AN ESTIMATION MODEL OF THE DRIVING MODES OF VEHICLE TRAFFIC FOR THE EXHAUST GAS VOLUME

T. Nishimura[1], Y. Hino[2]

1)Takashi Nishimura
Department of Civil Engineering
Osaka City University
Sumiyoshi-ku, Osaka 558,
Japan

2)Yasuo Hino
Department of Civil Engineering
Osaka City University
Sumiyoshi-ku, Osaka 558,
Japan

1. INTRODUCTION

In urban area, the air pollution by the exhaust gas from automobile traffics is a serious problem. The emission ingredients and volume of exhaust gas change corresponding to the driving modes of vehicle, which are essentially categorized to four types such as acceleration, cruising, deceleration and idling. Therefore, especially the congested traffic flow which will enforce drivers change to certain specified modes, such as the iteration of acceleration and deceleration or the slowest cruise, seems to influence to such emission volume.

To estimate the exhaust gas volume, it is usually based on the average speed and the emission factors for each average velocity range. While, such proportion of driving modes is also changed by the traffic flow condition, for example, as mentioned above, in case of a heavily congested flow the mode-pattern is often consisted of only two types, idling and cruising (= the slowest cruise). Therefore, another simple method for estimating exhaust gas volume based on the driving modes is conceived, which requires a development of a prediction model for the proportion of each mode in a traffic flow. Here a simple method for estimating each mode of traffic flow by a signal stop model has been developed. In this paper, the method that is applicable to various types of traffic flows and conditions of signal control, has been described, and the predicted value by this model has been compared with the observed value obtained by the test vehicle running, in terms of driving mode and travel time. Based on the model prediction, the exhaust gas volume is also able to be calculated with the emission factors for each driving mode.

2. BASIC SURVEY

2.1 Outline of Survey

To observe various factors in each traffic flow condition, which would be essential to consider the prediction model and its application, three types of major surveys were carried out on some arterial roads. One of them was related to the free traffic flow condition in a 890 metres length section with four intersections (Survey(I)) and others to the congested flow conditions. The later were executed both on a short section with one intersection in 300 metres length(Survey(II-1)) where traffic characteristics were able to be observed easily and on a long section with 17 intersections in 1600 metres length(Survey(II-2)) to observe the actual traffic flow and to record the test vehicle runnings.

2.2 Variables and Methods of Measurements

Factors which form traffic flow are primary concerns of this study, therefore the traffic variables should be determined in the first step of the survey. The following variables were considered in each survey; 1)signal time setting, 2)traffic volume, 3)the number of idling cars and their queue length(=traffic density or vehicle spacing) at intersection, 4)journey speed and running speed, 5)waiting time and delay in stopping and starting at signal(=stopping and starting wave), 6)shares in time of each driving mode.

The measurements of these variables were executed simultaneously by three parties; the first party observed mainly variable 1)-3),5) at roadside, the second party observed the traffic flow at an intersection by video camera to obtain variable 2), 3) and 5), and the rest observed the traffic flow condition on a flowing vehicle equipped with tachograph by recording test running to obtain variable 4) and 5).

3. PRIMARY ANALYSIS OF TRAFFIC FLOW

3.1 Classification of traffic flow

Data obtained by the actual test runnings in survey(II-1) were divided into some shorter sections with 100 metres length, and all data of driving modes were classified by the average speed ranges. The results and their model values about the ratio of driving modes are classified as shown in Table 1. Combining this classification and analysis of the similar data in survey(I) and (II-2), the traffic flow could be classified as shown in Table 2. And this classification seemed to be suitable for the actual condition confirmed by plotting them on a Q-V diagram (See Figure 1).

Table 1 Ratio of driving modes by average journey speed range

Averaged journey speed (km/hr)	Number of samples[2]	Time of driving modes – observed – (sec)					Typical ratio of driving modes – model – (%)			
		(a)	(d)	(c)	(i)	(T)	(a)	(d)	(c)	(i)
0 – 5	63	7.68	8.43	6.43	128.20	150.74	15.0[3]			85.0
5 – 15	87	7.14	8.18	2.44	48.00	65.76	12.6	14.9	–[4]	72.9
15 – 30	79	6.70	3.59	4.14	1.88	16.31	41.1	22.0	25.4	11.5
30 –	645	2.30	1.52	4.13	0.02	7.97	28.8	19.1	51.8	0.3

Note : 1) (a), (d), (c), (i) shows acceleration, deceleration, cruising, idling respectively, and (T) shows total time.
2) Datum for a short section (100m) is counted for one sample. (valid samples only)
3) Three modes are summed into the "Slow Cruising".
4) Cruising mode is neglected.

3.2 Factors to explain each traffic flow

The vehicle trajectories on a S-T diagram are compared in Figure 2. These are distinguished easily by the degrees of congestion and we can find that the vehicles in congested flow are compelled to stop many times not only at intersections but also at intermediates. This will have been occurred by the transaction of the delay caused by the forward congestion and its grade will change corresponding to the degree of congestion.

Table 2 Classification of traffic flow

Group		Driving Characteristics: Flow-out Traffic Volume (vehicles/greentime (sec)/lane)	Driving Characteristics: Averaged Journey Speed (m/sec)	Driving Pattern (typical driving modes)
Congested Region	(I)	$<30\times10^{-2}$	$-\ 1.4$	Slow C − I (2modes)
	(II)	30×10^{-2} − 70×10^{-2}	1.4 − 2.8	A − D − I (3modes)
Middle Region	(I)	70×10^{-2} − 105×10^{-2}	2.8 − 4.2	A − D − I (3modes)
	(II)		4.2 − 7.0	A − C − D − I (4modes)
Free Driving Region		$<70\times10^{-2}$	7.0 −	A − C − D − I (4modes)

Note : A: Acceleration D: Decelaration
I : Idling C: Cruising

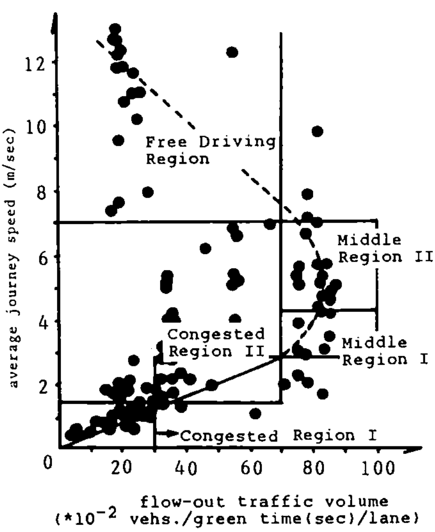


Figure 1 Classified flow data on a Q-V diagram based on Survey(II-1)

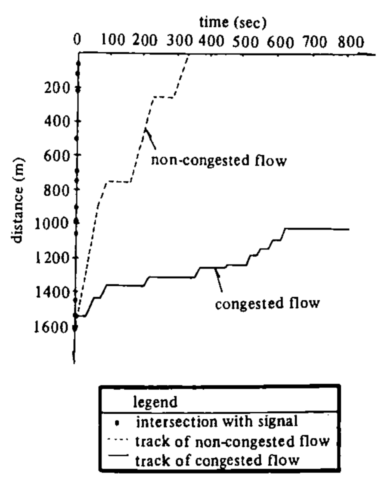


Figure 2 Comparison of vehicle trajectories on a S-T diagram

Traffic queue density and headway values in each flow condition were summarized as given in Table 3. In free flow conditions, as the mixing ratio of heavy vehicles raises, then the vehicles density decreases and also the headway spacing increases.

Average constitution ratio of driving modes, according to the classification of traffic flow, is shown in Figure 3. The driving modes constitution data obtained from Survey(II-2) are also plotted on triangular coordinates as shown in Figure 4, which shows the actual condition properly.

The degree of acceleration and deceleration in each traffic flow were analyzed as shown in Table 4. Based on this result, it was shown that in heavily congested flow these values were very small and therefore indistinguishable from the cruising mode with the lowest speed.

Table 3 Traffic queue density and headway in idling mode at intersections

Item	Category		Maximal Traffic Density (vehicles/100m)	Headway (m)
Mixing ratio of heavy vehicles (%)	0		17.2	6.0
	0 – 10		17.3	5.9
	10 – 20		16.1	6.4
	20 – 30		15.3	6.8
	30 –		13.9	7.4
Classification of traffic flow	Free Flow		(14.9)*	(6.7)*
	Middle Region	(I)	16.4	6.3
		(II)	16.5	6.2
	Congested Region	(I)	16.1	6.3
		(II)	16.6	6.1

Note ; ( )* was estimated by the regression

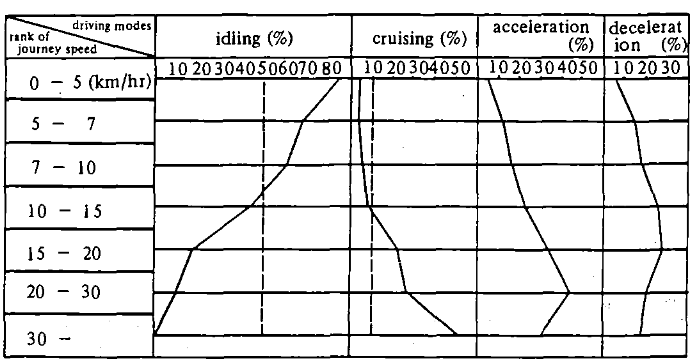


Figure 3 Average ratios of driving modes by journey speed range

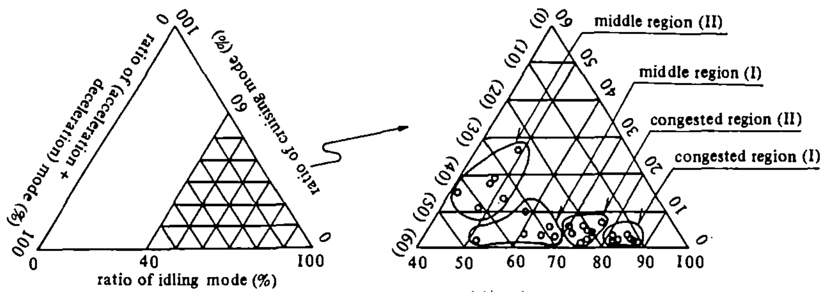


Figure 4 Classifying traffic flow and driving mode pattern (in congested traffic flow conditions)

Table 4 Degrees of acceleration and deceleration

Averaged Journey Speed (km/hr)	Acceleration (m/sec²)	Standard deviation	Deceleration (m/sec²)	Standard deviation
0 – 5	0.73	0.41	0.81	0.44
5 – 10	0.87	0.47	0.99	0.51
10 – 15	1.20	0.65	1.25	0.68
15 – 25	1.25	1.23	1.39	0.84
25 –	1.36	0.87	1.54	0.67

In congested traffic flow, drivers will be enforced to stop many times at the intermediate points on the road section as well as at signalized intersections. Then we observed the stopping ratio included in the cruising region according to the degrees of congestion. Following this result as shown in Figure 5, it was cleared that the less the traffic flow volume (i.e. the more the traffic congestion), the more the stopping ratio in the region of cruising mode.

From these facts, especially the driving patterns of the congested flow are considered appropriate to settle as below.

As shown in this table, the cruising modes were not recognized in the congested region(II). Therefore we need to examine the ratios of the accelerating and decelerating mode by the flow conditions. Analyzing the data obtained by test runnings, this ratios were seemed to be constant regardless of traffic condition within this region (see Figure 6).

	driving pattern	traffic condition
(I)	slow cruising & idling(2 modes)	saturated or saturating, headway spacings are small, and stop many times within the section
(II)	3 modes without cruising	headway spaces are becoming large momentarily, but driving mode can't get to the cruising mode, because of sharp acceleration and deceleration

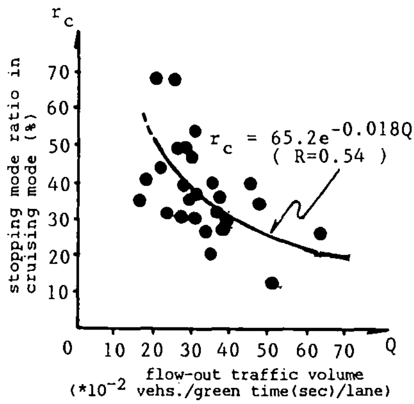


Figure 5 Stopping mode ratio in cruising mode in congested flow

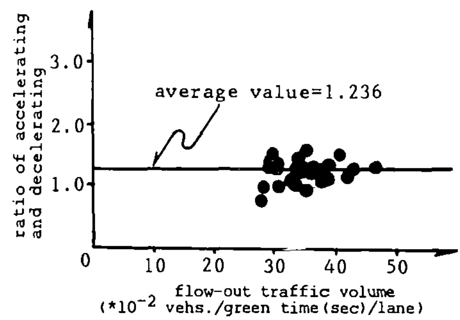


Figure 6 Ratio of accelerating and decelerating mode in congested region(II)

3.3 Stopping and starting condition

In general, arrivals and departures of vehicles on a S-T diagram, is able to be shown by drawing waves called stopping wave and starting wave respectively (See Figure 8). From the data obtained in the previous surveys, we could show two types of waves in accordance with traffic flow condition as shown in Figure 7. Here in case of the congested flow, it was observed that the gradients of stopping waves changed regularly by the flow level(i.e. the traffic volume or the average running speed), while the starting waves were little affected.

4. ESTIMATION MODEL FOR DRIVING MODES

4.1 Fundamental idea of signal stop model

On the free traffic flow conditions, the traffic flows passing through a signalized intersection are classified into three cases by the phase of signal, as shown in Figure 8 and as follows.

Case(1); when signal phase changes from green(G) to red(R),type of modes changes from cruising to idling through deceleration mode.

Case(2); when signal phase changes from (R) to (G),the modes of vehicles change from cruising to decelerating - accelerating - cruising modes without idling mode.

Case(3); during green, vehicles keep cruising mode.

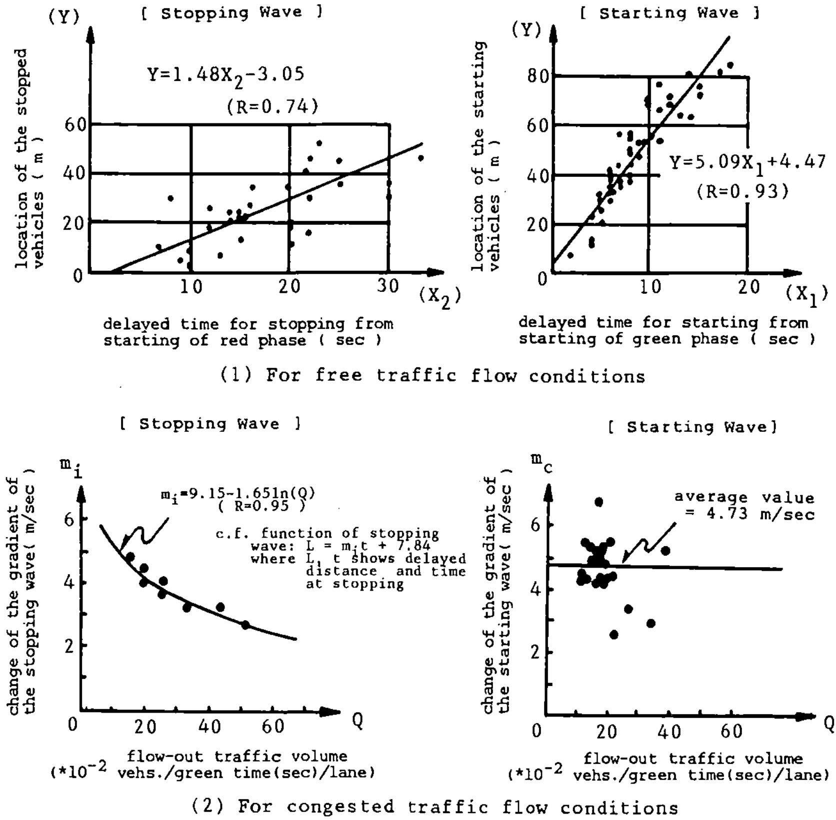


Figure 7 Stopping and starting waves and their characteristics

At the first step, we predict the ratio of vehicles of Case(1) (signal stopping ratio : p) based on the signal phase and flow arrival pattern, and we can estimate the composition of average time of each driving mode for this case of traffic flow . Next for the Case(2) and (3), they are all assumed to be cruising for simplicity, then each driving mode can be predicted.

For the congested flow, all vehicles are treated to be stopped at each signalized intersection (i.e. $p = 1.0$). But on the most heavily congested flow condition, the modes for acceleration and deceleration are not distinguished distinctly by the speed reduction. Then all vehicles are considered to belong to the special type of case (I) with very low speed.

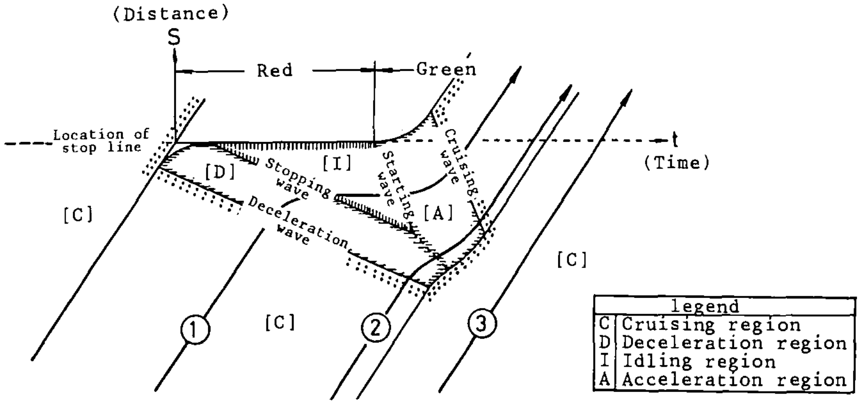


Figure 8 Classification of vehicle trajectories passing through a junction

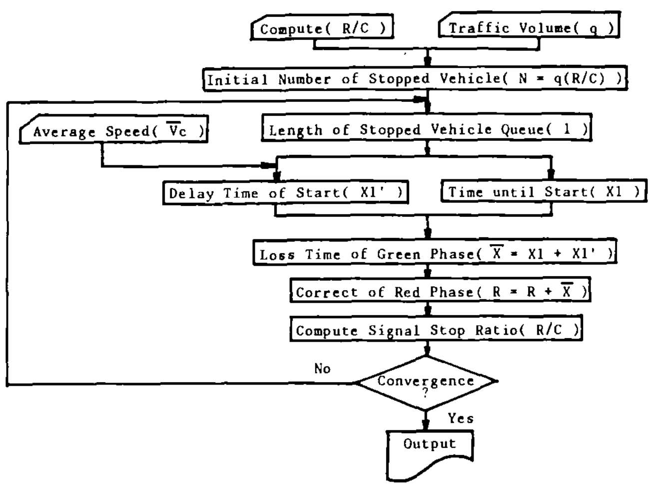


Figure 9 Flow chart of estimation method of signal stop ratio (Case II)

4.2 Estimation for a free traffic flow

A signal stop model was built based on the fundamental idea mentioned above, with the result of basic surveys (see Sec.2) about vehicle arrivals, signal stopping ratio, signal phases and vehicle runnings etc. The details of the estimation method based on the signal stop model are explained as follows.

Assuming a uniform vehicle arrival pattern, signal stopping ratio p is calculated in two cases of signal phase setting. Case 1 is related to the linked signal system. The first step in this case is to set the average arrival distribution pattern of vehicle. Second step is to classify these vehicles into the non-stopping(passing through) group and the stopping group, according to the location in arrival traffic flow. And last step is to compute the ratio of stopping vehicles (p). On the other hand, case 2 involves the non-linked signal system and in this case, the signal stop ratio is computed by the iterative convergence method shown in Figure 9.

A procedure of mode estimation is consisted of 1)computing the signal stopping ratio (p) and the number of stopped($p \cdot N$) and non-stopped vehicles($(1-p) \cdot N$) for the traffic volume(N), 2)computing the total time ($Tn = p \cdot N \cdot tn$) of each mode by the average hours(tn) of each mode for stopped vehicles and for non-stopped vehicles, which are assumed to be only the cruising mode, then the cruising time($Tc' = (1-p) \cdot N \cdot tc'$), 3)computing the composition ratio of time ($Rn = Tn / T$; $T = Tn + Tc$) of each mode, and 4)correcting these values by road and traffic conditions.

4.3 Estimation for a congested traffic flow

In the case of congested flow, all vehicles are assumed to be stopped at each signalized intersection and then the signal stopping ratio will be considered as $p = 1.0$. Furthermore in this case, it is generally assumed that the sufficient traffic demands(= arrival traffic volume) have been supplied continuously, and each region for driving modes will be also treated as simple as without both regions of deceleration and acceleration, in addition to the simplification as without considering the turning traffic from the cross road.

We can predict the time of each mode which should be regarded to two or three modes(see Table 2) by just the simple procedure as follows.

1) Determine the signal elements for prediction section and traffic volume for a basic intersection (which is set as the first major intersection on the prediction section).
2) Compute the average speed based on the traffic volume and select the classification type of traffic flow by the traffic volume and speed.
3) Set the form of stopping and starting wave according to the traffic volume, that is, draw the region of each mode on a S-T diagram and compute the area of each region, for each road section.
4) Compute time of two kind of modes which are consisted of idling and very slow cruising mode, by dividing the area by the length of the section. And to consider the stopping included in the cruising region, correct time of each mode by drawing the stopping time included in the cruising mode by the degree of congestion.
5) In case of the congested flow (II), the cruising time obtained in step 4) is divided into accelerating and decelerating time respectively by applying the ratio of them which is regarded to be constant(= [accelerating time] / [decelerating time in cruising time] = 1.236 as shown in Figure 6) based on the analysis of survey.

4.4 Practical utility of each model

In this paper, the prediction models were developed for 3 cases which are consisted of 1)free flow, 2)short section in a congested flow, and 3)long section in a congested flow. The practical utility of these models were examined through comparing the theoretically predicted volume by the model with the observed volume obtained by some test vehicle runnings.

The theoretical values about the travel time and composition ratio of each driving mode were shown to be in considerably good coincidence with the observed value as shown in Table 5. In congested flow, also an example of output based on a computer simulation system is shown in Figure 10.

Table 5 Comparison of results based on each model

(1) For free traffic flow

(%)

Direction	Item	deceleration	Idling	Acceleration	Cruising
east-ward	predicted	9.5	19.8	11.8	58.9
	observed	10.7	18.9	11.6	58.8
	error	11.2	4.8	1.7	0.2
west-ward	predicted	13.8	31.5	17.0	37.7
	observed	12.4	21.3	19.4	46.9
	error	11.3	47.9	12.4	19.6
average	predicted	11.9	26.3	14.7	47.1
	observed	11.1	21.1	15.0	52.8
	error	7.2	24.6	2.0	10.8

(2) For congested traffic flow

a) short section

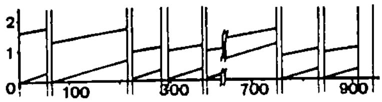
No. of section	Type of flow*	Traffic volume**	Idling mode(%) *** observed	predicted	error(%)	travel time (sec) observed	predicted	error(%)
①	I	26.2	75.1	77.3	2.9	312.5	439.6	40.7
	II	43.2	67.1	66.5	0.9	186.4	238.1	27.7
②	I	29.7	78.0	63.5	18.6	249.7	328.2	31.4
	II	38.6	75.6	57.0	24.6	207.9	241.5	16.2
③	I	29.8	84.1	78.6	6.5	129.8	204.5	57.6
	II	38.3	79.8	75.9	4.9	129.2	185.2	43.3

b) long section

	I	30.1	81.3	60.8	25.2	931.4	1043.5	12.0
	II	39.3	69.1	55.7	19.3	586.2	663.1	13.1

* In this table, the congested traffic flow I and II were only treated.
** These values are shown by " x10-2 vehs./green time 1 sec/lane".
*** The values in this column show the composition ratio of idling modes(%).

Based on the composition ratio of vehicles with different types of regulations for exhaust gas emission and the corresponding emission factor for each driving mode for them, the exhaust gas volume will be able to be calculated by using this model.



No.	S(i)	R(i)	T(i)	T(t)
1	5239.72	71.8%	156.7	218.2
2	15811.30	68.0%	261.0	383.7
3	18623.10	65.0%	298.0	458.1
4	22120.10	63.6%	342.6	538.8
5	27650.70	61.5%	420.3	683.6
6	37468.90	59.7%	559.7	936.9
7	40674.30	59.2%	608.3	1026.9
8	43941.40	58.7%	661.1	1127.2

legend	
S(i)	Area of idling region (m sec)
R(i)	Composition ratio of idling mode (%)
T(i)	Total time of idling mode (sec)
T(t)	Total time for each section (sec)

Figure 10 An example of output in a congested flow

5. EXAMPLE OF ESTIMATION BY SIGNAL CONTROL SCHEME CHANGE (ON A CONGESTED FLOW)

5.1 Extension of model application

In this paper, some models for estimation of driving modes were developed and their utilities were proved through comparison with the observed values. For applications of the models, a simulation model which can estimate driving modes of each individual vehicle on its trajectory on the S-T diagram, will be useful for controlling vehicles. The trajectories are able to be drawn easily, based on the regions of driving modes mentioned above and a parameter related to the average running speed. An example of trajectories based on the simulation method on the same road section shown in Sec. 4.4 is illustrated in Figure 11. At present, these process are shown to be in a considerable high accuracy for the congested flow, but it is not practical now in view point of accuracy for the free flow because it is not easy in the free flow to model the pattern and volume of arrival traffic by turning in from the cross roads at each intersection. As to this point, the methods are necessary to be improved.

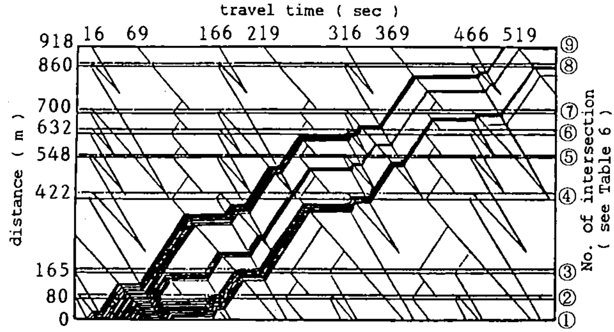


Figure 11 Examples of simulating individual vehicle trajectories

5.2 Estimation of the effect of signal control alternation

To estimate the difference of running conditions between two signal control schemes, the simulation model is applicable. For examples, two new schemes were introduced as follows. The first case is a modified case on the present scheme as to fix the offset time of each signal to zero, that is, the simultaneous control phase, and the second case is a modified case on the present scheme as to set the green time of each signal to 90 seconds(the split of green time = 0.6). The existing parameters(present scheme) of signals are shown in Table 6.

The differences of running conditions, as to the travel time and the composition ratio of idling mode, by these three signal control schemes are shown in Figure 12, where each plot means the value of individual vehicle. This figure shows that the running conditions of vehicles are changed by the signal control schemes, in other words, any alternative signal control schemes will be able to be evaluated by this model.

Table 6 Parameters of traffic signals on the observed section

No. of intersection	green phase (sec)	red phase (sec)	cycle time (sec)	offset time (sec)
①	87	63	150	+15
②	98	52	150	---
③	104	46	150	0
④	98	52	150	+15
⑤	98	52	150	+15
⑥	96	54	150	+15
⑦	98	52	150	+15
⑧	72	78	150	+15
⑨	53	97	150	+16

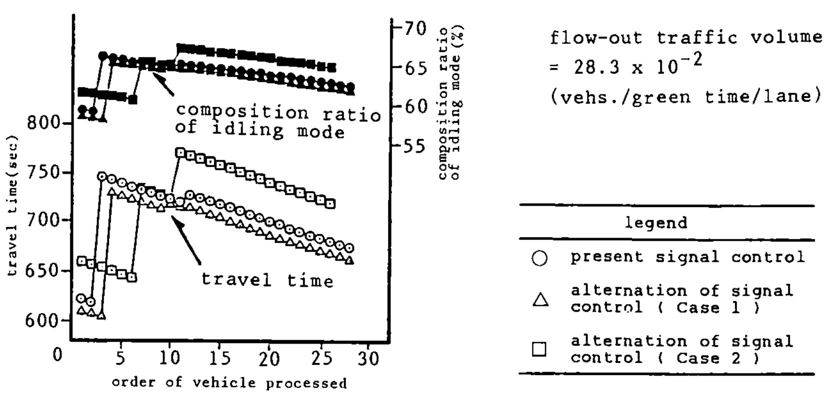


Figure 12 Examples of estimation for three types of signal control schemes by the simulation model

6. CONCLUSION

According to the results of application of the model to some study sections, we could consider the model having relatively high accuracy. This shows that by supplying the basic data such as the system of signal control, traffic volume and road conditions so on, the travel time and driving modes can be predicted at any road section or for any time period, based on this simple method. Also the exhaust gas volume will be able to be estimated easily and by using the emission factors for each mode of each vehicle type.

This model has developed a new approach of exhaust gas estimation for the road transportation source in more details than the average speed model.

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