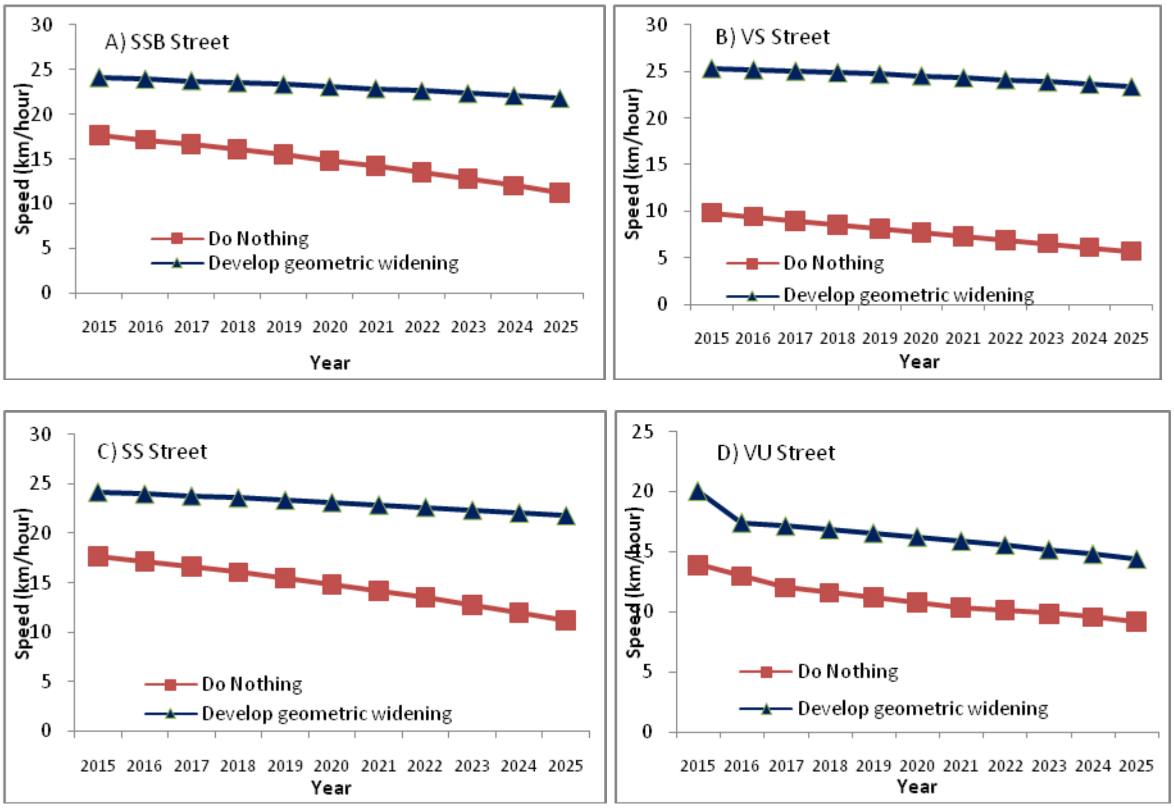

Fig. 2: Changes in Speed in 2015 – 2025 for All Arms of Intersections

Analyzing Vehicle Operational Cost (VOC):

After a geometric widening, VOC obtained varied. By using constant prices, VOC obtained in 2025 is as follows: at SSB Street, in 2015, it ranged from 13.29% to 21.67%, and in 2025, it reached 25.43% to 58.25%; at VS Street, in 2015, it ranged from 10.66% to 16.95%, and in 2025, it reached 19.43% to 37.89%; at SS, in 2015, it ranged from 7.50% to 11.30%, and in 2025, it reached 14.26% to 26.52%; while at VU Street, in 2015, it ranged from 1.93% to 4.06%, and in 2025, it reached 0.08% to 10.75%. This implies that development of geometric widening may lead to decrease of VOC as a result of the reduction in travel time at the intersection. Several studies reported that traffic congestion impose to fuel consumption and increase travel cost (Greenwood and Bennett, 1996; Lindsney and Verhoef, 2001; Weisbrod *et al*., 2003).

Because the intersection is part of the curved street after repair geometry, physical principles will largely determine the vehicle's appearance and movement of people in the arch of roads. This situation increased the vehicle speed. Therefore, that geometry was applied to all arms intersections studied. Most important in the design of the intersection is the radius of curvature and super-elevation (Morlok, 1995). Several studies report that geometric widening improves road quality, safety and hence reduce incidence of head-on crashes on two-lane roads (Zhang and Ivan, 2005; Zeeger *et al*., 1992).

Conclusion:

This study showed that without any actions (do nothing) the intersection performance in 2025 will experience high degree of saturation (DS) of all the arms, fell at 0.9 and severe degradation in which level of service fall at F level with DS > 1 (poorest service conditions). When geometric widening is developed at intersections, level of service will be of a very high that increasing at the level of A and C. Because the intersection is part of the curved street when geometry was modified, physical principles will largely determine the vehicle's appearance and movement of people in the arch of roads consequently increasing the vehicle speed. The projecting data on road geometric modification showed that acceleration increased in the middle of the period where vehicle speed on the roads may reach twofold. When no geometric improvement was done, this situation leads to decrease of speed and hence create congestion. This modification enhances of time and cost efficiencies, and thus more benefit in VOC and hence may accelerate the movement of goods and people. By using constant prices, VOC obtained in 2025 is as follows: at SSB Street, in 2015, it ranged from 13.29% to 21.67%, and in 2025, it reached 25.43% to 58.25%; at VS Street, in 2015, it ranged from 10.66% to 16.95%, and in 2025, it reached 19.43% to 37.89%; at SS, in 2015, it ranged from 7.50% to 11.30%, and in 2025, it reached 14.26% to 26.52%; while at VU Street, in 2015, it ranged from 1.93% to 4.06%, and in 2025, it reached 0.08% to 10.75%.

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