Journal of the Eastern Asia Society for Transportation Studies, Vol. 6, pp. 2307 - 2320, 2005

Predictive VMS Control Strategy for Alternative Routes

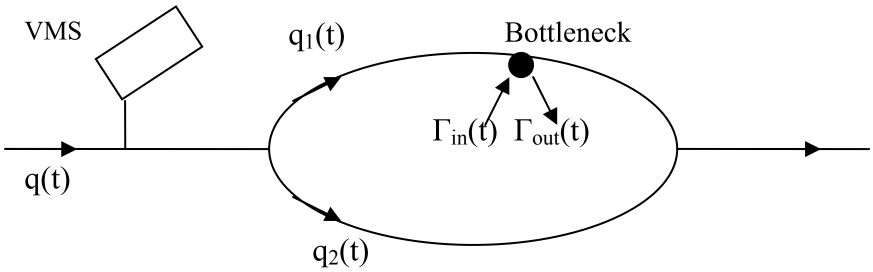
Eunmi PARK
Associate Professor
Dept. of Urban Engineering
Mokon University
800 Doan Dong, Seo Gu, Daejeon, Korea
Fax: 82-42-822-5931
E-mail: peunmi@mokwon.ac.kr

Abstract: It is a common practice that VMS (Variable Message Sign) is implemented on the network with alternative routes to achieve optimal traffic allocation among the alternative routes. But VMS has its own limitation. That is, desirable traffic allocation among alternative routes cannot be automatically achieved by the VMS information itself. Rather it is generally known that VMS information generally causes overreaction and concentration problem. Considered is a simple hypothetical network with two alternative routes, one bypass and the other with a physical bottleneck. The concentration problem is illustrated with this sample network. And strategic VMS control is proposed to compensate for the discrepancy between the system optimal and the predicted traffic allocations. To make this control concept work, a new concept and the estimation procedure for the dynamic capacity are provided especially for congested flow condition. Finally, functional requirements for VMS control with overreaction and concentration problem are summarized, which remains for further research.

Key Words: VMS control, Overreaction and concentration, Dynamic capacity, Maximum sustainable throughput

1. PROBLEM STATEMENTS

Consider a hypothetical network shown in Figure 1. The hypothetical network is composed of two alternative routes: there exists a bottleneck caused by on- and off-ramps on Route 1 while Route 2 is served as a bypass. It is assumed that the physical lengths of the two routes are same. There is a VMS implemented on the upstream to provide information about route choice for drivers. In such a hypothetical network as Figure 1, drivers generally prefer Route 2 to Route 1, which may cause the overloading of Route 2. In case of the hypothetical network that drivers dominantly choose one route over the other, this drivers' preference on route choice should also be taken into consideration for effective VMS control. It is a common practice that VMS is implemented on the network with alternative routes to achieve optimal traffic allocation among the alternative routes. Unlike other personalized dynamic route guidance system, the VMS pursues the system optimal by equalizing traffic flow among alternative routes. However, the optimal traffic allocation cannot be automatically achieved through VMS information provision itself. Rather the traffic would be concentrated on the physically preferable route when there is no information provided on the VMS and/or the traffic would be concentrated on the routed informed as preferable through VMS. This is so-called overreaction and concentration problem of VMS information provision. The author (2002, 2003, 2004) proposed feedback control scheme to cost-effectively deal with the overreaction and concentration problem of VMS information provision as well as to cope with the unpredictable disturbances. And a further research for predictive control scheme was also proposed to more effectively deal with the overreaction and concentration problem.



$q(t)$, $q_1(t)$, $q_2(t)$: Flow Rates
$\Gamma_{in}(t)$, $\Gamma_{out}(t)$: Flow Rates for On- and Off-ramps on Route 1
$TH_1(t)$, $TH_2(t)$: Dynamic Capacities

Figure 1. Hypothetical Network

There are some previous researches dealing with VMS control problems. Valdes-Diaz and *et. al*.(2000) presented the optimal traffic allocation of the network under incident scenarios but failed to address how to achieve the optimal traffic allocation by VMS control. Oh and Jayakrishnan (2001) argued that temporally changing VMS messages can achieve certain desirable flow split over time and proposed a dynamic system optimum traffic assignment for temporal VMS route guidance. Wang and *et. al*. (2003) developed a predictive feedback routing control strategy by incorporating a feature of traditional iterative simulation approach, that is, estimation of disturbances such as O-D. And then a comprehensive performance evaluation of the predictive feedback model is conducted, compared with the iterative simulation model. However, although the iterative simulation model guaranteed the exact optimal equilibrium while the feedback approach seeks for the approximate dynamic user equilibrium, the exact optimal equilibrium would be less meaningful if the estimated disturbances such as O-D do not coincide with what really happens in real network. In this sense, the performance evaluation based on the coincidence with the simulation model has many things to be desired. Also, it is considered that employing disturbance prediction model to the feedback control scheme is somewhat contradictory in that the beauty of feedback control approach is not to predict the unpredictable disturbances.

In this paper, the concentration problem is illustrated with a concrete example of network. And to cope with the concentration problem, a strategic VMS control approach is proposed based on the example. This paper is composed of the following sections: In section 2, overreaction and concentration problem should be illustrated based on a hypothetical network. And both the system optimal traffic allocation and the traffic allocation achieved by VMS information are estimated. Then a strategic approach for VMS control is proposed to compensate for the discrepancy between the system optimal and the estimated traffic split. In section 3, overall predictive VMS control scheme is proposed and briefly explained. To estimate the system optimal traffic allocation with reasonable accuracy, especially for real-time control, it is desired to adopt a dynamic capacity concept instead of the traditional deterministic capacity concept. The dynamic capacity should reflect on the throughput fluctuation caused by temporal-spatial congestion evolution. The problem of dynamic capacity estimation should be addressed separately in section 4. Finally some concluding remarks are made in section 5.

2. CONCENTRATION PROBLEM AND NEED FOR STRATEGIC VMS CONTROL

As mentioned in the previous section, the optimal traffic allocation among alternative routes cannot automatically achieved by VMS information itself. There exists some discrepancy between the desired traffic split and what really happens because of the existence of physically preferable route and/or because of the overreaction to the VMS message and the concentration on the route informed preferable. To compensate for this discrepancy, predictive and strategic VMS control scheme is required. In this section, the desired optimal traffic split and the expected traffic split are estimated based on the hypothetical network shown in Figure 1. And the discrepancy between these two splits is illustrated by some graphical representation.

Consider the hypothetical network in Figure 1 and assume the probability of choosing Route 2 is ε. Then, the traffic split rates for Route 1 and Route 2, $q_1(t)$ and $q_2(t)$, respectively, are as follows:

$$q_1(t) = \Gamma_{out}(t) + (q(t) - \Gamma_{out}(t)) \cdot (1 - \varepsilon) \quad (1)$$

$$q_2(t) = (q(t) - \Gamma_{out}(t)) \cdot \varepsilon \quad (2)$$

where , ε = Probability of Choosing the Route 2
$\Gamma_{out}(t)$ = Off-ramp Volume on Route 1
$q(t) = q_1(t) + q_2(t)$ (refer to Figure 1)

The author (2002, 2003) proposed a system optimal VMS control scheme achieved by equalizing residual capacity of each route. And the residual capacity for each route, $\delta i(t)$, was defined as the dynamic capacity, $THi(t)$, minus flow rate as shown in Eq. (3) and (4).

$$\delta_1(t) = TH_1(t) - q_1(t) - \Delta\Gamma(t) \quad (3)$$

$$\delta_2(t) = TH_2(t) - q_2(t) \quad (4)$$

where, $\delta_1(t)$, $\delta_2(t)$ = Residual Capacities for Route 1 and 2
$TH_1(t)$, $TH_2(t)$ = Dynamic Capacities for Route 1 and 2
$\Delta\Gamma(t) = \Gamma_{in}(t) - \Gamma_{out}(t)$

To determine residual capacity for each route, as shown in Eq. (3) and (4), dynamic capacity, $TH_i(t)$ should be estimated. In the previous researches performed by the author, estimation of the dynamic capacity, $TH_i(t)$ remained for further research. The concept and the estimation of the dynamic capacity should be explained in Section 4 in detail.

To find system optimal traffic split, make the residual capacities of the two routes equal.

$$\delta_1(t) - \delta_2(t) = 0$$

And insert Eq. (3) and (4) in place of $\delta_1(t)$ and $\delta_1(t)$, respectively, then

$$TH_1(t) - q_1(t) - \Delta\Gamma(t) - TH_2(t) + q_2(t) = 0 \tag{5}$$

Replace the $q_1(t)$ and the $q_2(t)$ in Eq. (5) by Eq. (1) and (2), respectively, and solve the equation for ε. Then the optimal traffic ratio choosing Route 2, ε^0 is obtained as Eq. (6).

$$\varepsilon^0 = \frac{(TH_2(t) - TH_1(t) + q(t) + \Delta\Gamma(t)}{2(q(t) - \Gamma_{out}(t))} = \frac{1}{2} + \frac{1}{2}\cdot(\frac{TH_2(t) - (TH_1(t) - \Gamma_{in}(t))}{(q(t) - \Gamma_{out}(t))}) \tag{6}$$

Eq. (6) represents that the optimal ratio choosing Route 2, ε^o is proportional to the capacity difference between the two routes, $(TH_2(t) - (TH_1(t) - \Gamma_{in}(t))$ and inversely proportional to the divertable traffic portion, $(q(t) - \Gamma_{out}(t))$. According to the Eq. (6), ε^o ranges as follows:

$$\varepsilon^0 = 0.5 \quad when \quad TH_2(t) = TH_1(t) - \Gamma_{in}(t)$$
$$\varepsilon^0 = 1.0 \quad when \quad TH_2(t) - (TH_1(t) - \Gamma_{in}(t)) = q(t) - \Gamma_{out}(t)$$
$$\varepsilon^0 = 0.0 \quad when \quad TH_2(t) - (TH_1(t) - \Gamma_{in}(t)) = -(q(t) - \Gamma_{out}(t))$$

As mentioned above, the optimal ε^o cannot be automatically achieved by VMS information itself. Rather the VMS information may cause overreaction and concentration problem because of drivers' preferences and the limitation of VMS information system itself, which is summarized as follows:

1. There are divertable traffic and non-divertable traffic in the hypothetical network in Figure 1, which are $q(t)$-$\Gamma_{out}(t)$ and $\Gamma_{out}(t)$, respectively.

2. All divertable traffic should be concentrated on the physically preferable route, i.e. Route 2 under the following conditions:
   - No information is provided
   - The information that the two routes are in the same condition is provided.

3. If the information that one route is preferable to the other is provided, then all the divertable traffic should be concentrated on the route informed as preferable.

In the above, extreme case of overreaction and concentration is assumed, that is, the flow ratio choosing the Route 2, ε should be 0 or 1. However, if it is feasible to estimate the real value for ε with reasonable accuracy, the estimated ε between 0 and 1 can be used. This extreme assumption is considered reasonable for such a hypothetical network that drivers' preference for the alternative routes is apparent as shown in Figure 1.

Based on the overreaction and concentration defined above, the ε actually achieved by VMS information should be the following value:

1. The ε should be 1, that is, all divertable traffic should be concentrated on Route 2, in case of the following VMS message types:

   - *Type 1*. No information is provided.
   - *Type 2*. The traffic condition of Route 2 is good but that of Route 1 is congested.
   - *Type 3*. The traffic conditions of both routes are good

When $\varepsilon = 1$, that is, for the above message types, the traffic split between the Route 1 and 2 is achieved by VMS information as Eq. (7) and (8):

$$q_1(t) = \Gamma_{out}(t) \tag{7}$$

$$q_2(t) = q(t) - \Gamma_{out}(t) \tag{8}$$

2. The ε should be 0, that is, all divertable traffic should be concentrated on Route 1, in case of the following VMS message type:

   - *Type 4*. The traffic condition of Route 1 is good but that of Route 2 is congested.

When $\varepsilon = 0$, that is, for the above message *Type 4*, the traffic split between the Route 1 and the Route 2 is achieved as Eq. (9) and (10):

$$q_1(t) = q(t) \tag{9}$$

$$q_2(t) = 0 \tag{10}$$

Figure 2 is to illustrate the discrepancy between the system optimal traffic split, ε^o in Eq. (6) and the achieved split, ε by VMS information. According to Eq. (6), the system optimal ε^o is a linear function of traffic condition and ranges from 0 to 1. On the other hand, the ε, assuming the overreaction and concentration as mentioned before, is a step function and has a value of 0 or 1.

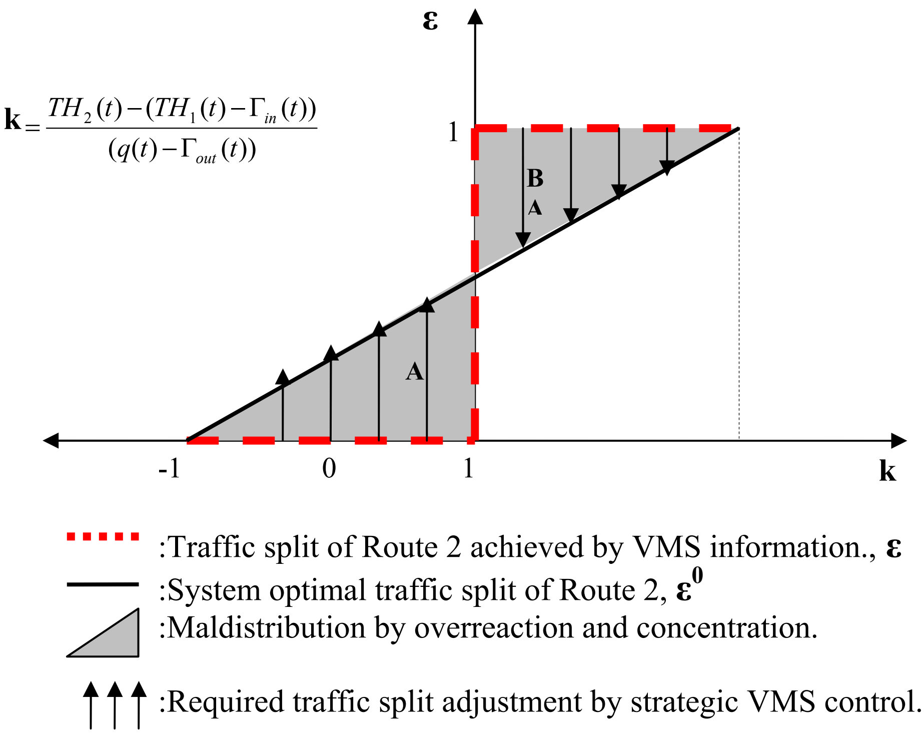


Figure 2. System Optimal vs. the Traffic Split Achieved by VMS Information

The shaded area in Figure 2 represents the inefficiency resulted from the overreaction and concentration problem. The shaded area implies that strategic message display by feedback regulation should be required to make up for the discrepancy between ε and ε^{o}. If ε is greater than the ε^{o} (i.e., A in Figure 2), the message to alleviate the concentration problem on the Route 2 is desired. If ε is less than the ε^{o} (i.e. B in Figure 2), the message to attract more traffic to the Route 2 is desired. Table 1 shows a strategic VMS message regulation example to compensate for the discrepancy between ε and ε^{o} in Figure 2. Detailed design for those kinds of message modification remains for further study.

Table 1. Control Strategies for VMS Message Modification in the Hypothetical Network

Cases	Expected Results from VMS Information	Strategic Modification of VMS Message
$\varepsilon = \varepsilon^0$	System Optimal should be achieved by the current VMS Message.	No modification is necessary.
$\varepsilon > \varepsilon^0$	The current message is causing over-Concentration problem on Route 2	It is desired to make the current message display interval shorter.
$\varepsilon < \varepsilon^0$	The current message is not strong enough to attract the desired traffic on Route 2.	It is desired that the current message be modified to attract more traffic on Route 2.
ε : Expected Traffic Split of Route 2 by VMS Information Provision ε^{o} : System Optimal Traffic Split of Route 2		

3. PREDICTIVE FEEDBACK CONTROL OF VMS

In the previous section, it is addressed that there always exists discrepancy between the optimal traffic split and the traffic split achieved by VMS information among alternative routes (refer to Figure 2). It is also indicated that the discrepancy results from the physical disparity of alternative routes and/or overreaction/concentration problem. This discrepancy implies that the strategic approach should be necessary for VMS control to be effective. In this context, VMS control objective should be to minimize the discrepancy and compensate for this discrepancy as soon as possible to keep the system in nearly optimal state.

To achieve this control objective, before implementing the desired control strategy, i.e., providing the desired VMS message, it is necessary to estimate the expected traffic split by the control strategy and to evaluate the discrepancy between the optimal and the expected traffic splits. And finally, before implementation, it is necessary to modify the control strategy to compensate for the discrepancy after the above-mentioned evaluation. These whole control procedures keep continued by a feedback loop. And VMS is controlled in a predictive way. This predictive feedback control scheme is shown as a schematic diagram in Figure 3. The functional requirements for the VMS control with overreaction and concentration problem are summarized as follows:

1. There should be a real-time traffic monitoring system implemented.

2. In the short-term prediction module, mainline volume, average speeds for each route, on- and off- ramp volume, etc. for the next time slice should be estimated.
3. In dynamic capacity estimation module, real-time capacity should be estimated as a function of temporal and spatial pattern of congestion evolution by kinematic wave theory.
4. System optimal traffic split among alternative routes should be estimated by equalizing residual capacities of the alternative routes.
5. Traffic allocation among alternative routes as a result of VMS message display should be predicted in advance
6. VMS message strategy is updated dependent upon the discrepancy between the system optimal and the predicted traffic splits among alternative routes.

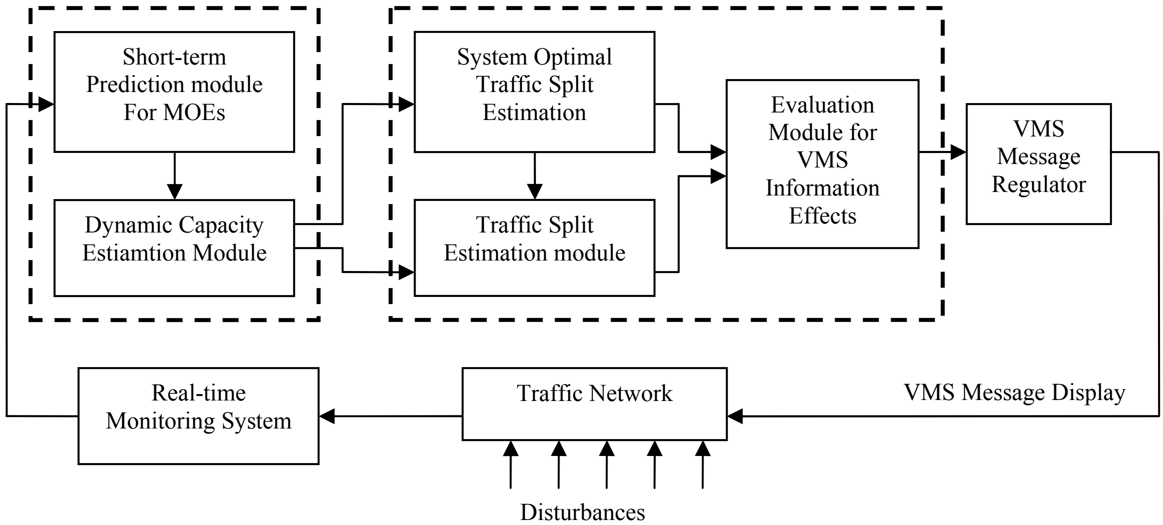


Figure 3. Predictive Feedback Control Concept for VMS

4. ESTIMATING DYNAMIC CAPACITY

In Section 2, dynamic capacity, $TH_i(t)$ was employed to find system optimal traffic allocation between alternative routes. The dynamic capacity cannot be replaced by the traditional static capacity provided in Highway Capacity Manual. The dynamic capacity should be estimated reflecting on the temporal and spatial evolution of queue from the downstream, which should be explained in detail in this section. To make the predictive VMS feedback control system work (refer to Figure 3), estimation of the dynamic capacity is crucial. The concept of the dynamic capacity is addressed and a procedure for real-time estimation of dynamic capacity fluctuation is proposed in this section.

The highway capacity provided in the Highway Capacity Manual (2000) is a typical concept of capacity, which is defined for the steady-state traffic flow assuming that traffic flow is in equilibrium condition. When capacity is obtained by field observation, a queue discharge rate is usually considered as the capacity. The queue discharge rate is the maximum observable flow rate when queue is dissipated at the downstream of the queue. Cassidy and Bertini (1999) showed in their empirical study that the queue discharge rate is 10% lower than the flow rate in normal traffic condition. They also indicated that this implies the ramp metering to prevent congestion should be justified for operational efficiency.

Conventionally, both capacity and breakdown are considered as deterministic phenomena: The maximum observable flow rate is the capacity and flow should be broken down when the flow is over the capacity. Lorenz and Elefteriadou (2000) insisted that the breakdown has a probabilistic nature, that is, all level of flow has its own probability of breakdown, let alone the maximum flow rate. In this context, it was proposed that definition of the capacity should be modified to the capacity with probability of breakdown (Lorenz and Elefteriadou, 2000, Persaud and *et. al*., 2001). Jia and *et. al*.(2000) indicated that the current capacity estimation by the HCM method is not appropriate enough in that the estimation is solely based on the physical characteristics of the corresponding section. And it is suggested that the capacity should be empirically determined reflecting on the traffic conditions of the connecting links.

In these previous researches, capacity was considered as a threshold value, which is closely related to transition from normal to congested flow. So, those researches focused on the interpretation of the transition phenomenon. If the control objective is to prevent from the congestion start, this kind of capacity as a threshold is reasonable enough to apply for real-time traffic management. But in case the congestion has started for various probabilistic reasons, the control objective should be to prevent from the congestion growing. And if the control objective is to prevent from the congestion growing, the traditional capacity as a threshold should not be applied for the real-time congestion management. When congestion grows with time and space, capacity is diminishing with the temporal and spatial evolution pattern of congestion. This implies that for congestion management, the traditional capacity is not good enough and the capacity diminution should be reasonably estimated with the temporal and spatial evolution of congestion.

Newell (1963) and Zhang (2001) suggested that acceleration and deceleration waves should be separately considered in that the two waves show different characteristics. In the same context but from the macroscopic point of view, this paper proposes that the 'output'- and 'input'- side capacities should be separately considered. The traditional capacities including HCM capacity and the queue discharge rate are 'output'-side capacity. On the other hand, the dynamic capacity proposed in this paper for congested flow management, which is estimated based on the temporal and spatial evolution of congestion, is 'input'-side capacity. These two different capacities are schematically illustrated in Figure 4. In this paper, dynamic capacity as a 'input'-side capacity is defined as a maximum sustainable throughput. Estimation of the maximum sustainable throughput should be explained below.

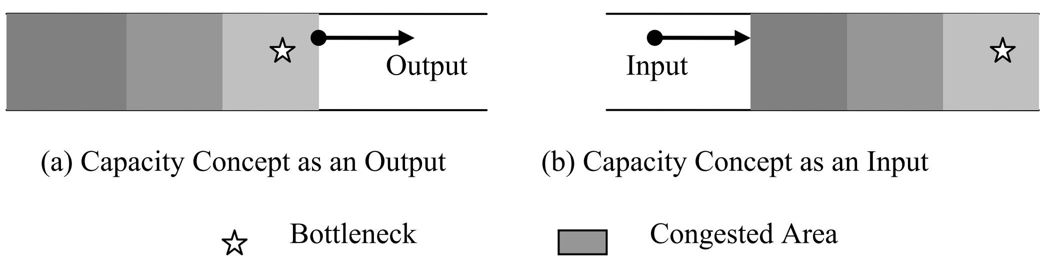
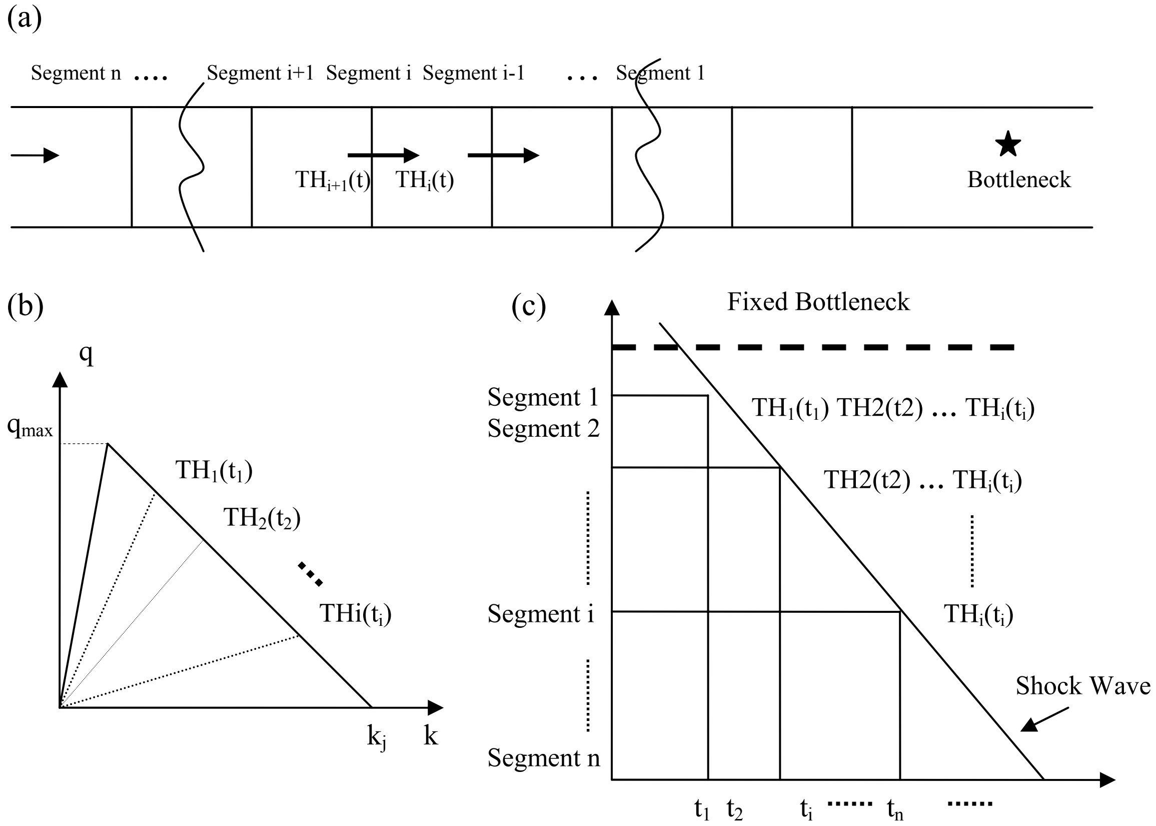


Figure 4. Two Different Capacity Concepts

Precise understanding of the temporal and spatial pattern of congestion evolution is essential in exploring the proposed dynamic capacity. Kerner (2000) noted that the capacity affected by downstream traffic conditions is not predictable because the non-linear process inside the congested region is not predictable. It seems unrealistic to expect any theory to predict the complicated freeway traffic features in precise detail. It might instead be more prudent to use simple theories that describe in reasonable ways the traffic features that are of great importance (Cassidy and Mauch, 2001). The traffic features of importance in this research should be a spatial and temporal pattern of congestion evolution and the capacity fluctuation corresponding to that pattern. Cassidy and Mauch (2001), Castillo (2001), and Lin and Lo (2003) showed that L-W-R model or Newell's simplified linear model could reproduce the temporal-spatial evolution of congested flow reasonably well.



THi(t_i): Maximum Sustainable Throughput at the downstream end of Segment i at time t_i.
t_i: Time that the shock wave reaches at Segment i

Figure 5. Dynamic Changes of Capacity under Congested Traffic Condition

The author (2004) has proposed to estimate the dynamic capacity based on Newell's simplified q-k model. To avoid unnecessary complexity and clearly show the proposed approach, a long and simple freeway section without on- and off- ramps is assumed (Refer to Figure 5(a)). A bottleneck is located at the downstream end of the freeway section. Assumed is the traffic condition that congestion occurred and is propagating upstream.

Figure 5(b) represents the Newell's simplified q-k model. The triangular-shape model is composed of two lines: one for normal flow and the other for congested flow. The gradients of the two lines are the free-flow speed for normal and the shock wave speed for congested flow, respectively. The radial lines from origin in Figure 5(b) represent the various traffic flow states whose speed is the gradient of each line. The intersecting point of the q-k model and a radial line represents the flow level when speed is the gradient of the radial line. The pattern of capacity reduction caused from congestion evolution can be estimated based on this relationship. Figure 5(c) is to show in diagram the temporal-spatial pattern of capacity reduction along the backward propagation of shockwave.

The pattern of the maximum sustainable throughput, $TH_i(t_i)$ reduction is estimated using the relationship shown in Figure 5(b).

$$TH_{i+1}(t_{i+1}) = TH_i(t_i) + \Delta TH \tag{11}$$

$$\Delta TH = \Delta k \cdot w \tag{12}$$

where, w = Shock Wave Speed
t_i = Time that the shock wave reaches at Segment i
Δk = Density Change

The problem is how to estimate the $TH_i(t_i)$ in real-time using the data from real-time traffic monitoring system. Density is not readily observable. In the real-time monitoring system, occupancy is collected instead of density. In short, density is replaced by occupancy in Eq. (12), of which the reason will be explained in the later part of this section even though it is well known that occupancy cannot be a direct substitute for density. So, Eq. (12) is rewritten as Eq. (13) for real-time estimation.

$$\Delta TH_i(t_i) = \Delta occ_i(t_{i-1}) \cdot \hat{w} \tag{13}$$

According to Eq. (13), max. sustainable throughput gradient, $\Delta TH_i(t_i)$ is estimated by downstream occupancy gradient and estimated shock wave speed. The downstream occupancy gradient and the shock wave speed are estimated with downstream flow rates and occupancies by Eq. (14) and (15), respectively.

$$\Delta occ_i(t_{i-1}) = \Delta occ_i(t_{i-1}) - occ_{i-1}(t_{i-2}) \tag{14}$$

$$\hat{w} = \frac{q_{i-1}(t_{i-1}) - q_{i-2}(t_{i-2})}{occ_{i-1}(t_{i-1}) - occ_{i-2}(t_{i-2})} \tag{15}$$

Then, the maximum sustainable throughput is obtained as Eq. (16).

$$TH_i(t_i) = q_{i-1}(t_{i-1}) + \Delta TH_i(t_i) \tag{16}$$

where, $q_{i-1}(t_{i-1})$ = Flow Rate of *Segment i-1* at Time t_{i-1} collected from Traffic Detector

According to Eq. (13), (14), and (15), the occupancy was substituted for density. These substitutions are not for finding an absolute value, but for estimating some trend. In many previous empirical studies, occupancy-spot speed-flow rate plots revealed the same form of the basic density-space speed-flow rate models. This implies that Newell's simplified q-k model may be adapted to the flow-occupancy model for the purpose of the above-mentioned estimation procedure.

Numerical Example

Estimation of the maximum sustainable throughput is illustrated using a 4.6 km freeway section in Seoul (Refer to Figure 6). In this freeway section, the downstream end of Section 1 turned out to be a bottleneck in a previous research (Lim and Park, 2003). Using the freeway data collected on September 1, 2003, the maximum sustainable throughputs were estimated as congestion propagated backward from the downstream bottleneck. By inspecting the data, it is concluded that congestion started from the bottleneck, that is, the downstream end of Segment 1 at 17:05 and the shock wave arrived at Segment 2 at 17:35, Segment 3 at 17:50, and Segment 4 at 18:05, respectively. Also, as congestion grows to upstream, the upstream flow rates are diminishing compared to the downstream flow rates, which provides a good rationale for estimating throughput reduction by Newell's simple hydrodynamic flow theory.

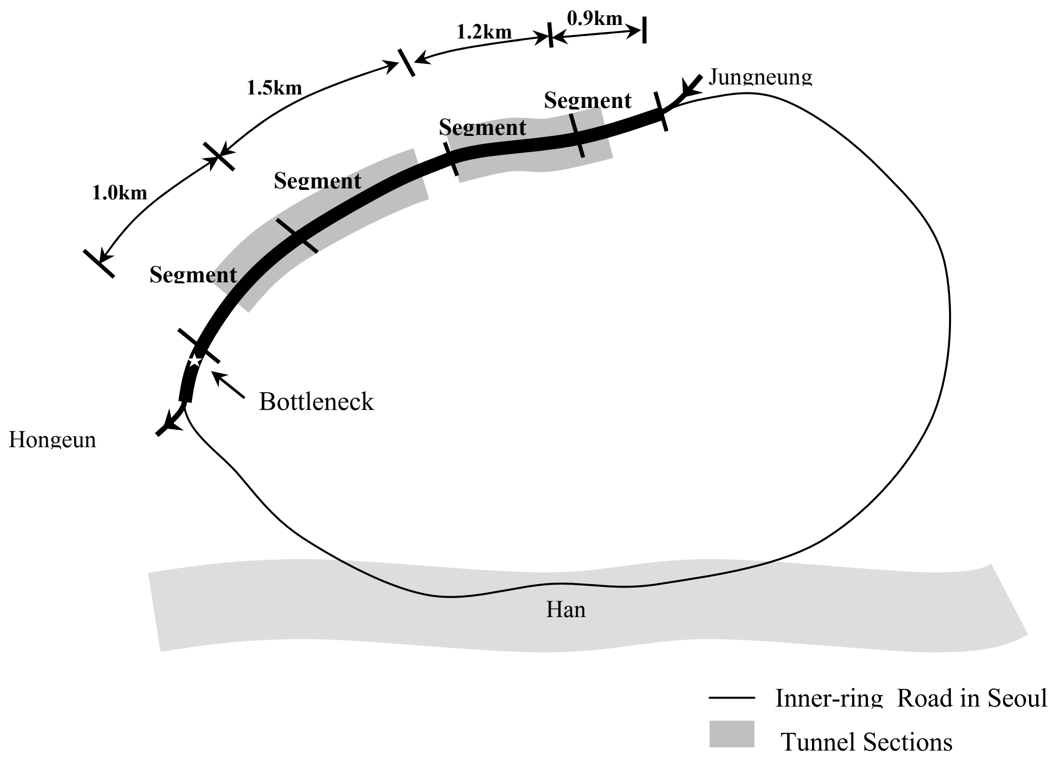


Figure 6. Sample Freeway Section

The Maximum Sustainable Throughputs, $TH_i(t_i)s$, proposed in this research are calculated using Eq. (15) and (16) and are summarized in Table 2. Problem is to estimate $TH_{i+1}(t_{i+1})$ at time t_i and see if this estimated $TH_{i+1}(t_{i+1})$ reasonably well coincide with the observed flow rate at time t_{i+1}. The calculated $TH_i(t_i)s$ are far from the maximum flow rate in Figure 7 as expected. They also showed the expected trend of throughput diminution although there exist some discrepancies between the estimated and the observed. Sophistication of the equations remain for further study by extensive real-time data analyses.

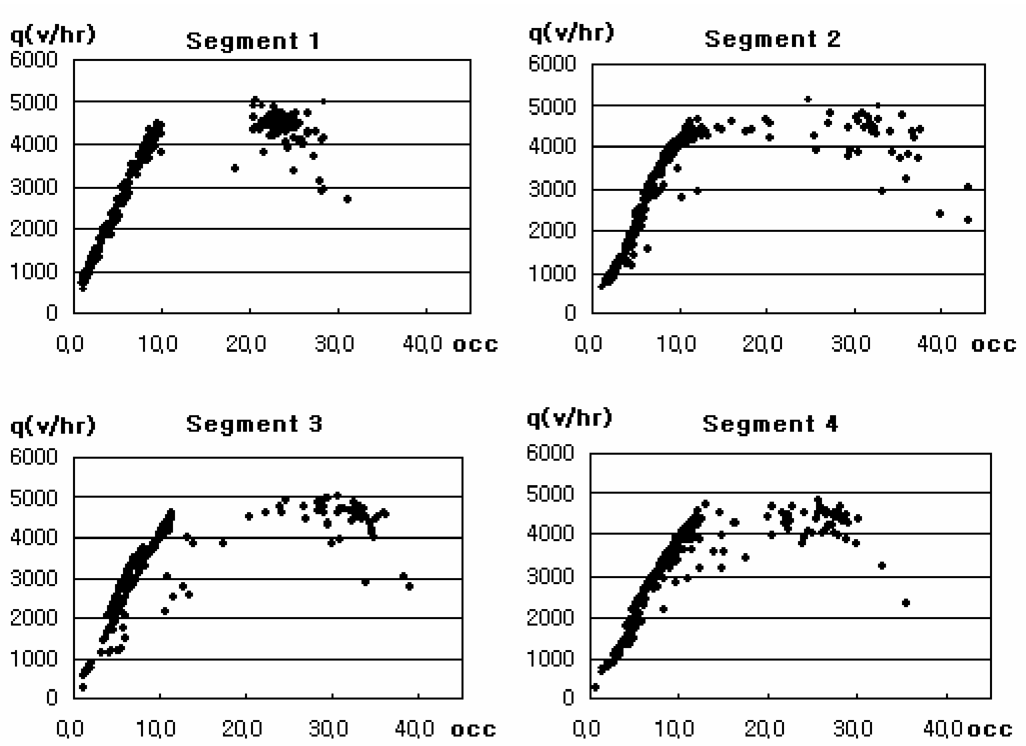


Figure 7. Flow-Occupancy Relationships

Table 2. Calculation of the Max. Sustainable Throughput $TH_i(t_i)$

		Segment 4			Segment 3			Segment 2			Segment 1		
		q_4	u_4	occ_4	q_3	U_3	occ_3	q_2	U_2	occ_2	q_1	u_4	occ_1
t_1	17:05	4212	25.0	25.7	4532	25.1	30.5	4320	58.5	13.0	**4420**	58.5	24.9
t_2	17:35	4084	61.1	11.4	4040	72.5	10.3	**4080**	21.9	29.8	4040	21.9	26.0
t_3	17:50	3676	54.1	13.2	**3884**	30.5	26.3	4072	17.4	31.9	4068	17.4	26.8
t_4	18:05	**3896**	22.5	24.3	4380	19.0	34.4	4300	19.1	32.8	4160	19.1	24.4

$$TH_1(t_1) = q_1(t_1) = 4420$$

$$TH_2(t_2) = q_2(t_2) = 4080$$

$$TH_3(t_3) = q_2(t_2) + (occ_3(t_2) - occ_2(t_1)) \times \frac{(q_2(t_2) - q_1(t_1))}{(occ_2(t_2) - occ_1(t_1))} = 3574$$

$$TH_4(t_4) = q_3(t_3) + (occ_4(t_3) - occ_3(t_2)) \times \frac{(q_3(t_3) - q_2(t_2))}{(occ_3(t_3) - occ_2(t_2))} = 4046$$

5. CONCLUDING REMARKS

VMS information system has its own limitation. That is, desirable traffic allocation among alternative routes cannot be automatically achieved by the VMS information itself. Rather it is generally known that VMS information generally causes overreaction and concentration problem. Considered is a simple hypothetical network with two alternative routes, one bypass and the other with a physical bottleneck. The discrepancy between the optimal and the achieved by VMS information due to the concentration problem is illustrated with this hypothetical network. VMS control objective should be to minimize the discrepancy and compensate for this discrepancy as soon as possible to keep the system in nearly optimal state. In this context a predictive feedback VMS control is proposed to compensate for the discrepancy between the system optimal traffic allocation and the predicted traffic allocation. The functional requirements for the predictive feedback VMS control system are briefly represented. Further development for the whole control scheme is ongoing for a separate research. To make this control concept work, dynamic capacity should be estimated especially for congested flow condition. A new concept and the estimation procedure for the dynamic capacity are provided. Sophistication of the equations should remain for further study by extensive real-time data analyses.

REFERENCES

Cassidy, M.J., Bertini, R.L. (1999), Some Traffic Features at Freeway Bottlenecks, **Transportation Research** 33B, pp 25-42.

Cassidy, M.J. and Mauch, M. (2001), An Observed Traffic Pattern in Long Freeway Queues, **Transportation Research** 35A, pp143-156.

del Castillo, J.M. (2001), Propagation of Perturbations in Dense Traffic Flow: a Model and its Implications, **Transportation Research** 35B, pp367-389.

Jia, Z., Varaiya, P., Chen, C., Petty, K. and Skabardonis, A. (2000), Congestion, excess demand, and effective capacity in California freeways, PeMS Development Group, UC Berkeley (Downloadable from website http://pems.eecs.berkeley.edu/resources /papers)

Kerner, B.S. (2000), Theory of Breakdown Phenomenon at Highway Bottlenecks, **79th TRB Annual Meeting**, Paper No. 00-1573.

Lim, J. H. and Park, E. M. (2003), An Analysis of Uninterrupted Traffic Flow Characteristics Using Detector Data, **Journal of Architectural and Urban Environmental Research**, Vol. 11, Mokwon University

Lin, W. and Lo, H.K. (2003), A theoretical probe of a German experiment on stationary moving traffic jams, **Transportation Research** 37B, pp251-261, Pergamon Press.

Lorenz, M. and Elefteriadou, L. (2000), A probabilistic Approach to Defining Freeway Capacity and Breakdown, TR **Circular 4th International Symposium on Highway Capacity**.

Newell, G.F. (1963), Instability in dense highway traffic, a review, **Proceeding of the 2nd International Symposium on the theory of Road traffic flow**, pp 73-83, London.

Oh, J. S. and Jayakrishnan, R. (2001), Temporal Control of Variable Message Signs towards Achieving Dynamic System Optimum, Paper No. 01-3363, **80th Annual Meeting of the TRB**, Washington D.C..

Park, E. M. (2002), Achieving Better Traffic Allocation in Urban Networks by Strategically Providing VMS Information, **In Proceedings of International Conference for the 20th Anniversary of Korean Society of Transportation**, Seoul, Korea, pp 428-438.

Park, E. M. (2002), Conceptual Design of Automatic Control Algorithm for VMSs, **Journal of Korean Society of Transportation**, Vol. 20, No. 7.

Park, E. M. (2003), Automatic Control Algorithm for VMS and Signal Coordination in Urban Traffic Network, **Journal of EASTS**, Vol 5, EASTS 03 Fukuoka, Japan.

Park, E.M. (2004), Dynamic Capacity Concept and its Determination for Managing Congested Flow, **Journal of Korean Society of Transportation**, Vol. 22, No. 3.

Park, E. M. (2004), Applying a New Capacity Concept for Real-time Traffic Control and Management, **10th World Conference on Transport Research**, Istanbul, Turkey, July, 2004.

Persaud, B., Yagar, S., Tsui, D. and Look, H. (2001), Study of Breakdown-Related Capacity for a Freeway with Ramp Metering, **80th TRB Annual Meeting**, TRB, Washington D.C..

Transportation Research Board, National Research Council, Special Report 209, **Highway Capacity Manual**, 2000 Edition.

Valdes-Diaz, D.M., Chiu, Y., and Mahmassani, H.S., (2000), Optimal Time-Dependent Variable Message Sign Diversion Strategy, **79th Annual Meeting of the TRB**, Washington D.C..

Wang, Y., Papageorgiou, M., and Messmer, A. (2003), A Predictive Feedback Routing Control Strategy for Freeway Network Traffic, **82nd Annual Meeting of the TRB**, Washington D.C..

Zhang, H.M. (2001), A note on Highway Capacity, **Transportation Research** 35B, pp929-937.