Traffic Signal Coordination Based on Vissim Software (Case Study of Sudirman Road in Denpasar City, Indonesia)

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Abstract. Transportation problems in the form of congestion, delays, as well as air and noise pollution are very common in several big cities in Indonesia such as Denpasar City (the capital of Bali Province). Traffic congestion has been experienced on almost all major roads in Denpasar City and one of them is Sudirman road. There are several signalized intersections located at close distances. Traffic jam is usually experienced during peak hour which causes an increase in travel time, energy consumption, and air pollution. There is a potential to coordinate these intersections in order to reduce congestion. The objective of this study is to optimize intersection performances by coordinating traffic signals. This study applied a micro-simulation approach by using Vissim software. The t-test method was used to test the validity of the simulation. The results indicated that the intersections were in the level of service F. Comparison of the intersection performances showed that there was an increase in the intersection performances as indicated by the decrease in the queue length, delay, stop delay, and fuel usage. There was a decrease in the queue length of about -18.52% (from 544.63 m to 443.74 m), a decrease in the delay of about -20.41% (from 344.19 sec/pcu to 273.94 sec/pcu), a decrease in the stop delays of about -21.61% (from 32.84 sec/pcu to 25.74 sec/pcu) and a decrease in the fuel use of about -5.15% (from 17.19 liters/hour to 16.30 liters/hour).

1 Introduction

Cities in developing countries like Indonesia have experienced continuous growth in private vehicle ownership which becomes one of the main concerns of the government. Based on the study in Badung Regency, Bali, Indonesia, it was identified that there are a lot of elements (safety, ability to accommodate more family members, and social standing) that affect the choice between a motorcycle and a car, including monthly family income, monthly transportation costs, the number of family members and students living in the home [1]. As the traffic volume continues to increase, many cities in Indonesia (including Denpasar City) have experienced increase in traffic congestion, especially at the signalized intersection. This condition will be followed by the increase in the environmental impact. One of the ways to

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reduce the environmental impact of the road traffic congestion at the signalized intersection is by implementing traffic signal coordination.

Traffic signal coordination is an important aspect of transportation engineering aimed at improving the efficiency of urban traffic flow. There are many studies applying a micro-simulation method to optimize signalized intersection performances. A study in Alexandria, Egypt focused on applying optimization to simulate traffic signal timings under oversaturated conditions, in order to find various solutions to the problem at hand [2]. The ExtendSim simulation environment has been used to create a number of computer simulation models to depict the actual system and suggested solutions. While the average wait time for a vehicle has decreased by 32%, the average line length has decreased overall by 36%. Vissim is one of the powerful simulation software [3]. VISSIM software can be used to simulate traffic flow and evaluate the performance of traffic signal coordination systems. [4] investigated "self-organizing signals," a novel traffic signal control paradigm based on local actuated control but with certain extra principles that generate cooperation mechanisms. When compared to an optimum coordinated-actuated scheme without transit priority, simulation experiments in VISSIM on arterial corridors in Massachusetts and Arizona demonstrate overall delay savings of up to 14%, and more than 30% in scenarios with transient oversaturation.

An adaptive signal control plan along the Huangshan Road in Hefei, China has been designed [5]. They used Transyt software to find the optimal fixed-time signal plan and evaluating the plan using Vissim software. It was found that delay in the adaptive signal control was reduced noticeably than that in the fixed time control. The VISSIM software is used to simulate the traffic system before and after the improvement to overcome traffic delay in the main riad in Beijing, China [6]. They discovered that while the average number of cars per vehicle, the per capita delay, and the parking time have all dramatically decreased, the number of vehicles and the number of passengers have clearly increased. The Vissim software was applied to analyze the installation of a traffic signal at the skewed T-Intersection in the Emakulam district of Kerala, India [7]. It was found that the vehicle delay has decreased after the installation of the signal. The Vissim software was applied to design and evaluate an isolated traffic light controlled intersection in Spisska Nova Ves, Slovakia [8]. From the two models developed have led to a 75% reduction of the queue length. The Vissim software was used to analyze installation of traffic signal at unsignalized intersection in Bekasi, Indonesia [9]. The study found that replenishing the intersection's two-phased signals with a 106-second cycle time, as an alternative counter condition, was successful in reducing 24% of traffic conflict. Vissim has also been used to simulate traffic signal coordination. An investigation on the benefits of signal coordination by means of traffic microsimulation software, PTV Vissim in Bangalore (the capital city of Karnataka), India has been conducted [10]. From Mother Theresa intersection to Sarvanton intersection, travel time and delay were reduced after signal synchronization by 102.4 seconds and 110.32 seconds, respectively. The traffic signal controllers have been optimized for a congested corridor in Malabe town, Sri Lanka using Vissim software [11]. They found that emissions and fuel consumption were reduced by 14.89%.

The applications of microsimulation modelling for assessing traffic safety that have been subjected to critical analysis in terms of the application of various simulation tools [3]. They stated that there is still a significant void in the development and application of simulation model to evaluate traffic safety of non-lane based heterogeneous traffic environments that predominate in many developing countries. Road traffic compositions in developed and developing countries such as Indonesia are different. The road traffic in Indonesia is dominated by motor cycle. Traffic signal coordination in Denpasar City is usually evaluated manually. The application of the microsimulation model will be required to evaluate several alternatives to obtain suitable traffic management solutions. The main objective of this study was to minimize traffic congestion and fuel consumption by coordinating two signalized intersections in Denpasar City as a case study, based on vissim simulation.

2 Traffic Signal Coordination

By allocating the right-of-way, one of the key goals of traffic signal timing (TST) settings is to move people through an intersection safely and effectively. Some of the TST setting parameters ought to be flexible enough to accommodate changes in traffic demand, while others ought to be under the authority of the traffic management agency. Green time, cycle length, phase sequence, change interval, and offset make up these control parameters. [12].

Some of the often used microsimulation programs for investigating the wide range of dynamic problems in urban traffic are AIMSUN, CORSIM, MATSim, Paramics, SUMO, and VISSIM. The features and traits of many widely used traffic simulation systems has been assessed and also presented a comparative analysis by highlighting a few unique features [13]. VISSIM, AIMSUN, and CORSIM were shown to be acceptable for modeling aspects such arterial, freeway congestion, and integrated networks of freeways and streets, while AIMSUN, CORSIM, and PARAMICS were found to be useful for modeling intelligent transportation systems (ITS) [14].

According to [11]. the VISSIM microsimulation software is the most well-known and often used of those. A multi-modal microscopic traffic flow simulation program called PTV VISSIM was developed by PTV in Karlsruhe, Germany. Among the uses are traffic engineering, public transportation, urban planning, fire safety, and 3D visualization for illustrative and public communication. VISSIM can alter driver, vehicle, and other behaviors from the point of origin to the point of destination. Vehicles such as vehicles, buses, and trucks, as well as public transportation, bicycles, pedestrians, and rickshaws, can all be simulated using VISSIM and interacted with. Priority rules, conflict zones, and signal heads can all be used in VISSIM to depict vehicle conflict points.

3 Research Methods

Figure 1 shows the study location at two intersections along Sudirman Street in Denpasar City, Bali, Indonesia. Denpasar City has an area of 127.78 km2 with a total population of 726,599 people [15].The majority of the road network's traffic volume occasionally increases. Particularly at peak times in the morning and afternoon, there has been traffic congestion. This condition has led to an increase in energy consumption and air pollution.

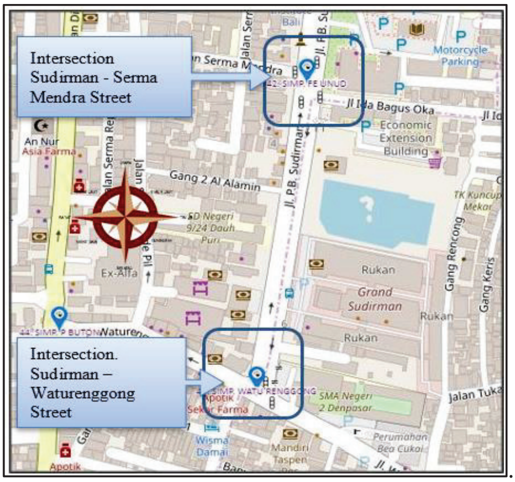

Fig. 1. Study Location at Two Intersection Along Sudirman Street in Denpasar city.

Data collected include the intersection geometry, traffic signal (timing, phasing, and cycle time), traffic volume, distance between the two intersections, and average travel time. Traffic volume data were collected for 12 hours from 07:00 a.m. to 07:00 p.m. during the weekdays. Using a measuring wheel, field measurements were used to gather geometric data. Using a test vehicle, data on typical journey times was gathered. By making observations at the signalized junctions, the signal timings, phasing, and cycle times were gathered.

The model of the chosen corridor was created with the help of the microsimulation program VISSIM. In the early stages of the investigation, the queue length was taken into consideration as the performance measure for calibrating and testing the program at the junction level. The line length, average stop delay, average vehicle delay, CO emissions, NOx emissions, and fuel consumption were taken into account to assess the effectiveness of the traffic signal modification. Using the calibration parameters, the base model was adjusted to the local circumstances.

By comparing the observed and anticipated values, the validation process was carried out based on the t-test. Data for the vehicle volume, vehicle composition, turning movement, and signal timing were entered into the VISSIM program while the model was being created. The gathered and examined data, along with the preset calibration parameter values, were used to create the corridor's base model. The VISSIM software was used to optimize the traffic signals. Priority rules and a new signal program were developed as a stage-based signal controller. The best traffic signal controller timings were then discovered by doing the signal timing optimization.

4 Results And Discussion

4.1 Model idation

The average value of the two variables (mean) for the field is 433.2564, while for Vissim it is 401.9744. Thus, descriptively, it can be concluded that there is a difference in the average traffic volume results between the field and Vissim. Furthermore, to prove whether the difference is significant or not, it can be seen in Table 1. The result of the independent sample t-test indicates that there is no significant difference between the observed and predicted values.

Table 1. Output independent t-test.

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Output	Equal variances assumed	,030	,863	,315	76	,754	31,28205	99,31263	-166,51620	229,08030
	Equal variances not assumed			,315	75,950	,754	31,28205	99,31263	-166,51830	229,08240

Intersection performance analysis was carried out using two methods: based on regulations in the Indonesian Highway Capacity Manual and based on the output of a model simulation using the Vissim software. The two methods produced different performance outputs. Furthermore, the two output results were compared based on similar intersection performance parameters. Table 2 shows the results of a comparison of the intersection performances between IHCM and Output Vissim for the afternoon peak.

Table 2. Comparison of the intersection performances based on IHCM and Output Vissim for the afternoon peak.

No	**Condition**	**Traffic volume (pcu/hr)**					
		Int FE Unud				**Int Waturenggong**	
		N	E	S	W	N	E
1	Traffic counting	1957,90	114,20	500,90	586,10	1821,70	1003,70
	VISSIM	1837,00	135,00	365,00	557,00	1990,00	836,00
	Difference	120,90	20,80	135,90	29,10	168,30	167,70
	Percentage (%)	6,17%	15,41%	27,13%	4,97%	8,46%	16,71%
	Condition	Queue length (m)					
		Int FE Unud				Int Waturenggong	
		N	E	N	W	N	E
2	IHCM	710,75	34,94	38,29	320,32	145,67	822,44
	VISSIM	680,66	40,50	36,36	338,85	215,83	873,43
	Difference	30,09	5,56	1,93	18,52	70,15	51,00
	Percentage (%)	4,23%	13,73%	5,04%	5,47%	32,50%	5,84%
	Condition	**Avg. Delay (sec/pcu)**					
		Int FE Unud				**Simpang Waturenggong**	
		N	E	N	W	N	E

3	IHCM	555,67	41,54	37,08	346,19	36,32	722,04
	VISSIM	512,72	40,22	37,43	336,11	44,82	643,56
	Difference	42,95	1,32	0,35	10,09	8,50	78,48
	Percentage (%)	7,73%	3,17%	0,93%	2,91%	18,96%	10,87%
	LoS	F			F		

Based on Table 2, it is known that during peak hour conditions, the largest percentage difference in volume occurs in the southern approach of the FE Unud intersection, namely 27.13%; the largest percentage difference in queue length occurs in the southern approach of the FE Unud intersection, at 12.44%; and the largest percentage difference in the average delay occurs in the northern approach of the Waturenggong intersection, at 18.96%.

4.2 Analysis Traffic Signal Coordination for Existing Condition (Before Coordination)

Based on the survey results at the study site, the average travel speed (v) from the FE Unud Intersection to the Waturenggong Intersection was 30 km/hour, converted to 8.333 m/s. Travel speed (v) also applies in the reverse direction. The distance (l) from the FE Unud Intersection (FE) to the Waturenggong Intersection (WR) is 400 m. Offset values for existing conditions were 48 seconds. The bandwidth used was the fastest green time, which was 45 seconds from the direction of Sudirman Street (N) to Waturenggong Street (W), and 25 seconds from the direction of Waturenggong Street (E) to Sudirman Street (N). Based on this analysis, it can be seen that the signal arrangement in the afternoon is not coordinated between the two intersections.

4.3 Analysis Traffic Signal Coordination (After Coordination)

From the results of the coordination analysis of the existing condition intersections, it can be concluded that the two intersections do not yet have signal coordination during the morning peak hours, afternoon peak hours, and evening peak hours. During morning peak hours, the results of the intersection performance from the IHCM analysis and the Vissim software output show that the longest queues and delays are at the northern approach to the FE Unud intersection and the northern approach to the Waturenggong Intersection. Because the queue length and the biggest delay are on the northern approach, the green time distribution must be greater on the northern approach than the east approach at the Waturenggong intersection.

At noon peak hours, the intersection performance from the IHCM analysis and Vissim software output shows similar results to the intersection performance in the morning. The difference occurs in the afternoon peak hours. The results of the intersection performance from the analysis of IHCM and the output of the Vissim software show that the longest queues and delays are at the north approach of the FE Unud intersection and the east approach of the Waturenggong Intersection. Because the queue length and the biggest delay are on the east approach, the green time distribution must be greater on the east approach than the north approach at the Waturenggong intersection.

The bandwidth used is the fastest green time, which is 40 seconds from the direction of Sudirman Street (N) to Waturenggong Street (W) and 30 seconds from Waturenggong Street (E) to Sudirman Street (N). After setting the signal phase timing, the two intersections have also been coordinated in the afternoon peak. Based on the results obtained from the analysis, several alternative signal timings were inputted into the Vissim software, as can be seen in Figure 2. The two intersections were coordinated based on the same cycle time of 110 seconds.

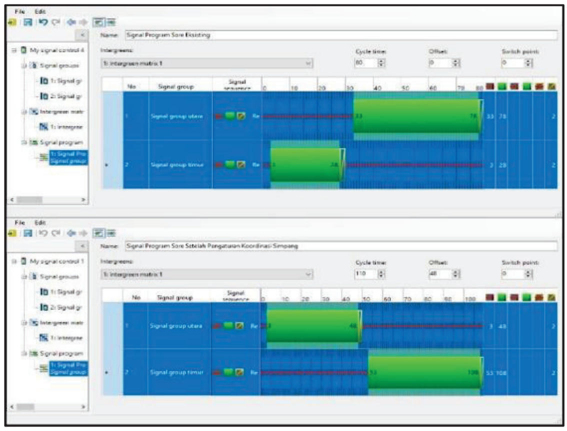

Fig. 2. Vissim Software Program Signals at the Waturenggong Intersection Before and After the Intersection Coordination Settings at Afternoon Peak Hours.

4.4 Intersection Performance Results After Setting Signal Coordination in the Vissim Software

Based on the signal coordination analysis that has been carried out, the new intersection performance results are obtained from the output of the Vissim software. The performance results will be compared with the intersection performance resulting from the output of the Vissim software when the existing conditions were obtained previously to better understand the differences between the two. The performance parameters being compared are queue length, delay, stop delay, and fuel usage. Table 3 shows a comparison of before and after coordination.

Table 3. Comparison of the Intersection Performance Before and After Coordination (Afternoon Peak).

Intersection	Movement	qlenmax		vehdelayall		stopdelayall		fuel consumption	
		(m)		sec/pcu		sec/pcu		liter/hr	
Condition		Existing	Coordinated	Existing	Coordinated	Existing	Coordinated	Existing	Coordinated
FE Unud	N	680,66	669,86	512,72	487,39	46,73	43,60	11,72	11,52
	E	40,50	36,50	40,22	40,27	33,24	31,24	1,80	1,80
	S	36,36	33,36	37,43	35,93	28,31	28,17	3,52	3,52
	W	338,85	332,85	336,11	326,11	57,62	55,50	3,88	3,88
	Avg	274,09	268,14	231,62	222,42	41,47	39,63	5,23	5,18
	Percentage %	-2,17%		-3,97%		-4,45%		-0,95%	
Waturenggong	N	215,83	273,83	44,82	54,82	31,06	32,03	27,75	26,36
	E	873,43	613,65	643,56	493,06	34,62	19,46	6,62	6,24
	Avg	544,63	443,74	344,19	273,94	32,84	25,74	17,19	16,30
	Percentage %	-18,52%		-20,41%		-21,61%		-5,15%	

From Table 3 it can be seen that at peak hours in the afternoon there was a decrease in performance parameters after an alternative application of signal coordination was carried out, namely at the FE Unud intersection there was a decrease in queue length of -2.17%, delay of -3.97%, stop delay of -4.45% and fuel use of -0.95%, while at the Waturenggong intersection, there was a decrease in queue length of -18.52%, -20.41% delay, -21.61% stop delay, and -5.15% fuel usage.

5 Conclusion

Based on the results of the validation using statistical analysis of the t-test, it can be concluded that there is no significant difference between observed and predicted traffic volume. Based on the intersection coordination analysis, alternative results of signal coordination between the two intersections are obtained, which are inputted and re-analyzed with the Vissim software using the node results to obtain a new intersection performance. After carrying out the application of signal coordination, it is known that there is a decrease in the performance parameters of queue length, delays, stop delays, and fuel usage, respectively, during morning peak hours, afternoon peak hours, and evening peak hours. The most significant decrease occurred at the Waturenggong intersection arm during the afternoon peak hours, namely a decrease in the queue length parameter of -18.52%, a delay of -20.41%, stop delay of -21.61%, and a fuel consumption savings of -5.15%.

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