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VEHICLE ACTUATED SIGNAL CONTROL FOR LOW CARBON SOCIETY

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ABSTRACT: The purpose of this study is to propose and evaluate the vehicle actuated signal control for coordinated intersections to reduce CO_2 emission from the transportation sector for the low carbon society. The study area is a group of 3 signalized intersections locating along the National Highway No. 2 in Phol district, Khon Kean province, Thailand. This study proposed and evaluated the several signal control strategies to increase the effectiveness of these intersections. The proposed strategies consist of i) fixed time control, ii) coordinated control, iii) semi actuated control, and iv) fully actuated control. This study applied the traffic microsimulation to evaluate the proposed strategies. The developed traffic microsimulation model was calibrated by using the traffic data surveyed during the morning peak. The study found that the fully vehicle actuated signal control was the best strategy to improve the level of service of intersections and to reduce CO_2 emission. Average delay, average stop time delay, average maximum queue length and CO_2 emissions of total systems decreased by, 44.7%, 55.2%, 33.0% and 8.7%, when compared with existing fixed time control. Therefore, the fully vehicle actuate signal control could be promoted for the low carbon society.

Keywords: Vehicle actuated signal control, CO_2 emissions, Low carbon society, Traffic simulation

1. INTRODUCTION

The global climate has currently become worse because of global warming. It impacts the average temperature of the atmosphere and the ocean of the earth. CO_2 emissions have increased by 36% from 1973 to 2009 [1]. The transport sector emits a large proportion of CO_2 emissions among human activities. The amount of CO_2 emissions has increased rapidly due to the high level of motorization caused by economic growth, particularly in developing Asian countries. The international community has recognized the necessity to reduce greenhouse gas (GHG) emissions by 50% within 2050 to keep the mean global temperature change within 2 degrees Centigrade compared to preindustrial times [2]. To achieve this target, it is very important to promote the Low Carbon Societies (LCS) in Asia. This is due to developing Asian countries accounting for more than half the global population and GHG emissions. The CO_2 emissions from the transport sector will significantly increase due to rapid economic growth and urban sprawl in the developing countries of Asia.

To reduce emissions from the transport sector, the World Conference on Transport Research Society [3] proposed the CUTE matrix, introducing three strategies, including AVOID, SHIFT and IMPROVE. Many researches have proposed various measures according to this matrix, including AVOID measures (e.g., land use allocation [4]), SHIFT measures (e.g., shift to public transport [5]) and IMPROVE measures (e.g., changing motorcycles to electric motorcycles [6]), for Asian developing countries.

Traffic flows at almost intersections in these countries are controlled by the fixed time control. This conventional signal control causes high delays due to regardless of the change in traffic volume. The traffic flows emit high CO_2 emissions at intersections. The improvement of signal control is therefore an interesting measure for Asian developing countries. The purpose of this study is to propose and evaluate the vehicle actuated signal control for coordinated intersections to achieve the low carbon society.

2. RESEARCH METHODOLOGY

The study area was a group of 3 signalized intersections, controlled by fixed time, along the National Highway No. 2 in Phol district of Khon Kean province as displayed in Fig. 1. It was the four-lane divided highway. There was a high number of traffic volumes, 41,656 pcu/day, along the main highway [7]. The roadside land uses are the commercial and residential areas which generate a volume of local traffic along minor roads.

The research methodology is classified into four steps: i) proposal of the signal control strategy, ii) survey of road geometry and traffic data, iii) the development of a traffic microsimulation model and iv) the evaluation of the signal control strategies. Each approach in the model development and application section will be described in the following sub-sections.

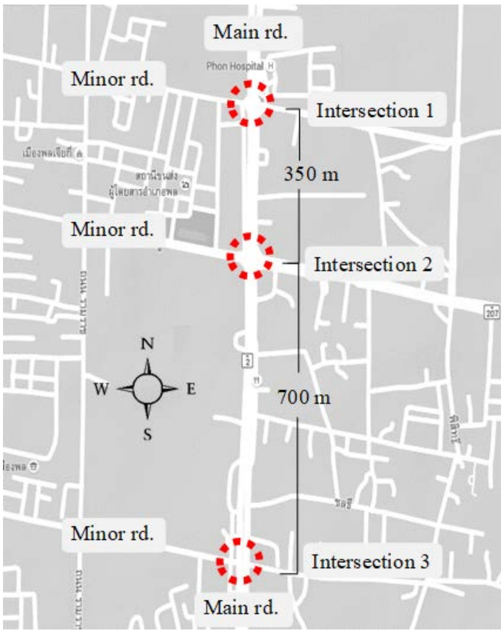

Fig. 1 Three consecutive signalized intersections

2.1 Proposal of Signal Control Strategy

This study proposed four types of the signal control strategy, including the fixed time control, the coordinated traffic control, the semi-actuated control and the fully-actuated control, to achieve the low carbon society. Their definitions and applications were explained as follows:

2.1.1 Fixed time control

The fixed time control is the pre-timed control which its phasing and timing are designed by the pre-counted traffic volume. Some fixed-time systems use different preset time intervals for morning peak period, evening peak period, and other off-peak periods. It gives the most green time to the heaviest traffic movement based on maximum information, regardless of changes in traffic volumes. It cannot compensate for unplanned fluctuations in traffic flows. Therefore, it is ideally suited to closely spaced intersections where traffic volumes and patterns are consistent on a daily or day-of-week basis. Such conditions are often found in downtown areas [8,9].

2.1.2 Coordinated traffic control

The coordinated traffic control is to provide a smooth flow of traffic along street and highway corridors to reduce travel times, stops and delay. A well-timed and coordinated system permits continuous movement along a corridor. It is used in the case of very light side-street traffic [8,9].

2.1.3 Semi-actuated control

The semi-actuated control is used where a small side road intersects with a major road or arterial. The detectors are placed only on the side road. The green time is on the major road at all times unless a "call" on the side road is noted. It is used in the case of very light side-street traffic, it reduces the delay incurred by the major road through movements. On the other hand, major road receives the green time based on maximum traffic flow, regardless of changes in traffic volumes [8,9].

2.1.4 Fully-actuated control

The fully-actuated control refers to intersections for which all phases are actuated, and it therefore requires detection for all traffic demands and patterns vary widely during the course of the day. There are several advantages of fully-actuated control. First, it reduces delay relative to pre-timed control by being highly responsive to traffic demand and to change in traffic pattern. In addition, detection information allows the cycle time to be efficiently allocated on a cycle-by-cycle basis. Finally, it allows phases to be skipped if there is no call for service, thereby allowing the controller to reallocate the unused time to a subsequent phase [8,9].

2.2 Survey of Road Geometry and Traffic data

This study collected the road geometry and traffic data for the development of a traffic simulation model. This study classified the vehicle type into four types, including motorcycles (MC), passenger cars (PC), pickup trucks and vans (LT), and trucks and buses (HT). This study collected the turning count data by vehicle type during morning peak hours (7:00 – 8:00 am.) for a development of Origin-Destination matrices. This study applied the spot speed method to survey the approaching, turning and crossing speeds by vehicle type at intersections.

2.3 Development of Traffic Microsimulation Model

This study selected the VISSIM software to develop the traffic microsimulation model because the VISSIM presently is only one of traffic simulation software that has a function enabling to model lateral behaviour of the motorcycle when the motorcycle taking over the slower or stopping other vehicles at the signalized intersection. Moreover, the VISSIM can measure the speed-time profile of individual vehicle while it travels passing the signalized intersection. The speed-time profile of the individual vehicle, i.e. instant speed and acceleration by every second, was necessary information as an input data for the CO_2 emission models. This study inputted the developed OD matrices into the VISSIM through the function of turning movements by vehicle type.

This study followed the guidelines proposed by FHWA [10] for application in the traffic microsimulation software. Before application of the traffic microsimulation model, it was essential to calibrate the developed traffic microsimulation to be as close to the real-world traffic conditions as possible by adjusting the driving behavior parameters [11]. In the calibration process, this study simulated the OD matrix on the developed network. The criteria for traffic measures resulting from the simulation, including traffic flow, the maximum queue length, and travel time, were compared with the field data. The differences and GEH statistics were compared with the acceptance targets proposed by the Wisconsin Department of Transport [12] and Ahmed [13]. The driving behavior parameters were adjusted until the criteria for traffic measures passed the acceptance targets.

2.4 Evaluation of Signal Control Strategies

This study proposed four vehicle actuated signal control strategies for a group of intersections to achieve the low carbon society. The conditions after the implementation of four proposed signal control strategies were compared with the existing fixed time control condition. The traffic microsimulation model was applied to simulate the before and after traffic conditions. This study considered the traffic Measure Of Effectiveness (MOEs) and CO_2 emissions as evaluation criteria. The traffic MOEs consist of the average delay, maximum queue length and average travel time of the total system. The CO_2 emissions of the total system were also evaluated and compared.

2.5 Calculation of CO_2 Emissions

This study applied the methodology and the developed CO_2 emission models of motorcycle for the traffic microsimulation model, from the previous study [14], to calculate CO_2 emissions of all vehicles. This study also applied the emission data measured in the Automotive Emissions Laboratory of the Thailand's Pollutant Control Department [15] to develop CO_2 emission models according to fuel type, including gasoline and diesel. This study applied the output from the traffic microsimulation model, including the instantaneous speed and acceleration of each individual vehicle, with the CO_2 emission models to calculate the CO_2 emission.

This study calculated CO_2 emission rates (g/s) according to a motorcycle, a gasoline vehicle and a diesel vehicle by applying Eq. (1), (2) and (3), respectively.

$$\mathrm{LN\ (ERMC)} = 0.269 + 0.005u - 0.548a \quad (1)$$
$$\mathrm{LN\ (ERGasoline)} = -1.003 + 0.02u + 0.51a \quad (2)$$
$$\mathrm{LN\ (ERDiesel)} = -0.239 + 0.028u + 0.193a \quad (3)$$

where ER is the emission rate (g/s), u is the instant speed (km/h) and a is the instant acceleration (m/s^2)

The total emission for each vehicle was calculated from a summary of instantaneous values at each second. Finally, the total emission of all vehicles was calculated using Eq. (4). That is the sum of all vehicles of all vehicle types.

$$\text{Total } CO_2\text{Emission} = \sum_{k}^{4}\sum_{j}^{m}\sum_{i}^{n} \text{Instant Emission of a Vehicle} \quad (4)$$

where
i= 1, 2, 3, ..., n (Number of time steps in second)
j= 1, 2, 3, …, m (Number of vehicles)
k= 1 = motorcycle, 2 = passenger car, 3 = pickup truck and van, and 4 = truck and bus

3. RESULTS AND DISCUSSIONS

This section presents the results of the development of the traffic microsimulation model and the evaluation results of proposed signal control strategies for the low carbon society.

3.1 Results of the Model Calibration

The result of the model calibration for traffic flow is presented in Table 1. The differences between the observed and modeled traffic flow and GEH of all links passed the acceptance target, proposed by the Wisconsin Department of Transport [12]. This result means that simulated traffic volume was close to traffic volume in the field. The result of the model calibration for a maximum queue length is presented in Table 2. The differences between the observed and modeled maximum queue length passed the acceptance target, proposed by Ahmed [13]. This result means that maximum queue length of the simulated traffic flow was close to maximum queue length in the field. In addition, the result of the model calibration for travel time is presented in Table 3. The difference between the observed and modeled travel time of all vehicles passed the acceptance target, proposed by the Wisconsin Department of Transport [12]. These results imply that the developed traffic microsimulation model could closely simulate traffic condition compared with real world conditions.

Table 1 Results of model calibration of traffic flow

Link	Modeled (veh/hr)	Observed (veh/hr)	Diff. (veh/hr)	GEH	Acceptance target		Pass/fail
					Diff.*	GEH**	
			Intersection 1				
SB-L	51	46	-5.0	0.72	Within 100	<5	Pass
SB-T	355	355	0.0	0.00	Within 100	<5	Pass
SB-R	100	108	8.0	0.78	Within 100	<5	Pass
NB-L	68	58	-10.0	1.26	Within 100	<5	Pass
NB-T	374	380	6.0	0.31	Within 100	<5	Pass
NB-R	63	67	4.0	0.50	Within 100	<5	Pass
WB-L	57	53	-4.0	0.54	Within 100	<5	Pass
WB-T	258	238	-20.0	1.27	Within 100	<5	Pass
WB-R	79	67	-12.0	1.40	Within 100	<5	Pass
EB-L	36	42	6.0	0.96	Within 100	<5	Pass
EB-T	217	206	-11.0	0.76	Within 100	<5	Pass
EB-R	252	233	-19.0	0.16	Within 100	<5	Pass
			Intersection 2				
SB-L	52	54	2.0	0.27	Within 100	<5	Pass
SB-T	361	345	-16.0	0.85	Within 100	<5	Pass
SB-R	39	52	13.0	1.93	Within 100	<5	Pass
NB-L	185	205	20.0	1.43	Within 100	<5	Pass
NB-T	476	478	2.0	4.94	Within 100	<5	Pass
NB-R	86	107	21.0	2.14	Within 100	<5	Pass
WB-L	30	35	5.0	0.88	Within 100	<5	Pass
WB-T	252	250	-2.0	0.13	Within 100	<5	Pass
WB-R	30	36	6.0	1.04	Within 100	<5	Pass
EB-L	95	80	-15.0	1.60	Within 100	<5	Pass
EB-T	304	291	-13.0	0.75	Within 100	<5	Pass
EB-R	120	136	16.0	1.41	Within 100	<5	Pass
			Intersection 3				
SB-L	12	22	10.0	2.43	Within 100	<5	Pass
SB-T	459	448	-11.0	4.43	Within 100	<5	Pass
SB-R	143	203	60.0	4.56	Within 100	<5	Pass
NB-L	217	215	-2.0	0.14	Within 100	<5	Pass
NB-T	525	539	14.0	0.61	Within 100	<5	Pass
NB-R	104	95	-9.0	0.90	Within 100	<5	Pass
WB-L	24	29	5.0	0.97	Within 100	<5	Pass
WB-T	85	81	-4.0	0.44	Within 100	<5	Pass
WB-R	33	21	-12.0	2.31	Within 100	<5	Pass
EB-L	85	102	17.0	1.76	Within 100	<5	Pass
EB-T	67	80	13.0	1.52	Within 100	<5	Pass
EB-R	252	233	-19.0	1.22	Within 100	<5	Pass

*Diff., hourly link flow of modeled versus observed within 100 veh/h, for flow < 700 veh/h, within 15% for 700veh/h < flow < 2,700 veh/h; **GEH statistics < 5; GEH $=\sqrt{(V - C)2/((V + C)/2)}$, where GEH is GEH statistic; V is simulated traffic flow; C is surveyed traffic flow; [12].

Table 2 Results of the model calibration of the maximum queue length

Link	Modeled (m)	Observed (m)	Diff. (%)	Acceptance target (Diff.*)	Pass/fail
			Intersection 1		
SB	52	54	3%	Within 20%	Pass
WB	59	72	18%	Within 20%	Pass
NB	102	126	19%	Within 20%	Pass
EB	50	48	-5%	Within 20%	Pass
			Intersection 2		
SB	96	96	0%	Within 20%	Pass
WB	63	66	4%	Within 20%	Pass
NB	112	96	-17%	Within 20%	Pass
EB	77	72	-7%	Within 20%	Pass
			Intersection 3		
SB	158	162	3%	Within 20%	Pass
WB	21	18	-17%	Within 20%	Pass
NB	129	126	-2%	Within 20%	Pass
EB	64	72	11%	Within 20%	Pass

*Diff, maximum queue length of modeled versus observed within 20% [13].

Table 3 Results of the model calibration of the travel time

Link	Modeled (s)	Observed (s)	Diff. (%)	Acceptance target (Diff.*)	Pass/fail
NB	296	265	-12%	Within 15	Pass
SB	304	302	-1%	Within 15	Pass

*Diff, travel time of modeled versus observed within 15% [12].

Table 4 Results of the effectiveness of traffic flow measures and CO_2 emissions reduction among scenarios

Parameters	Existing	Fixed time	Coordinated	Semi-actuated	Fully-actuated
Aver delay (s/veh)	123	111 (-9.8%)	98 (-20.3%)	105 (-14.6%)	68 (-44.7%)
Aver stopped delay (s/veh)	96	84 (-12.5%)	76 (-20.8%)	79 (-17.7%)	43 (-55.2%)
Aver max queue length (m)	100	86 (-14.0%)	62 (-38.0%)	69 (-31.0%)	67 (-33.0%)
CO_2 emission (kg/hr)	2,151	2,142 (-0.4%)	2,126 (-1.2%)	2,138 (-0.6%)	1,963 (-8.7%)

3.2 Evaluation Results of Signal Control Strategies

The evaluation results of the traffic flow measures of effectiveness and the CO_2 emissions are presented in Table 4. As expected, all proposed signal control strategies could improve maximum queue length, travel times, delays, stop time delays and reduce CO_2 emission in the selected study intersections.

The updated fixed time control decreased the average delays, the average stopped delays, the maximum queue length, and CO_2 emissions for the total systems by 9.8%, 12.5%, 14.0%, and 0.4%, respectively. This result was caused by the signal timing updated according to the current traffic volume.

The coordinated control decreased the average delays, the average stopped delays, the maximum queue length, and CO_2 emissions for the total systems by 20.3%, 20.8%, 38.0%, and 1.2%, respectively. This result was caused by the traffic flows along the major road could cross the intersections with less stop for the traffic signal.

The semi-actuated control decreased the average delays, the average stopped delays, the maximum queue length, and CO_2 emissions for the total systems by 14.6%, 17.7%, 31.0%, and 0.6%, respectively. This result was caused by a facilitation of the traffic along minor roads.

The fully-actuated control decreased the average delays, the average stopped delays, the maximum queue length, and CO_2 emissions for the total systems by 44.7%, 55.2%, 33.0%, and 8.7%, respectively. It caused that traffic along major and minor roads could pass the intersections with less stop.

Consequently, the fully vehicle actuated signal control is the most efficient strategy among the proposed strategies.

4. CONCLUSIONS AND RECOMMENDATIONS

This study proposed and evaluated the several signal control strategies to increase the level of service of the intersections and decrease CO_2 emissions of total systems. The developed traffic microsimulation model was applied to evaluate the proposed strategies. The study found that the fully vehicle actuated signal control was the best strategy to improve the level of service of intersections and to reduce CO_2 emissions. Therefore, the system should be promoted to achieve the low carbon society.

As recommendations for further studies, a study on providing advanced information regarding signal phases and timing to vehicles travelling on a signalized corridor (V2X communication), extending from cars [16,17] to motorcycles with the vehicle actuated signal control, should to be evaluated on its increasing intersection's level of service and reduction on CO_2 emissions.

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6. REFERENCES

[1] Intergovernmental Panel on Climate Change (IPCC), IPCC Guidelines for National Greenhouse Gas Inventory, Volume 1, Revised, Reporting Instructions, 2006.

[2] National Institute for Environmental Studies (NIES), Asian Low Carbon Society Research Project. Report. National Institute for Environmental Studies. Japan, 2011.

[3] World Conference on Transport Research Society (WCTRS), Putting Transport into Climate Policy Agenda - Recommendations from WCTRS to COP18, Report, 2012.

[4] Klungboonkrong P., Jaensirisak S., Satiennam T., Potential performance of urban land use and transport strategies in reducing greenhouse gas emissions: Khon Kaen case study, Thailand, International Journal of Sustainable Transportation, Vol.11, No.1, 2017, pp.36-48.

[5] Satiennam T., Jaensirisak S., Natevongin N. and Kowtanapanich W., Public Transport Planning for a Motorcycle Dominated Community, Journal of the Eastern Asia Society for Transportation Studies, Vol.9, 2011, pp.970-985.

[6] Satiennam T., Satiennam W., Tankasem P., Jantosut P., Thengnamlee J., & Khunpumphat W., A Study of Potential Electric Motorcycle Use to Support a Low Carbon Society: Case of a Developing Asian City, Advanced Materials Res., Vol. 931-932, 2014, pp. 541-545.

[7] Department Of Highway (DOH), 2015, Traffic Volumes along Main National Highways in 2014 <http://bhs.doh.go.th/download/traffic>.

[8] Roess P., Prassas S. and McShance S. Traffic Engineering Four Edition. [n.p.]: Transportation and System Engineering, 2010.

[9] Federal Highway Administration., Traffic Signal Timing Manual chapter5, from http://ops.fhwa.dot.gov/publications/fhwahop 08024/ chapter5.htm, 2015.

[10] Dowling R., Skabardonis A., and Alexiadis V., Traffic Analysis Toolbox Volume III: Guidelines for Applying Traffic Microsimulation Software, Report No. FHWA-HRT-04-040, Contract or Grant No. DTFH61-01-C-00181, FHWA, 2004.

[11] Dowling R., Skabardonis A., Halkias J., McHale G. and Zammit G., Guidelines for Calibration of Microsimulation Models Framework and Applications, In Transportation Research Record: Journal of the Transportation Research Board, No. 1876, TRB, National Research Council, Washington D.C, 2004, pp. 1–9.

[12] Freeway System Operational Assessment, Paramics Calibration & Validation Guidelines, Technical Report I-33 (Draft), Milwaukee, Wis, USA, Wisconsin Department of Transportation, 2002.

[13] Ahmed S., Calibration of Vissim to the Traffic Conditions of Khobar and Dammam, Saudi Arabia [Master, Thesis], King Fahd University of Petroleum and Minerals, Saudi Arabia, 2016.

[14] Satiennam T., Seedam A., Radpukdee T., Satiennam W., Pasangtiyo W., and Hashino Y., Development of On-Road Exhaust Emission and Fuel Consumption Models for Motorcycles and Application through Traffic Microsimulation, Journal of Advanced Transportation, Vol. 2017, 2017.

[15] Office of Transport and Traffic Policy and Planning (OTP), The Study to Develop Master Plan for Sustainable Transport System and Mitigation of Climate Change Impacts, Final Report, Office of Transport and Traffic Policy and Planning, Thailand, 2013.

[16] Barth M., Mandava S., Boriboonsomsin K., and Xia H., Dynamic ECO-driving for arterial corridors, in Proceedings of the IEEE Forum on Integrated and Sustainable Transportation Systems (FISTS ’11), pp. 182–188, Vienna, Austria, June-July 2011.

[17] Xia H., Boriboonsomsin K., and Barth M., Indirect networkwide energy/emissions benefits from dynamic eco-driving on signalized corridors, in Proceedings of the 14th IEEE International Intelligent Transportation Systems Conference (ITSC’11), pp. 329–334, IEEE, Washington, DC, USA, October 2011.