A DYNAMIC SIMULATION MODEL FOR THE EVALUATION OF TRAFFIC MANAGEMENT SCHEMES

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1. INTRODUCTION

The potential new advanced technologies developed recently around world are to influence traffic movement and travel behaviour. In special, traffic information systems have become principal issues in many countries as a modern technology for alleviating traffic congestion in urban area. Traveler information is essential for the roadway system to operate efficiently and safely. In mainline control, traveler information systems advise motorists freeway conditions so that the driver can take appropriate action, thus enhancing the efficiency and safety of traffic operations. Traveler information allows the driver to make informed decisions and act accordingly: i.e., continue on a planned route or divert to an alternate to avoid delays.

Traffic management schemes are the operation tools producing a consistent, efficient allocation of traffic resources such as traffic information, optimum signal control and traffic demand strategies in order to avoid or reduce the urban congestion. This management schemes lead to make the best use of available road capacity. Management schemes also enable to reduce the time and resources needed to deal with traffic incidents, to respond automatically to changing traffic controls and conditions, and to avoid congestion areas. In these respects, it is necessary to consider a tool of evaluating the traffic management schemes for the purpose of more efficient management and assessment of the effects of the schemes. The traffic management evaluation model is also useful for developing new management schemes. Some of such kinds of traffic models have been developed since late 1970 such as SATURN(Van Vliet, 1982), CONTRAM(Taylor, 1990), INTEGRATION(Aerde, 1985). These models, however, have the both sides of advantages and shortcomings respectively to assess the traffic management schemes.
In this paper, we propose a traffic management model based on traffic simulation, which is mainly for evaluation of traffic schemes. The model will be developed somewhat different from the previous models in that it include several traffic assessment tools capable of evaluating traffic management scenarios. In this paper, several traffic management schemes are presented and evaluated with the model. Solution algorithm is also suggested briefly and an contrived network is used for example.

2. URBAN TRAFFIC MANAGEMENT

2.1 Traffic management system

Modern traffic management systems are consisted of some subsystems such as data collection, decision-making, execution and evaluation as shown in Figure 1, closing the loop of control functions within a time interval. The principle elements of the each subsystem are summarized in Table 1.

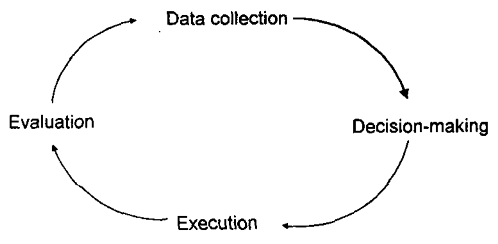

Figure 1. Traffic management system

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Table 1. Management subsystems

subsystems	purpose	elements
Data collection	- collect data from field equipments	- detectors(sensors) - CCTV monitoring - Automatic vehicle identification(AVI)
Decision-making	- select appropriate traffic management schemes	- data fusion in addition to historic information - real-time traffic prediction - select responsive traffic management schemes
Execution	- implement management schemes	- traffic control - traffic management - traffic information
Evaluation	- measure the performance of the traffic schemes	- evaluate the MOE

Data collection is the first subsystem for collecting field data by detectors, CCTV and automatic vehicle identification. Decision-making is the next subsystem for selecting an appropriate traffic management schemes according to traffic conditions and then execution subsystem follows. After execution the management schemes are evaluated and these sequential subsystems are iterated until a steady state station is obtained.

Among the subsystems above, our main interesting systems in the paper are the second[Decision-making] and the fourth[Evaluation]. Decision-making system is the procedure of selecting the best management schemes for alleviating traffic congestion, based on the real-time data. The evaluation subsystem is the procedure of measuring the performance of the traffic schemes with measure of effectiveness(MOE).

2.2 Urban traffic management schemes

Urban traffic management schemes for efficient traffic control are mainly classified by four parts : traffic operation, traffic routing, transit operation and demand management. More details of each schemes are as lists.

1) traffic operation
   - signal optimization(Traffic control : signal control, ramp metering)
   - Integrated control freeway and adjacent arterial
   - incident management
2) traffic routing
   - traffic information
   - alternate routing
3) Transit operation
   - transit
   - HOV
4) demand management
   - road pricing

3. BRIEF REVIEW OF EXISTING MODELS

The principal use of traffic assignment model has nowadays shifted the appraisal of traffic management schemes for reducing traffic congestions. As mentioned above, the management schemes include traffic engineering tools as well as transportation planning and demand management schemes. To assess the management schemes, we need appropriate model for evaluating the schemes. In the center of the model, dynamic traffic assignment is located, combined with some additional appraisal tools such as information, signal control and so on. Since late 70s, several dynamic assignment models have been proposed. Table 2 shows the brief summary of the models and their properties.

Table 2. Dynamic traffic assignment models

models	Mathematical programming model	Optimal control model	Simulation -based model	Heuristic model	Stochastic route/departure time choice model	Mahmassani model
formulation	mathematics	mathematics	simulation	mathematics	simulation	simulation
existence of solution	proof	proof	NA	proof	NA	NA
route choice criterion	Wardrop's principle	Wardrop's principle	User Opt.**	Wardrop's principle	extended Wardrop's principle	bounded rationality
solution algorithm	equilibrium approach	equilibrium approach	incremental approach	equilibrium apprpach	stochastic process	
elastic demand	inelastic	elastic	fixed demand pattern	fixed demand pattern	elastic	elastic
queueing	implicit	implicit	explicit	implicit	implicit	explicit
flexibility	low	low	high	medium	medium	high
applied network	small	small	large	large	medium	large
researchers	Merchant & Nemhauser(1978) Ho(1980) Carey(1986,1987)	Luque et.al(1980) Wie(1990) Ran etal.(1993)	Yagar(1971) Leonard et.al.(1989) Aerde(1985)	Janson(1991) Lim(1997)	Ben-Akiva et,al.(1987) Vythoulkas(1990) Cascetta et.al.(1989)	Mahmassani et.al(1991)
package*			CONTRAM INTEGRATION		STODYN	DYNASMART

* *see Watling(1994) in more detail on packages*
** *not meaning for Wardrop's Equilibrium*

As shown in Table2, dynamic traffic models so far can be broadly classified into two approaches : mathematical approach and simulation-based approach. Mathematical approach may be also divided into mathematical optimization approach and optimal control-based approach. Mathematical methods are formulated as an equivalent minimization program in order to search for optimum and suggested solution algorithm to attain it. Merchant and Nemhauser(1978) were the pioneers who formulated the dynamic program with a nonlinear and nonconvex mathematical program. Almost a decade later, Carey(1986) reformulated Merchant's model as a convex, nonlinear program. In conjunction with, recently optimal control-based approach has been developed by some researchers(Friesz, et.al.: 1989, Ran,et.al. : 1993). These mathematical approaches, however, have been applied to small or medium networks due to their strong mathematical assumptions such as monotonous non-decreasing cost function, FIFO(first in first out) rule and constraints for feasible sets. These assumptions also make the models difficult to depict real traffic conditions.

On the other hand, simulation-based dynamic models use the simulation within an iterative assignment framework. Such a method does not have the attractive analytical properties of the approaches described above. However, it is far easier to incorporate traffic management strategies within the model. In these respects, Simulation modeling is an increasing popular and effective tool for analyzing a wide variety of dynamical problems which are not amenable to study by other means. These problems are usually associated with complex processes which can not readily be described in analytical terms. Usually, these processes are characterized by the interaction of many system components or entities. Often, the behavior of each·entity and the interaction of a limited number of entities, may be well understood and can be reliably represented logically and mathematically with acceptable confidence.

4. FRAMEWORK FOR DYNAMIC TRAFFIC MANAGEMENT MODEL

Urban traffic management model consists of an interaction between the traffic manager and the individual drivers. They have somewhat different traffic behaviors and may pursue different objectives respectively. The traffic manager represents the community interests and pursue its goal, the driver seeks only his own benefit. Given demands for travel in an urban area and a fixed supply of transportation facilities, the traffic amanger must consider a variety of management strategies to induce a traffic flow pattern that will meet the overall objectives of the community. The manager's criteria for evaluating his actions may include public interest measures of performance such as travel time, energy consumption, noise and pollutant emissions, etc. On the other hand, the individual driver is assumed to selfishly strive to minimize only his own travel costs, subject to the constraints imposed by the physical system supply, the manager's intervening actions and the interactions resulting from other drivers' decisions. Thus the traffic management problem can be set as system-optimization for flows that result from user-optimization. This leads to a traffic management model capable of simulating traffic measures of traffic manager and behavior of drivers. In this paper, a traffic management model is developed mainly for evaluation of traffic schemes. The model will be developed somewhat different from the previous models in that it include several traffic assessment tools capable of evaluating traffic management scenarios.

4.1 Structure of the traffic management model

The traffic management model is a simulation-based dynamic traffic assignment model integrated with traffic management schemes. Urban road networks are represented in detail for the purpose of describing the drivers' travel behavior. The developed model is mainly divided into two parts : a traffic simulation model and a traffic management model. The traffic simulation model describes the traffic flow on the road network in mesoscopic. A packet-based traffic model will be developed to simulate the vehicle motions. The simulation model will be combined with a traffic assignment model and reflect the drivers' behavior. This leads the link flow to user equilibrium state. The traffic management model is for setting traffic information and traffic signal strategy for certain control purpose. Various traffic management strategies are considered with the information and signal control. Some traffic management strategies using signal control and traffic information are developed in the paper and tested in a contrived network. The effects of these management schemes are evaluated by the traffic simulation model.

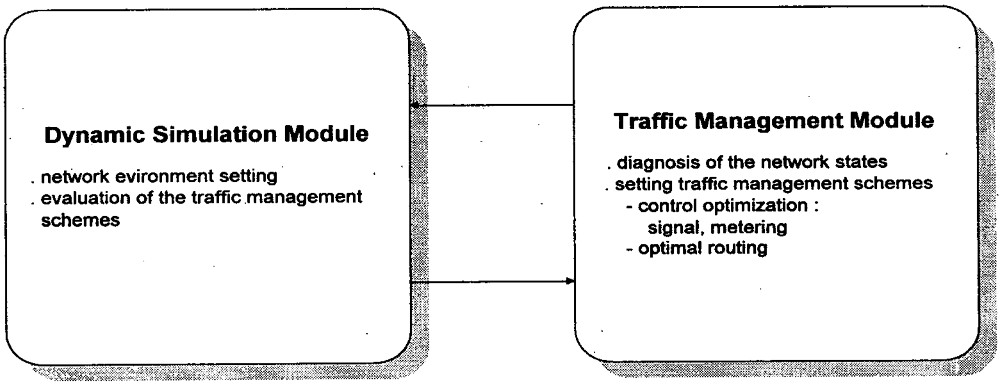

Figure 2. Framework of dynamic traffic management model

4.2 Elements of simulation model

For the purpose of evaluating diverse traffic management schemes, the developed model requires some basic elements. The requirements of the model in the paper are as follows.

1) Optimal routing algorithm

The basic principle of optimal routing algorithm in the model is the extension of Wardrop Equilibrium to dynamic version : For each origin-destination pair and each time slice, more costly routes are not used. This define the dynamic equilibrium as the condition that all used routes have identical cost and solution algorithm attain the same route cost at each time slice. Although incremental network loading technique is used for assigning trips at each time slice, iterations are executed until obtaining a convergence value within the model. To search for minimum time path, a modified Dijkstra's algorithm and D'Esopo's algorithm are adopted.

2) Supply

Simulation models will be grouped according to three fairly commonly used levels of aggregation : microscopic, mesoscopic and macroscopic. A microscopic model describes both the system entities and their interactions at a high level of detail, thus the model can describe the network as a vehicle-based dimension. A mesoscopic model generally represents most entities at a high level of detail but describes their activities and interactions at a much lower level of detail than would a microscopic model. On the other hand, A macroscopic model describes the traffic movement as flow-delay relationship as a whole and simulate the interactions at a low level of detail. In the model, we adopted a mesosocpic simulation model and the movements of vehicles are described as a packet similar to CONTRAM. A packet is assumed to consist of 10 vehicles and has the same property.

3) Demand

The density of packets represents travel demands of each time slice. Travel demands are divided into two groups such as auto and transit by disaggregated choice model. The proportions of each group are determined by Logit model according to their disutilities, or route cost. In order to consider time-variant travel demand, a pre-specified demand patterns or a departure time choice model are adopted.

4) Multiple User Class(MUC)

Multiple user classes(MUC) have more than one class of user, where class may be defined on the basis of vehicle type, driver's cost functions, the sections of the network available, etc. Each class of user is assumed to choose a minimum cost route in accordance with its own definition of cost. MUC would also allow a approximation to the effects of traffic information within ITS. Guided class can be assumed to have perfect knowledge of network conditions, thus the guided class is assumed to follow user-equilibrium behaviors. But unguided class group has uncertainty of network states, so this group is assumed to follow stochastic user-equilibrum principle. We may also classify the group by the degree of guidance. MUC model is getting important in traffic management because it can assess the effects of each user class more detail.

5) Dynamic evolution

Driver behaviors are varied with the travel time which is combined a running time and a junction delay. Travel time $t(f,\lambda)$ on link i is calculated as follows,

$$t_i(f,\lambda) = t_{oi}(f) + d_i(f,\lambda)$$

where $t_{oi}(f)$ is link traversal time and $d_i(f,\lambda)$ is delay, or queueing time. f is link flow vector and λ is green time split vector. With the link length(L) and travel speed(v), Equation(1) can be rewritten as

$$t_i(f,\lambda) = (\frac{L}{v})_i + d_i(f,\lambda)$$

Delay $d_i(f,\lambda)$ is a principal parameter for describing the performance of signalized intersections. There have been developed some signalized delay function since Webster(1958). Akcelik(1988) reviewed the signal delay functions proposed so far and unified them in a simple equation with different values of parameters. This paper use Koti(The Korea Transport Institute) delay function, proposed by Kim, et.al.(1991), which can depict Korean traffic conditions. The Koti delay function is as follows.

$$d(f,\lambda) = \frac{0.5C(1-\lambda)^2}{1-\lambda x} + 225[(x-1) + \sqrt{(x-1)^2 + \frac{12x}{c}}]$$

where the subscript i is omitted for simplicity, $d(f,\lambda)$ is a average overall delay in seconds per vehicle and C is signal cycle time in seconds. x is the degree of saturation(= $\frac{f}{\lambda s}$), s is a saturation flow and λ is green time split. c is the capacity for that link, or $c = \lambda s$. This delay function consists of two terms such as the uniform delay(d_u) and the overflow(d_o) terms.

$$d(\cdot) = d_u + d_o$$

The first term of the equation accounts for uniform delay, i.e., the delay that occurs if arrival demand is uniformly distributed over time. The second term of the equation accounts for incremental delay of random arrivals over uniform arrivals, and for the additional delay due to cycle failures.

Akcelik(1988) suggested the relationship between the average overflow queue(q_o) in vehicles and the overflow delay(d_o) in seconds. This relationship come from the deterministic queueing theory in oversaturated condition, which overflow queues are dependent on only capacity of that link.

$$d_o = 3600 \frac{q_o}{c}$$

where c is the capacity in vehicles/hr. From equation(5), the average overflow queue(q_o) can be obtained as

$$q_o = \frac{1}{3600} d_o c$$

where q_o is allowing for randomness. In order to take account of time-varying evolution of queues, in the paper the average overflow queues are transmitted to next time interval as an overflow delay.

6) Information provision strategy and degree of information guidance

Traffic information plays an important role in drivers' route choice behaviors and it is classified into individual system and collective system. On the other aspect, the provision of traffic information is also falled into two parts; minimizing travel cost for driver(user equilibrium guidance) or network as a whole(system optimality guidance). It is recently a key issue to traffic manager that any route guidance strategy is to be used. There exist several strategies in respect of the management purposes and also exist conflicts of interest between the equipped drivers who want to improve their travel time, and the traffic managers, whose objectives is reducing overall traffic congestions. One of the solutions to this problem would seek a strategy which combines the objectives of the user and the system. Three information strategies are, in the paper, introduced such as 'User Optimality strategy', 'System Optimality strategy' and 'In-between strategy'. The UO routing strategy is implemented by performing user equilibrium assignment with an average travel cost on link as follows.

[UO strategy] $t_a(f^t, \lambda^t)$

Where, $t_a(f^t, \lambda^t)$is a total travel cost on link a at time t , a function of flow f and green time split λ. In order to implement the SO routing strategy, system optimal assignment is performed with a marginal link travel cost as the same above.

[SO strategy] $t_a(f^t, \lambda^t) + f^t \cdot \frac{\partial t_a(f^t, \lambda^t)}{\partial f^t}$

And lastly, the In-between routing strategy is to be considered as follows.

[In-between strategy] $t_a(f^t, \lambda^t) + \gamma f^t \cdot \frac{\partial t_a(f^t, \lambda^t)}{\partial f^t}$

where, γ is a parameter between 0 and 1. In the case of γ=0, The In-between routing strategy is equivalent to the UE routing strategy, and γ=1 then to the SO routing strategy.

Another important element in traffic information system is the degree of information guidance. Guided travelers determine their route and mode by expected travel time and almost no perception error. Otherwise, Unguided travelers get much more inaccurate travel conditions. In the paer we assume that guided driver follows user-equilibrium(UE) principle and the unguided follow stochastic user equilibrium(SUE) principle with some variance of travel time. Thus link travel time of unguided driver can be formulated as

$$T_a \sim N(t_a, \delta t_a)$$

where, T_a follows normal distribution with mean t_a and variance δt_a.

7) Traffic signal control

Since 1950s, various signal control policies have been proposed. Some of them are Webster's equisaturation policy(1958), Allsop's delay minimization (1971), Smith's capacity maximization(1979) among others. Most popular signal policy in traffic engineering is Webster' policy which is setting the green split to each approach in proportion to the traffic volumes. The policy is based on the premise that overall delays at a junction are approximately minimal when the f/c ratio of each approach is equal, which is known as equisaturation policy.

The Webster's signal policy is adopted as signal control policy in this paper. Webster policy is as follows in 4-phase cases.

$$Eq_i. \quad \frac{f_i}{\lambda_i s_i} \qquad i=1,..,4$$

Where, $Eq_i.$ stands here for " equate for all approach i ". f_i, λ_i, s_i are the traffic flow, green time split and saturation flow rate on approach i respectively. In this paper we consider two kinds of signal controls ; pre-timed signal setting and responsive signal setting. Pre-timed signal setting is, as you know, the operation of traffic signal with pre-determined fixed cycle length and green time split, but responsive signal setting is based on current traffic flows.

4.3 Overall solution algorithm

For solving the program, A solution algorithm is presented as follows. The iterations are repeated until each link flows converge to Wardrop's equilibrium.

[step 0] Initialization
- network setting
- iteration n=0
- time slice t=1

[step 1] Mode choice
- choose mode choice with Logit model, based on travel times

[step 2] Packet generation
- for each mode, time slice and origin-destination pairs, generate packets

[step 3] Traffic management schemes
- for specific management purpose, select traffic management schemes
  - calculate green split based on signal policy
  - determine traffic information provision and degree of information

[step 4] Dynamic Assignment(Incremental Network Loading)
- for each time slice
  - for each user class
    - (1) calculate link travel time
    - (2) minimum path search
    - (3) packet moving

[step 5] Convergence check
- if $f^{t,n+1} \simeq f^{t,n}$, stop
- otherwise, n=n+1 and goto [step 3]

[step 6] if t $\geq$ time periods , stop
- otherwise, t=t+1 and goto [step 2]

5. NUMERICAL EXAMPLE

5.1 A test network

A numerical example is presented to illustrate the application and the assessment of the developed dynamic traffic management model. The example network is shown in Figure 3, includes one origin-destination pair from node 1 to node 7. and five signalized intersection(node 2 to node 6). Each signal intersection has 120 seconds of cycle length, 2 seconds of loss time and 10 seconds of minimum green time. Trip demands for each time slice are shown in Table 3.

Table 3. Trip demands

Origin	Destination	trip demand for each time slice						
		1	2	3	4	5	6	7
1	7	300	380	460	450	400	420	300
7	1	300	380	460	450	400	420	300

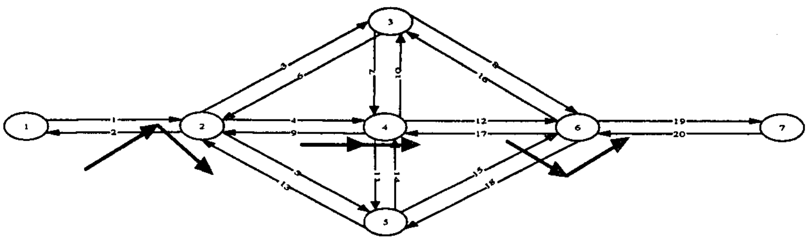

Figure 3. Example network

5.2 Results

1) Model convergence

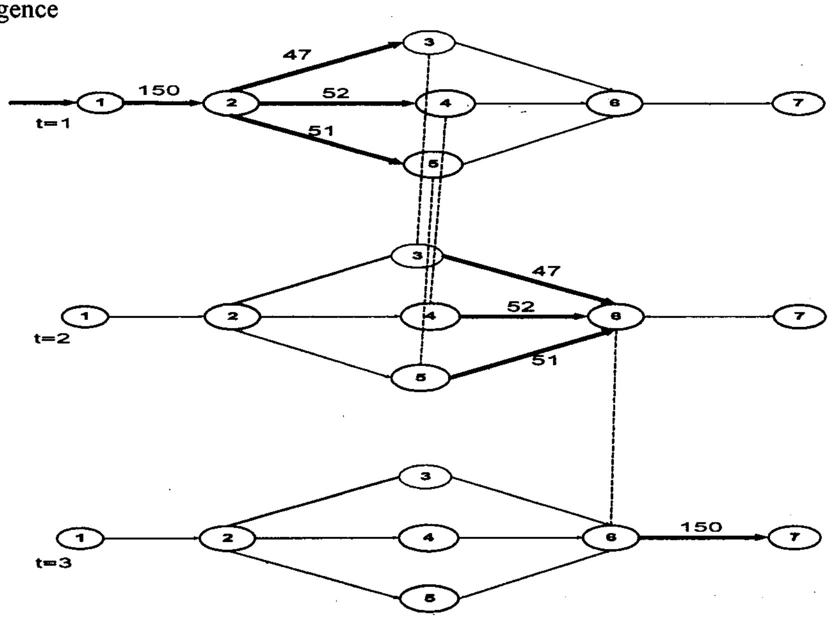

Figure 4. Traffic flow pattern for each time slice

Table 4. Path travel time

time slice	path travel time(sec)			
	path 1 ②→③→⑥	path 2 ②→④→⑥	path 3 ②→⑤→⑥	difference
1	6.33	6.40	6.40	0.07 (0.0109)
2	6.86	6.86	6.86	0.0 (0.00)
3	7.13	7.06	7.06	0.07 (0.0098)
4	7.20	7.20	7.13	0.07 (0.0097)
5	7.06	7.06	7.13	0.07 (0.0098)
6	7.06	7.06	7.00	0.06 (0.0085)
7	6.88	6.93	6.93	0.05 (0.0072)

Figure 4 depicts the traffic flow patterns for each time slice. Vehicles originating from origin node 1 are moving to destination node 7 as time slice elapses. As shown in figure, vehicles are splitted to three paths at node 2 and proceeded to node 6. At node 6 all vehicles are gathered again and terminated their trips at node 7.
Table 4 shows the path travel time for each paths. In the model, we assumed that each drivers follow user-equilibrium principle : all used paths have the same travel cost. If we ignore small perturbations, three paths have the same travel times for each time slice as shown in Table. These figures show that traffic flows converge to Wardrop's equilibrium.

2) Traffic flow evolutions
For each time slice, traffic flow, green time and queue evolutions are shown in Figure 5 and Figure 6. As shown in Figure 5, green times at approach 1 are determined according to the traffic flows so that both green time and traffic flow show similar trends. In this paper, green times are calculated with Webster signal policy. This figure also depicts the evolution of traffic queues. In some cases, traffic queues have big fluctuations between intervals due to green times of the approach ; thus queues increases as green time decrease and vice versa.

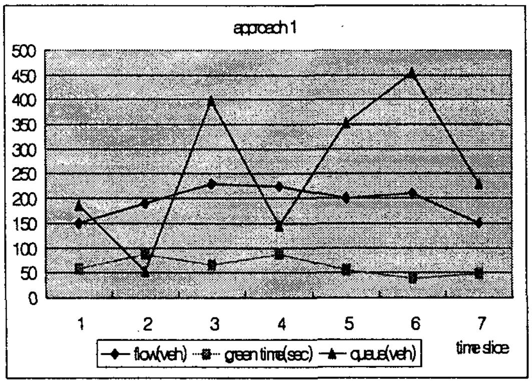

Figure 5. In the case of approach 1

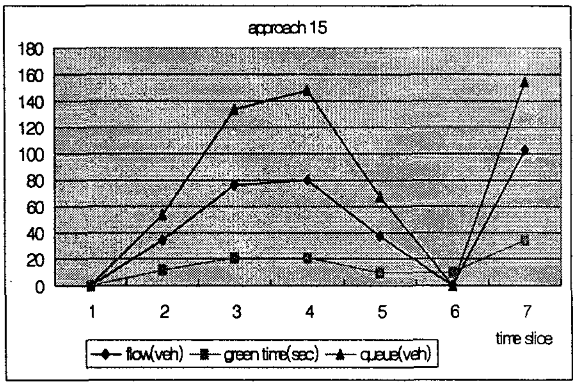

Figure 6. In the case of approach 15

3) Effects of traffic information

Figure 7 depicts the relation between the degree of traffic information(β) and the total travel time as time slice elapses. Note that the effect of information is expressed as a ratio of the total travel time under the no information base case; thus values in excess of 1.0 correspond to a worsening of system performance compared to the do-not information following case.
In earlier time slices, there exist the effects of traffic information, but as the time slice elapse total travel time has increased. And in some cases the ratio excess the value of 1.0, which means for adverse impact of traffic information. The reasons of the worsening travel time in this paper are come from the overreaction to traffic information and the concentration on specific path suggested by Ben-Akiva, et.al.(1991). These results also show that if driver responds to traffic information sensitively, traffic information may lead to worsening the road networks.
Figure 8 shows the relation between the time slice and the degree of information. We can find that there are significant differences between each time intervals. As shown in Figure, time slice 4 have lower values as a whole. But the others have higher value of 1.0 as the β increases. This phenomenon imply that choosing departure time is getting important in such conditions

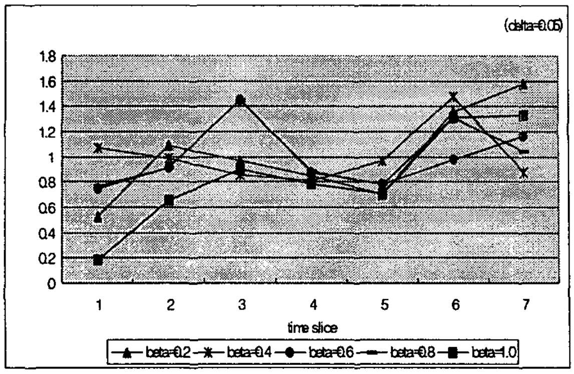

Figure 7. Relation between total travel time and time slices

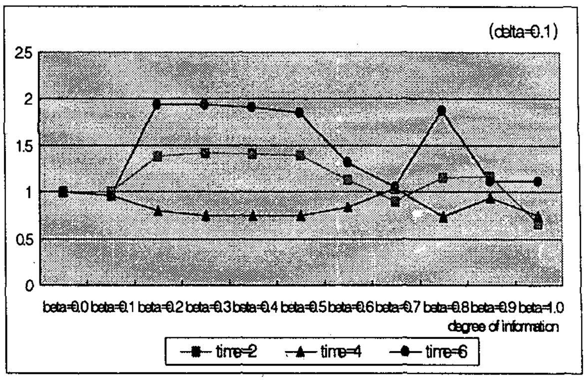

Figure 8. Relation between total travel time and beta(β)

6. CONCLUSION

This paper is a preliminary research for developing traffic management model, therefore we suggest some normative developing directions relating to the model for further researches. Developed model is based on traffic simulation because it is easy to integrate traffic management schemes with the model. From the results of evaluating the model with an example network, we have conclusion that the model can be useful in assessing diverse traffic management schemes.

Further studies related to this research include the following issues:
First, so as to simulate the behavior of drivers more precisely, a stochastic element is included in the model. Second, the effects of traffic management are tested only in normal traffic conditions, not incident situation, therefore the incident case has to include for evaluation of these strategies. Finally, the elastic demand is to be considered for the purpose of representing departure time and route choices.

7. REFERENCE

Aerde V.(1985) Modelling of Traffic flows, Assignment and Queueing in Integrated Freeway/Traffic signal networks, Ph.D thesis, University of Waterloo

Allsop, R. E. (1971) Delay-minimizing settings for fixed time traffic signals at a single road junction. J. Inst. Math. Its Appl. 8, 164-85

Allsop, R. E. (1974) Some possibilities for using traffic control to influence trip destinations and route choice, Proceedings of the 6th International Symposium on Transportation and Traffic Theory, 345-374. Elsevier

Akcelik, R.(1988) The highway capacity manual delay formula for signalized intersections, ITS Journal, March, 23-27

Astarita V.(1996) A Continuous Time Link Model for Dynamic Network Loading Based on Travel Time Function, proceeding of the 13th International Symposium on Transportation and Traffic Theory

Ben-Akiva,M.,De Palma A. and Kanaroglan P.(1986) Dynamic model of peak period Traffic congestion with Elastic Arrival Rate, Transportation Science 20, 164-181

Ben-Akiva,M.,A.De Palma, and I.Kaysi(1991) Dynamic network models and driver information systems, Transportation Research 25A, 251-266

Boyce, D., B. Ran., L.J. LeBlanc(1995) Solving on Instantaneous Dynamic User-Optimal Route Choice Model, Transportation Science, 128-142

Carey M.(1986) A constraint qualification for a dynamic traffic assignment model, Transportation Science 20, 55-58

Carey M.(1987) Optimal time-varying flows on congested networks, Operations Research 35, 58-69

Cascetta E.(1989) A Stochastic process approach to the analysis of temporal dynamics in transportation networks, Transportation Research 23B, 1-17

Emmerink,R.H., K.W.Axhausen, P.Nijkamp and P.Rietveld(1995(a)) The potential of information

provision in a simulated road transport network with non-recurrent congestion, Transportation Research(C), Vol.3, 293-309
Emmerink,R.H., K.W.Axhausen, P.Nijkamp and P.Rietveld(1995(b)) Effects of information in road transport networks with recurrent congestion, Transportation 22, 21-53
FHWA(1996) Traffic control systems handbook, FHWA-SA-95-032
Fisk, C. S. (1984) Game theory and transportation systems modelling. Transportation Research, 18B, 301-313
Friesz T.L.,Luque F.J., Tobin R.L. and Wie B-K.,(1989) Dynamic network traffic assignment consistent as a continuous time optimal control problem, Operations Research 37, 893-901
Heydecker, B.G., J.D. Addison(1996) An exact expression of dynamic traffic equilibrium, proceedings of the 13th International Symposium on Transportation and Traffic Theory, Pergamon
Gartner, N. H., Gershwin S. B., Little J. D. C. and Ross P. (1980) Pilot study of computer-based urban traffic management, Transportation Research 14B, 203-217
Janson, B.(1991) Dynamic traffic assignment for urban road networks, Transportation Research 25B, 143-161
Janson, B. and F. Southworth(1992) Estimating departure times from traffic counts using dynamic assignment, Transportation Research 26(B), 3-16
Kim,Y.C.,C.W.Lee(1991) Signalized Intersection Delay Model, Journal of Korea Transportation Research Society Vol.9, No. 2, 27-40
Leonard, D.R., P.Gower and N.B.Taylor(1989) CONTRAM: Structure of the Model, TRRL, Research Report 178
Lim, Y.T. & Lim, K.W.(1997) Development of A Heuristic Dynamic Traffic Assignment Model, Journal of Korean Society of Transportation Vol. 15, No. 2, 51-66
Mahmassani,H.S. and J.Chen. PS-T.(1991a) Comparative assessment of origin-based and en route real-time information under alternative user behavior rules, Transportation Research Record 1306, 69-81
Mahmassani,H.S. and Jayakrishnan R.(1991b) System performance and user response under real-time information in a congested traffic corridor, Transportation Research(A) 25(5),293-308
Marcotte. P. (1983) Network optimization with continuous control parameters. Transportation Science, 17, 181-197
Merchant D.K. and Nemhauser G.L.(1978a) A model and an algorithm for the dynamic traffic assignment problems, Transportation Science 12, 183-199
Merchant D.K. and Nemhauser G.L.(1978b) Optimality conditions for a dynamic traffic assignment model, Transportation Science 12, 200-207
Ran B., D. Boyce & L. J. LeBlanc(1993) A new class of instantaneous dynamic user-optimal traffic assignment models, Operations Research, 192-202
Sheffi Y. and Powell W. B. (1983) Optimal signal setting over transportation networks. Transportation Eng., 109(6), 824-839
Smith, M. J. (1979) The existence, uniqueness and stability of traffic equilibria. Transportation Research 13(B), 295-304
Smith M. J.(1993) A new dynamic traffic model and the existence and calculation of dynamic user equilibria on congested capacity-constrained road networks, Transportation Research 27B, 49-63
Taylor,N.B.(1990) CONTRAM5 : An Enhanced Traffic Assignment Model, TRRL Res. Report 249, Crowthorne
Vuren.T.V., Watling,D.P.(1991) A multiple user class assignment model for route guidance, TRR 1306
Vythoulkas P.C.(1990) A dynamic stochastic assignment model for the analysis of general networks, Transportation Research 24B, 453-469
Wardrop,J.G.(1952) Some theoretical aspects of road traffic research, Proceedings of Institute of Civil Engineering, part 2, 325-378
Watling D.(1994) Urban traffic network models and dynamic driver information systems, Transport Reviews, Vol. 14, NO. 3, 219-246
Webster, F. V. (1958) Traffic signal settings. Road Research Technical paper no.39, H.M.S.O.
Wie,B-K.,T.L. Friesz and R.L. Tobin(1990) Dynamic user optimal traffic assignment on congested multidestination network, Transportation Research 24B, 431-442
Yagar S.(1971) Dynamic traffic assignment by individual path minimization and queueing, Transportation Research 15, 179-196