A STUDY REGARDING THE DEVELOPMENT AND IMPROVEMENT OF A TRAFFIC FLOW SIMULATION MODEL FOR A SIGNALIZED INTERSECTION

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Abstract : *This paper presents a simulation program for signalized intersections. The simulation system considers the movement of individual vehicles as they negotiate both the straight portion of the road feeding the intersection and the turns at the intersection. Results show that the model can be used to analyze and/or evaluate the efficiency of traffic signals.*

1. INTRODUCTION

Traffic jams may be considered an everyday fixture everywhere in urban areas today. Such jams undoubtedly affect and influence our societies negatively. There are several factors that contribute to traffic congestion and this paper focuses on traffic signals at intersection, recognizing the fact that they add to traffic congestion if their parameters are not properly set. It is obviously difficult to expand the width of existing roads under the constraint of land acquisition due to the extremely expensive land cost in highly dense urban district. Therefore, it is necessary to explore other alternative forms of traffic management, e.g., installation of traffic signals, channelization including the provision of exclusive lane turning bays, etc. to control the flow of vehicles[1), 2)]. There are several simulation models[3), 4)] available for use in a wide range of transportation planning applications with regards to traffic jams at an intersection. The importance of these models stems from the fact that they help in greatly expanding the opportunities for the development of and/or testing of proposed traffic management strategies prior to implementation. This study applies a traffic flow simulation model on a conventional signalized intersection where traffic congestion is commonly observed. The simulation model presented here is an improvement over the one previously developed by authors[5), 6), 7), 8)], and was used to derive the effects of various alternatives to stem traffic congestion around the periphery of the target intersection. It should be noted that the direction of traffic flow (as presented in this paper) is different from that of the Philippines because the model was developed and improved in Japan.

2. DESCRIPTION OF THE SIMULATION MODEL

2.1 Frame of the Simulation Model

The model was formulated to be able to meet the following requirements: (1) The required simulation time must be shortened, vis-avis the original model, (2) There must be a graphical output of vehicular flow, and (3) Given the actual volume of incoming vehicles, rate of left and right turning traffic, and signal parameters, then the delay time and total number of vehicles must be counted and accumulated during the simulation run.

The actual simulation system may be briefly described as follows: Traffic flow is divided into two categories, one is the movement of vehicles along a straight road, the other is the turning movement of vehicles at the signalized intersection. The vehicle movement along road before and after the intersection, e.g., acceleration, deceleration and lane changing, is simulated. The road length of the East to West and West to East sections are 320 meters each while the North to South and South to North sections are 240 meters each. Further, the simulation model uses two types of vehicles categorized by size, the small vehicles (cars) are assigned a length of 5 meters while the big vehicles (trucks) are assigned a length of 8 meters. The vehicle movement at the intersection, i.e., through, left, and right turns, is likewise simulated. The simulation model also provides exclusive right turn lanes and optionally, an exclusive right turn phase. Figure-1 illustrates the general simulation flow while Table-1 shows the input data required by the model and the output that the mode generates. The simulation time of this model using a standard 486-based Personal Computer takes only 1/10 of the actual time (1/50 of actual time in case graphic display is suppressed).

Generation of vehicles and their free speed is implemented as follows: (1) Vehicles are randomly generated at the entry point using a random function based on the exponential distribution of headway, (2) A free speed is randomly assigned to each generated vehicle using the normal distribution function.

2.2 Vehicle Movement

2.2.1 *Vehicle Following Movement*

While within the simulation frame, a vehicle changes its speed and/or lane depending on the position and speed of four other vehicles in its vicinity at each time increment of the simulation. For example, a vehicle under consideration (target vehicle) and the other four vehicles that affect its movement from simulation time t to $t+1$ are shown in Figure-2.

The speed of the target vehicle can range from zero (complete stop) to a maximum speed equal to that initially assigned when the vehicle was generated at the entry point. This is under the assumption that different drivers regardless of the speed limit, tend to maintain a maximum speed that is perceivably "safe" to them. This speed can be lower or higher the legal maximum speed limit. A safe distance between the target vehicle and the front vehicle is defined in such a way that if the headway between the target vehicle and the front vehicle is less than this distance, the target vehicle decelerates (unless it can change lane) to maintain that safe distance. If the headway is greater than this distance, the vehicle accelerates in order to achieve the initial speed assigned when it was generated.

2.2.2 *Lane Changing*

A vehicle will tend keep on using the lane where it was assigned when it was generated at the entry point, hence after changing lane (to avoid a slow front vehicle) it returns to its original lane at the earliest opportunity. A vehicle in the fast lane will tend to give way to the vehicle behind it if that vehicle has a faster speed. Finally, if a vehicle attempts to change lane, the positions at the next simulation increment is checked for collision conditions. Lane changing is then allowed if such conditions are not detected.

The conditions for changing lanes based on Figure -2 are shown in equation (1).

$$X_d+V_d\times\Delta t-L_d - (X_b+V_b\times\Delta t) \geq CL$$
$$X_b-L_b-X_e > CL \quad \cdots(1)$$

where:

- X_d ; coordinates of a front vehicle located neighbouring lane.
- X_e ; coordinates of a behind vehicle located neighbouring lane.
- V_d ; speed of a front vehicle located neighbouring lane.
- L_d ; length of a front vehicle located neighbouring lane.
- CL ; distance between vehicles which is possible to change lane.

2.2.3 *Left and Right Turn Movement*

Through and left turning vehicles enter the intersection only during the green phase of the signal cycle. Turning vehicles need to check several conditions before they are allowed to navigate the intersection. For example, the mesh system shown in Figure-3 is defined for a vehicle turning right from the major road (2x2 lanes) to the minor road (1x1 lanes). This figure likewise lists some of the conditions that must be met before the vehicle is allowed to turn right. These sets of conditions pertain to the presence or absence of vehicles within the defined grids of the mesh together with the current state of the signal.

For the case of a vehicle turning from the minor road (1x1 lanes) to the major road (2x2 lanes), another mesh system is defined and is shown in Figure-4. The three conditions that are checked to determine whether the vehicle may or may not turn right are likewise listed in this figure.

2.3 Intersection Configuration

Several alternatives were considered in applying simulation model. These alternatives are combinations of intersection configuration, presence or absence of exclusive right turn bays, and presence of absence of exclusive right turn phase. Five possible alternatives are listed in Table-2 to which the simulation model was applied. Actual computer graphic screen outputs are shown in Figure-5, showing intersection configuration and signal parameter settings.

3. CALIBRATION OF THE MODEL

3.1 Simulation Data

To test the simulation model, a survey of several intersections which have the same shape as the simulation frame mentioned in Section 2.3. was made. One intersection which has the same shape as intersection pattern no. 3 was found along National Route #16 in Ohuda. Simulation input parameters for this intersection are summarized in Table-3. Another intersection which has the same shape as intersection of pattern No. 4 was found in Local Route Moriya-Nagareyama Line in Kashiwanoha, and the simulation input parameters for this intersection are listed in Table-4.

3.2 Simulation Results

The main output of the model is a listing of the accumulated delay time due to the red phase of the signal as well as delay times due to right turning vehicles for each of the legs of the intersection. To test whether the model is properly duplicating actual existing conditions, the accumulated number of vehicles that utilized the intersection taken from the video tapes were graphed against those which used the intersection during the simulation run. The resulting graphs for the two intersections considered in the simulation runs are shown in Figure-6 and Figure-7. These graphs show that the simulated number of vehicles passing the intersections during each signal cycle is similar to the observed number recorded at the actual intersection.

4. EXECUTION OF THE MODEL

4.1 Simulation of Alternative Conditions

Five different scenarios were evaluated to test some possible countermeasures to alleviate traffic congestion at the intersections being studied. These five scenarios form a subset of the various combinations of the existence of the exclusive right turn lane and the exclusive right turn signal phase. The 5 representative alternatives evaluated are shown in Table-2. Each alternative were tested at different traffic volumes at the major road (1500, 2000, 2500 vehicles/hour), different rate of right-turning vehicles (3.0, 6.0, 9.0, 12.0%) and different traffic volumes at the minor road (1500, 2000, 2500 vehicles/hour). The other simulation input parameters are fixed as follows: (1) 30% of the major road volume are heavy vehicles and 3.0% of the volume are left-turners and (2) with regards to minor road flow, 94.0% are through vehicles, 3.0% are left-turners, and 3.0% are right-turners.

The performance of the intersection based on external conditions, i.e., presence or absence of right turn bays, and different vehicular volumes, is discussed in Section 4.2.1. The performance of the intersection also depends on internal factors such as length of a signal cycle and splits and this is discussed in Section 4.2.2. The delay time per signal cycle and the total number of vehicles passing an intersection are accumulated and used as performance indicators of the intersection.

4.2 Performance of Intersection

4.2.1 *Response to External Condition*

The response of the simulation model in the case of 2000 vehicles/hour on the major flow is shown in Figure-8 as an example. The results obtained here imply that there are some thresholds for the installation of the exclusive right turn lanes under following conditions: (1) 2000 vehicles/hour on opposite flow and 6.0% rate of right-turners, and (2) 2500 vehicles/hour on opposite flow and 3.0% rate of right-turners. In addition, the results also suggest that the exclusive right turn signal phase is necessary in the case of 2500 vehicles/hour on opposite flow and 12.0% rate of right-turners. Figure-9 and Figure-10 also show the existence of certain thresholds for the introduction of the exclusive right turn phase simultaneously implemented with exclusive right-turn lanes in the case of 1500 and 2000 vehicles/hour.

4.2.2 *Response to Internal Condition*

In order to determine the optimum length of the signal cycle and its signal indicator composition, the simulation is run under the different conditions of traffic volume and signal cycle length. The total delay time is calculated in each combination of the volume and the cycle length. A summary of the relationship between them is illustrated in Figure-11, which indicates that the optimum length of a cycle is 150 seconds. The current length, on the other hand, is 170 seconds which means that the optimum condition is not realized.

As to the composition of the signal indicators within the signal cycle, the simulation is run under different combinations of signal indicators or splits. The 9 splits selected and the current split being implemented are shown in Table-5. In Case 1, the right turn phase was reduced to 3 seconds while maintaining the original cycle length of 170 seconds. This is because the volume of right-turning vehicle is relatively small. Cases 2 to 9 examine different splits at a cycle length of 150 seconds, the optimum cycle length indicated in Figure-11. Cases 2 to 8 maintain a 6-second right turn phase with Case 3 being the optimum split. Case 9 was simulated with 150 seconds cycle length and 3 seconds for the right turn phase. The simulation for Case 9 shows that setting these signal parameters will result in the least delay.

Considering the above, the applicability of this model lies not only on giving the thresholds of the provision of the exclusive right-turn lane and the exclusive right-turn signal phase as an external factor, but also on optimizing the signal cycle and the signal splits as an internal factor.

5. CONCLUSION

The improved model developed and presented in this paper was shown to be able to reproduce real-world conditions to a very high degree. This study concludes that: (1) certain guidelines in designing a particular intersection in detail, e.g., provision of exclusive right-turn bays, can be set by reviewing the performance of the intersection under simulated conditions, and (2) assessment of proposed traffic management strategies, particularly setting of signal parameters, prior to actual implementation can be easily done using the simulation program discussed in this paper. More accurate models may still be realized through further research along the following lines: (1) consideration of the behavioral characteristics of pedestrians and bicycle riders, and (2) applying this model to other types of actual intersections.

While the model was developed and improved in Japan, the program was written in such a way that it can easily be ported to sites where traffic flow is opposite that of Japan, hence this simulation program may be readily used in Metro Manila.

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Table-1 Input and Output Data

Input Data	• traffic volume • generated speed (mean, standard deviation, max, min) • rate of heavy vehicle • rate of vehicle turning to the right and left • signal parameters
Output Data	• the number of generated vehicles • the number of through vehicles • total delay time per signal cycle • delay time

Table-2 Intersection Configuration

Type	Lane	Exclusive right turn lane	Exclusive right turn phase
No. 1	4 lanes x 2 lanes	none	none
No. 2	4 lanes x 2 lanes	exist on 4-lane road	none
No. 3	4 lanes x 2 lanes	exist on 4-lane road	exist on 4-lane road
No. 4	2 lanes x 2 lanes	exists on both roads	exist on both roads
No. 5	2 lanes x 2 lanes	exist on road with much higher traffic volume	exist on road with much higher traffic volume

Table-3 Simulation Parameters (pattern No. 3)

			Ave Spd (m/s)	Var (m/s)	Max Spd (m/s)	Min Spd (m/s)
W-E	First Lane	Car Truck	18.9 17.1	3.3 3.5	27.0 23.6	13.5 10.5
	Second Lane	Car Truck	14.7 15.9	3.0 3.3	23.6 21.0	10.5 11.8
N-S		Car Truck	14.0 12.0	2.0 2.0	20.0 18.0	8.0 5.0

Phase	Green	Yellow	All Red	Red	C_0 (sec)
ϕ_1	121	4	3	42	170
ϕ_2	6	3		161	
ϕ_3	27	3	3	137	

Table-4 Simulation Parameters (pattern No. 4)

		Ave Spd (m/s)	Var (m/s)	Max Spd (m/s)	Min Spd (m/s)
W-E	Car Truck	9.9 9.5	1.6 1.8	14.2 14.2	7.4 7.8
N-S	Car Truck	9.9 9.5	1.6 1.8	14.2 14.2	7.4 7.8

Phase	Green	Yellow	All Red	Red	C_0 (sec)
ϕ_1	38	3	3	56	100
ϕ_2	8	3		65	
ϕ_3	29	3	3	65	
ϕ_4	7	3		90	

Table 5 - Signal Patterns

Split	Phase	Green	Yellow	All Red	Red	Co	Delay per Cycle
Current	ϕ1	121	4	3	42	170	2138.6
	ϕ2	6	3		161		
	ϕ3	27	3	3	137		
Case 1	ϕ1	124	4	3	39	170	1966.0
	ϕ2	3	3		164		
	ϕ3	27	3	3	137		
Case 2	ϕ1	111	4	3	32	150	1742.9
	ϕ2	6	3		141		
	ϕ3	17	3	3	127		
Case 3	ϕ1	108	4	3	35	150	1725.7
	ϕ2	6	3		141		
	ϕ3	20	3	3	124		
Case 4	ϕ1	106	4	3	37	150	1727.8
	ϕ2	6	3		141		
	ϕ3	22	3	3	122		
Case 5	ϕ1	114	4	3	29	150	2267.3
	ϕ2	6	3		141		
	ϕ3	14	3	3	130		
Case 6	ϕ1	116	4	3	27	150	3965.7
	ϕ2	6	3		141		
	ϕ3	12	3	3	132		
Case 7	ϕ1	104	4	3	39	150	1787.9
	ϕ2	6	3		141		
	ϕ3	24	3	3	120		
Case 8	ϕ1	118	4	3	25	150	5589.4
	ϕ2	6	3		141		
	ϕ3	10	3	3	134		
Case 9	ϕ1	114	4	3	29	150	1600.7
	ϕ2	3	3		144		
	ϕ3	17	3	3	127		

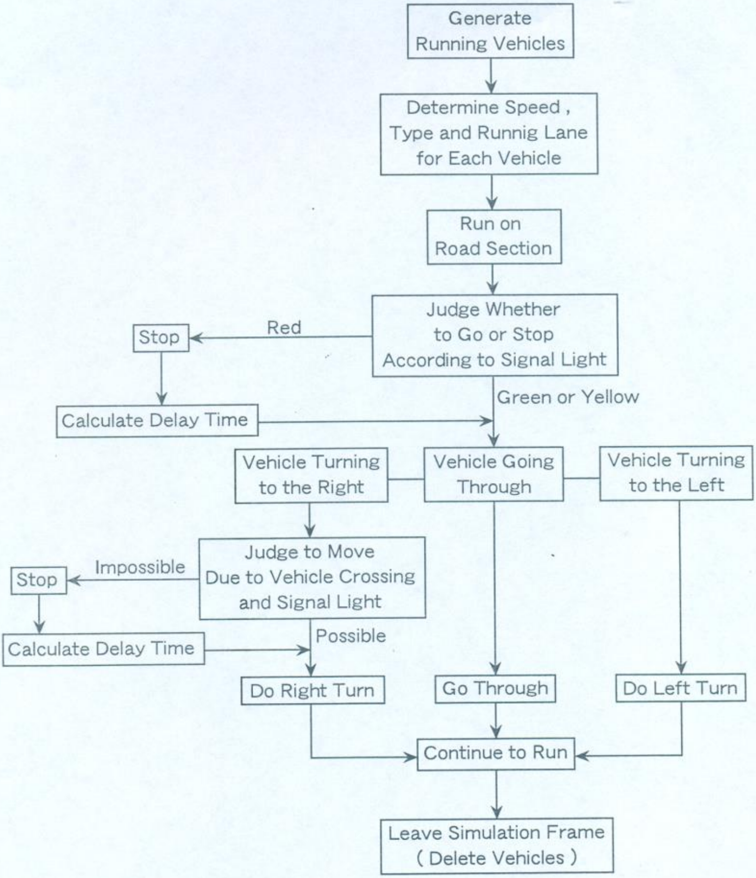


Figure-1　Simulation Flow

Car Following / Lane Changing

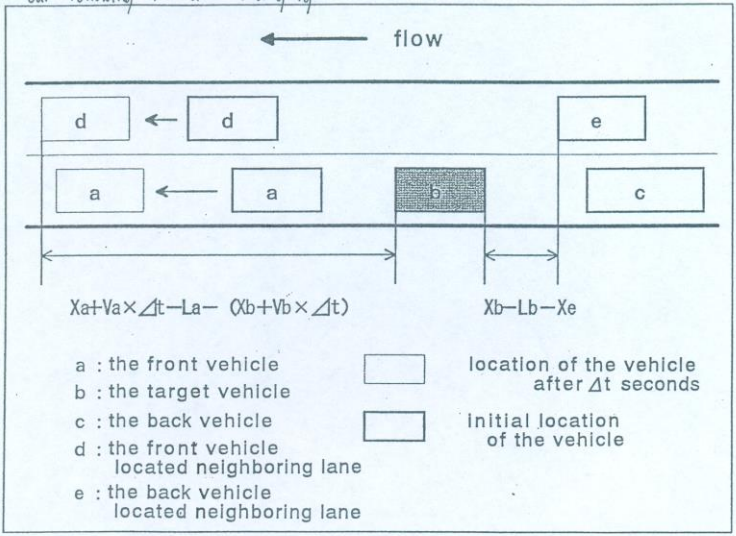
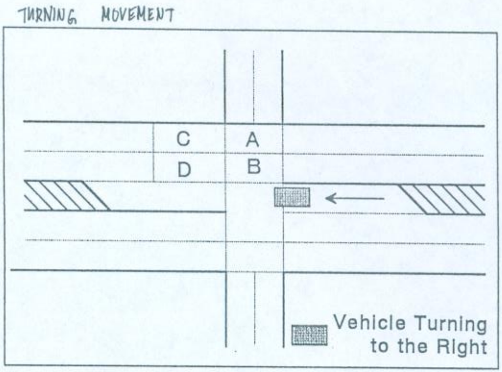


Figure-2 Target Vehicle and The Surrounding Vehicles That Affect Its Movement



Condition 1:

-No vehicle in A

-Right turner in B or No vehicle in B

-Left turner in C or No vehicle in C

-No vehicle in D

Condition 2:

-No vehicle in A or Right turner in A

-No vehicle in D

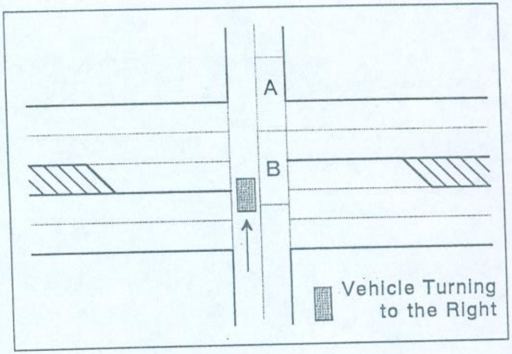
-Signal phase is red

Condition 3:

-Right turner in A

-No Thru vehicle in C

Figure-3 Right Turn Logic for Road of 4 Lanes



Condition 1:

-No vehicle in B or Right turner in B

-No vehicle in A or Right turner in A or Left turner in A or Speed of vehicle in A is 0(stopped).

Condition 2:

-No vehicle in B

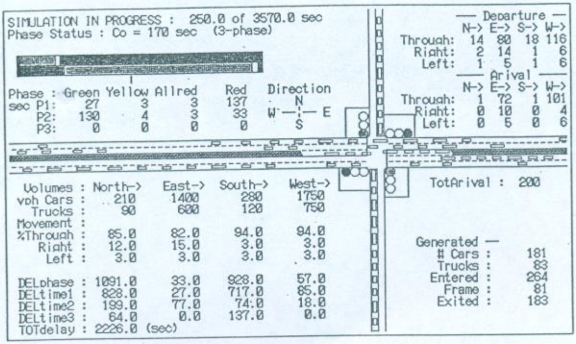
-Right turner in A or Left turner in A or No vehicle in A

Condition 3:

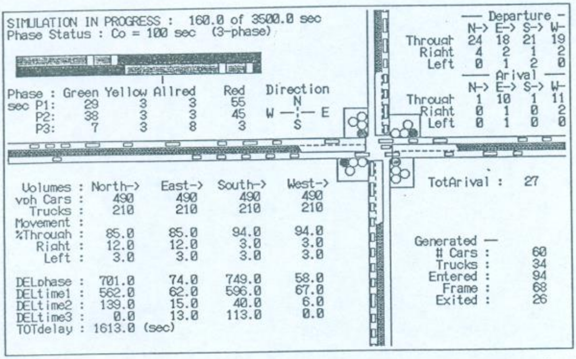
-Signal is red

-No thru vehicle in B

Figure-4 Right Turn Logic for Road of 2 Lanes



(Exclusive Right Turn Lanes which Exist on 4 Lanes' Road)



(Exclusive Right Turn Lanes which Exist on Crossing 2 Roads)

Figure-5 Graphic Screen Output of Intersection

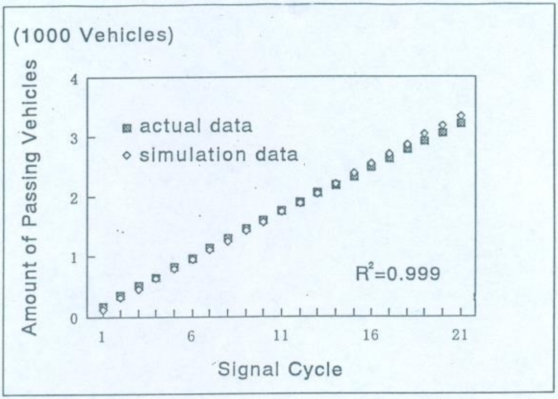


Figure-6 Accumulated Intersection Utilization of Pattern No.3

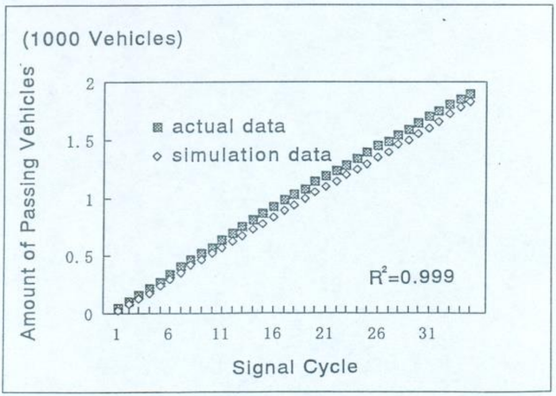


Figure-7 Accumulated Intersection Utilization of Pattern No.4

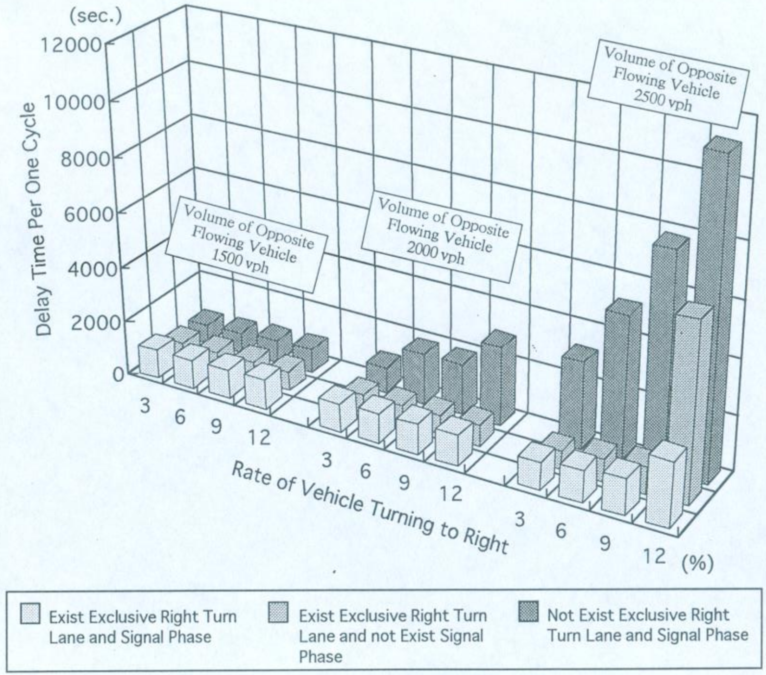


Figure-8 Relations Among Delay Time, Rate of Right-Turn and Traffic Volume on Opposite Flow
(2000 vph on Main Flow)

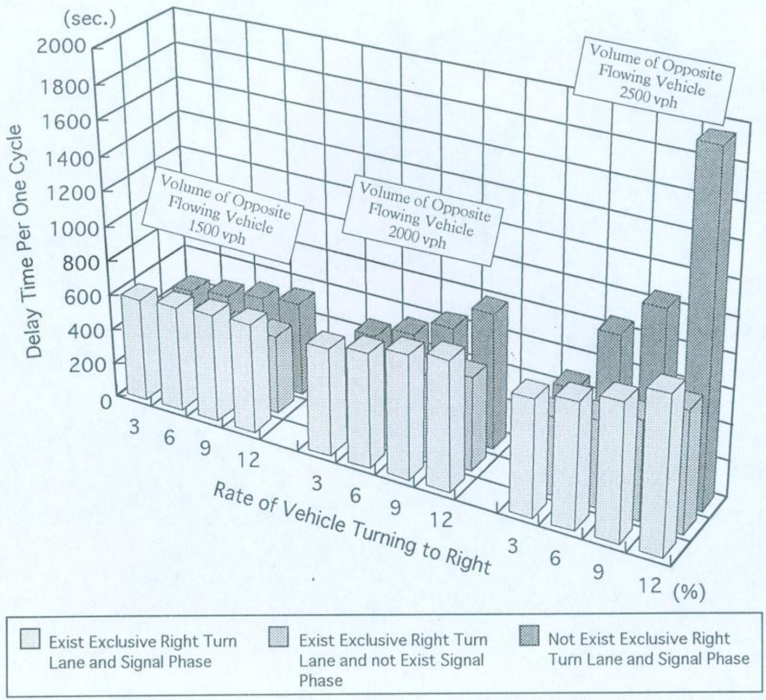


Figure-9 Relations Among Delay Time, Rate of Right-Turn and Traffic Volume on Opposite Flow (1500 vph on Main Flow)

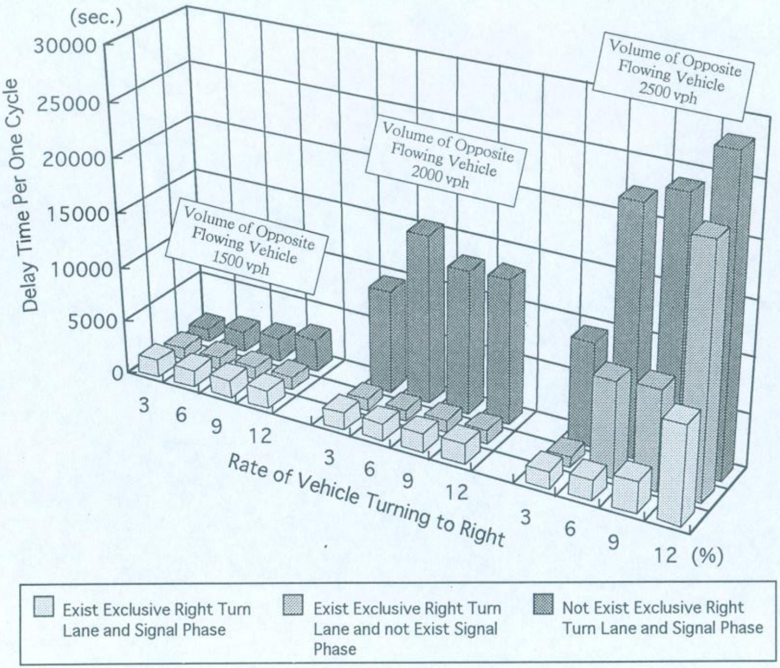


Figure-10 Relations Among Delay Time, Rate of Right-Turn and Traffic Volume on Opposite Flow (2500 vph on Main Flow)

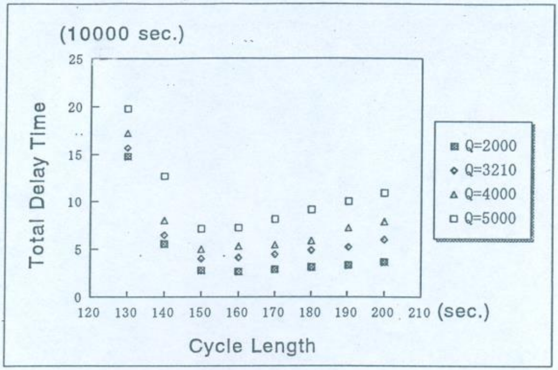


Figure-11 Total Delay Time Vs. Cycle Length