突發的 交通混雜 發生時 動的經路案內를 위한 適應型 알고리즘

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돌발적 교통혼잡발생시 동적경로안내를 위한 적응형 알고리즘개발에 관한 연구
An Adaptive Strategy for Providing Dynamic Route Guidance under Non-Recurrent Traffic Congestion

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요 약

첨단교통정보시스템(ATIS)의 핵심 요소라할 수 있는 동적경로안내 시스템(Dynamic Route Guidance System : DRGS)은 운전자가 목적지에 도착하기까지 실시간 교통정보를 토대로 최적경로를 안내해 줌으로써 날로 심화되어 가고 있는 교통혼잡을 최소화할 수 있으리라 기대를 모으고 있다. 특히 교통사고나 긴급도로공사 등으로 인해 발생하는 돌발적 교통혼잡하에서는 DRGS의 역할이 더욱 커질 것으로 예상되고 있다. 본 논문은 돌발적 교통혼잡하에서 보다 효과적인 DRGS의 경로안내 알고리즘을 개발하는 데 그 목적이 있다.

이를 위해 우선 하부구조기반(Infrastructure Based) DRGS와 개인차량기반(In-vehicle Based) DRGS의 장단점을 운전자, 교통행정당국, 그리고 교통체계관점에서 비교하였고, 시스템 아키텍쳐와 경로안내 알고리즘간의 상호관계를 규명하였다. 또한 효율적인 경로안내를 위해 사용자 평형(User Equilibrium) 경로안내전략과 시스템최적화(System Optimal) 경로안내전략을 이상형 교통망(Idealistic Network)을 통해 비교분석하였다.. 여기에는 현재 ITS-America에서 System Architecture 평가를 위해 사용한 INTEGRATION이라는 ITS Simulation Model과 그 통행저항함수를 사용하였다. 이를 토대로 돌발적 교통혼잡상황 아래서 사용자평형 경로안내를 제공할 경우 야기될 수 있는 Braess' Paradox 문제와, 총통행시간을 최소화하기 위한 시스템최적 경로안내를 제공할 경우 일어날 수 있는 사용자 호응도(User Compliance)문제를 동시에 고려한 적응형 동적 경로안내 알고리즘을 개발하였다. 여기에는 돌발적 교통혼잡하에서 통행시간을 동적으로 예측하기 위해 이산형 확정적 대기행렬모형(Discrete Deterministic Queueing Model)이 사용되었다.

한편 알고리즘의 효율성을 평가하기 위해 이상형 교통망과, 실제 미국 Virginia 주의 Fairfax County에 소재한 주간 고속도로 66번(I-66)과 인접 교통망의 교통자료를 사용하여 각종 돌발교통혼잡 상황을 전제로 한 Traffic Simulation과 정보제공시나리오를 INTEGRATION Model을 이용해 실행하였다. 그 결과 적응형 알고리즘이 개개인의 최단시간 경로를 제공하는 사용자 평형 경로안내전략에 비해 교통혼잡도와 정체시간의 체류정도에 따라 3%에서 10%까지 전체 통행시간을 절약할 수 있다는 결론을 얻었다.

I. INTRODUCTION

1.1 Background

Traffic congestion on urban road networks has been recognized as one of the most serious problems with which modern cities are confronted. It is a wide spread belief that the expansion of physical capacities of transportation facilities is not a proper solution considering the cost and environmental issues regarding road construction. Hence, transportation engineers have been searching for enhanced traffic management schemes which utilize existing facilities such as Urban Traffic Control Systems (UTCS) and Freeway Traffic Control Systems (FTMS).

However, as these systems reach maturity, the potential for future improvements in traffic flow through improved traffic control has begun to reach an asymptotic limit. (Van Aerde, 1990) Consequently, new type of traffic management approach must be found to handle the urban traffic congestion.

In this context, Intelligent Transportation Systems (ITS), a technology based on the recent and remarkable development in computer, communications and general information technologies is generally expected to be the most promising solution to traffic congestion problems. The technology has grown rapidly since the passage of the Intermodal Surface Transportation Efficiency Act in 1992. ITS has been divided into five major functional areas. Among them, Advanced Traveler Information System (ATIS) utilizes the above mentioned technologies to collect, analyze, communicate and present information to assist surface transportation travelers in moving from a starting location (origin) to their desired destination. Especially, as a major component of ATIS , Dynamic Route Guidance System (DRGS) is seen as a powerful user service in ITS.

According to recent studies, a certain percentage of urban trips are planned irrationally and result in unnecessary delays. (Jeffery, 1987) DRGS has the potential of resolving these problems by providing driver with optimal routing to reach their destination based upon dynamic real time information. Therefore, it is generally anticipated that DRGS will play an important role in reducing urban traffic congestion and improving traffic flows and safety.

1.2. Problem Statement

Development of new technologies for the solution of any problem requires a detailed examination of all the practical issues. For the successful implementation of a DRGS, three critical issues should be considered. These issues include system architecture, routing strategy and evaluation of the DRGS benefits. Each of these issues has been briefly summarized in the following sections.

1.2.1. System Architecture

First of all, how the functions involved in route planning are distributed between the vehicles and a Traffic Management Center (TMC) is an overriding issue from the system architectural point of view. In the TMC based system, which is infrastructure-based, the route-planning function is performed centrally by a computer system located at a TMC, while the in-vehicle based system uses a digital map stored on a computer system in the vehicle for its own routing. Therefore, the system architecture of dynamic route guidance system is directly connected with its routing strategy. The research will compare these two alternative system architecture.

1.2.2. Routing Strategy

One of the most critical issues in DRGS is to develop optimal routing strategies that maximize the benefits to overall system and users while improving traffic stability in the network. The strategy has two competing perspectives: users perspective vs. operator perspective.

From a system operator's point of view, they are mainly interested in moving as many people as possible in a given time period. Practically, system operators consider what routes drivers should use, to minimize the overall travel time to all drivers, rather than letting the drivers simply select routes which minimize their own individual travel time. Theoretically, these routing strategies can be described as system optimal and user optimal respectively. The system optimal strategy has been considered for transportation of military supplies or for a railroad by central authority for the minimization of the total cost over the whole network. Now with the advent of DRGS, this strategy may also be used for general network to make the most of available capacities in the network.

On the other hand, it is obvious that system users are interested in reaching their destination quickly and safely. Especially, when the congestion occurs in an urban transportation network, the main concern of DRGS is to provide individual driver with fast and safe routing advice toward his or her destination for the user equilibrium status.

However, both objectives often can't be simultaneously satisfied. While the system optimal strategy has the advantage of saving a certain amount of total system travel time, the motorists might not comply. This is because system optimal routing may not recommend the best route for each individual driver.

Furthermore, if user equilibrium strategy provides all the guided drivers with the same minimum travel time path information, it is evident that the guided vehicle will concentrate at a link with a relatively low impedance and create congestion on that link. Theoretically, we can call this as "Braess Paradox".(Braess, 1968) With low market penetrations, the guided vehicles are too few to cause new congestion. However, in case of high market penetration of DRGS, it is envisaged that the phenomenon will spread out to the whole road network. (Kan Chen, 1991)

Consequently, careful consideration should be given to adopting DRGS routing strategies. The research proposes an adaptive strategy for providing dynamic route guidance which compromise both objectives and ultimately pursue system optimal network status.

1.2.3. DRGS Benefits Evaluation

Lastly, the usefulness of dynamic route guidance system can be determined by evaluating its potential benefits. Quantitative estimates of the potential benefits for different network conditions, traffic patterns, and the level of market penetration needs to be performed to select the optimal strategies for DRGS.

In particular, it is generally believed that DRGS will be more beneficial when the non-recurrent congestion caused by accidents or roadwork occurs. It is reasonable to believe that under normal traffic conditions, only a few drivers need to re-route themselves to keep the equilibrium state in the network; but under abnormal traffic conditions like non-recurrent traffic congestion, most of the drivers will need the DRGS re-routing information to settle the disequilibrium status.

This research will present the quantitative evaluation of DRGS benefits with the proposed strategy under non-recurrent congestion using a simulation model. Figure 1.1 illustrates the relationship among the three critical issues and implementation of DRGS.

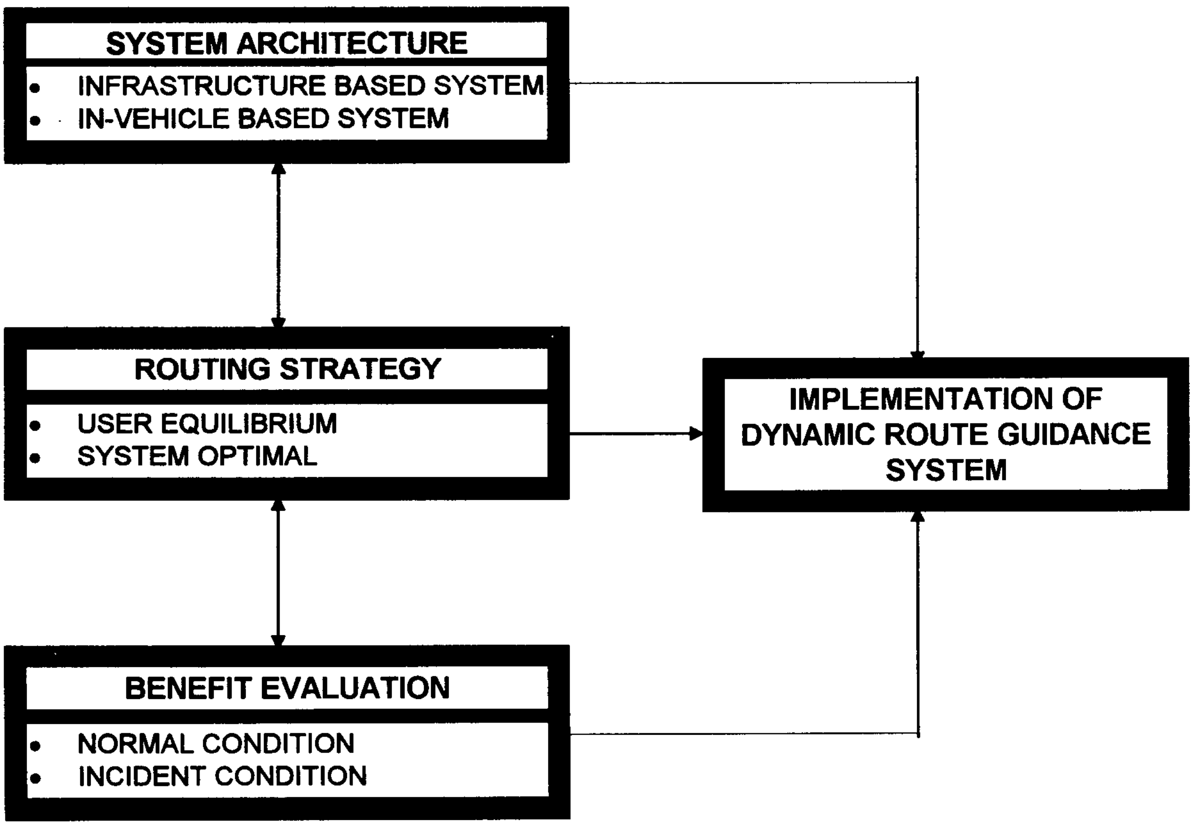


Figure 1.1 Block diagram of the relationship among the three critical issues for DRGS implementation

1.3 Objectives of the Research

The goal of the research is to develop an effective and efficient strategy for providing dynamic route guidance under non-recurrent congestion. The research will provide a systematic evaluation of the DRGS routing strategies in the idealistic and realistic networks using simulation model analysis.

To fulfill the final research goal, the following objectives have been defined

- Study the theoretical viewpoint of the two alternative routing strategies: system optimal vs. user optimal.
- Develop effective and efficient Dynamic Routing Algorithms to pursue system optimal and user optimal with the consideration of the state of the network.
- Evaluate the routing strategies for DRGS by their benefits using integrated traffic simulation model.

II. COMPARISON OF DRGS ROUTING STRATEGIES

2.1 Relationship between System Architecture and Routing Strategy

Table 2.1 is a summary table of the characteristics of the two system architecture. mentioned above. Each system architecture is establishing the strategies in order to complement their disadvantages such as privacy and initial cost.

From the viewpoint of DRGS routing strategy, Infrastructure based system has advantage of pursuing system optimal traffic operation, which is more essential under abnormal traffic conditions such as non-recurrent congestion and natural disaster. But it should concern the problem of user compliance, when some of equipped drivers are urged not to choose minimum travel time path for the whole system optimal.

On the other hand, In-vehicle based system can utilize the user-specified route selection criteria to avoid "Braess Paradox" under normal traffic condition. However, it may be of no use under abnormal traffic conditions and high DRGS market penetration state. Conclusively, it is envisaged that Infrastructure based system is more appropriate system architecture for the DRGS routing strategy under non-recurrent congestion.

2.2 Routing Strategies for DRGS

There are two well-known principles for traffic assignment which were first introduced by Wardrop (1952).

> (i) " The journey time on all routes actually used are equal, and less than those which would be experienced by a single vehicle on any unused route."
> (ii) "The average journey time is a minimum."

The first principle ensures that no traveler can improve his travel time by unilaterally changing routes. In other words, it can be described as a stable condition which is achieved when there is no force to move the flows out of the equilibrium situation. Thus, the flows resulting from the assignment based upon the first principle is called "User Equilibrium".

Table 2-1 Comparison of the alternative DRGS system architecture

		Infrastructure based Architecture	In-vehicle based Architecture
Driver	Initial Cost	low	high
	Market Penetration	high	low
	Equity	poor	good
	Privacy	poor	good
	Compliance	poor	good
Traffic Authority	Initial Cost	high	low
	Control	good	poor
System	Robustness	low	high
	Communication	very high	high
	Braess paradox	poor	poor
Routing Strategy	Normal condition	System,User Optimal	User Optimal
	Abnormal condition	Controllable	Uncontrollable

On the other hand, "System Optimal" is the traffic assignment based upon second criterion to minimize the total travel time spent in the whole network. Generally this flow pattern does not represent an equilibrium condition, since drivers can reduce their travel time by unilaterally changing routes. Hence, this traffic assignment technique has not been adopted practically as a model of actual driver behavior and equilibrium.

With the advent of Dynamic Route Guidance System, Wardrop's assumptions that driver will have perfect knowledge of link travel times when selecting their routes, is likely to become realistic. This makes the Dynamic Route Guidance System feasible to achieve the most efficient routing strategy which minimize the total system travel time especially under recurrent and non-recurrent congestion. Thus, the evaluation of the potential benefits of the alternative strategies under various traffic situations will play an important role in the successful development of effective DRGS.

For the nonlinear optimization programming, a consistent link performance function is adopted from INTEGRATION traffic simulation model. It will be used later as a simulation model for evaluating DRGS routing strategies. The link performance function of INTEGRATION (Van Aerde 1994) is

$$t = t_f \left\{ 1 + (\frac{S_f}{S_c} - 1)(\frac{V}{C})^3 \right\}$$

Where: t = link travel time (seconds)
t_f = travel time when traveling at the free speed (seconds)
S_c = speed at capacity(km/h)
S_f= free speed(km/h)
C = link capacity(vph)
V = link flow(vph)

If we follow the parabolic speed-flow relationship proposed by Greenshields, the speed at capacity S_c is set to half of the free speed S_f. [See Highway Capacity Manual (1985)]. Accordingly, the link performance function is simplified as follows;

$$t = t_f \, (1+\left(\frac{V}{C}\right)^3)$$
$$= t_f + \frac{t_f}{C^3}(V)^3$$

Using this link performance function, the objective function for simple networks using User Equilibrium route guidance strategy is reformulated as follows;

$$\min \quad Z_1(x) = \sum_k \int_o^{x_k} (t_f + (\frac{t_f}{C_k^3})x^3)dx$$

The objective function for simple networks using System Optimal route guidance strategy can also be reformulated as follows;

$$\min \quad Z_2(x) = \sum_k x_k \left\{ t_f + (\frac{t_f}{C_f^3})x_k^3 \right\}$$

As the formulation is a convex nonlinear problem, Sheffi's algorithms can be used to solve it. [See Sheffi(1985)]

2.3 Comparison of User Equilibrium vs. System Optimal

2.3.1. The Differences between UE and SO

It can be seen that UE route guidance strategy considers average travel time when selecting the minimal path, while SO route guidance strategy considers marginal travel time on each link. If the traffic flow over the network is relatively low, the difference between the UE and SO flow is negligible. This is because the marginal travel time on each link at this non-congested range is very small. As the link flow increases, the marginal travel time will also increase proportionally. This will result in a different UE and SO flow pattern.

2.3.2. Example Problem

To illustrate this better, a simple network with two alternative links is used. It is shown in Figure 2.1.

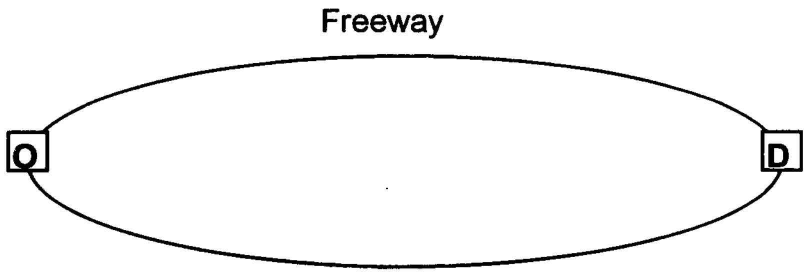


Figure 2.1 A simple network of two alternative links

Consider an idealized simple network as shown Figure 2.1. The freeway and the arterial have two lanes. The network has the following link characteristics,

- freeway capacity C_f=2000 vehicle per hour(vph)/lane
- arterial capacity C_a=1000 vehicle per hour(vph)/lane
- freeway and arterial distance $l_f = l_a$ = 2 mile
- free flow speed on freeway s_f= 65 mile per hour(mph)
- free flow speed on arterial s_a= 45 mile per hour(mph)
- total traffic demand varies 0 vph to 6000 vph (system capacity)

The formulation of mathematical programming for User Equilibrium route guidance strategies is expressed as,

$$\min \quad Z_l(x) = \int_o^{x_f} (\alpha_f + \beta_f x^3)dx + \int_o^{x_a} (\alpha_a + \beta_a x^3)dx$$

subject to

$$x_f + x_a = Q \qquad (2.1)$$

$$x_f, x_a \geq 0$$

Similarly, the formulation of mathematical programming for System Optimal route guidance strategies is expressed as,

$$\min \quad Z_l(x) = x_f(\alpha_f + \beta_f x_f^3) + x_a(\alpha_a + \beta_a x_a^3)$$

subject to

$$x_f + x_a = Q \qquad (2.2)$$

$$x_f, x_a \geq 0$$

A computer program has been developed using MATLAB to obtain the eq(2.1) and eq.(2.2) nonlinear Programming solutions. Figure 2.3 and Figure 2.4 illustrate the distribution of assigned traffic volumes on alternative routes graphically. The graphics imply that SO route guidance strategy utilizes the network fully since it starts to assign the traffic volume to the arterial when the level of traffic demand approaches 30% of the system capacity.

On the other hand, UE route guidance strategy does not use the arterial until the level of traffic demand reaches half of the system capacity. It has also observed that the route traffic volumes of SO route guidance strategy are more evenly distributed than that of UE route guidance strategy. These results are consistent with the fact that the SO route guidance strategy pursues the maximum utilization of the system

The differences in total travel time between the UE and SO strategies are illustrated in Figure 2.2. As we expected, there is no remarkable difference between both low and high traffic demand. This implies that the gap of marginal travel time between the alternatives is negligible in low or high traffic demand range. However, significant differences are found within the mid-range traffic demand. In this case, the maximum total travel time difference occurs when the level of traffic demand is half of the system capacity. At this point, SO route guidance strategy can save more than 11% of the total travel time of UE route guidance strategy. It is also noted that UE traffic assignment shows relatively unbalanced distribution around the mid-range traffic demand especially when the maximum difference in total travel time occurs.

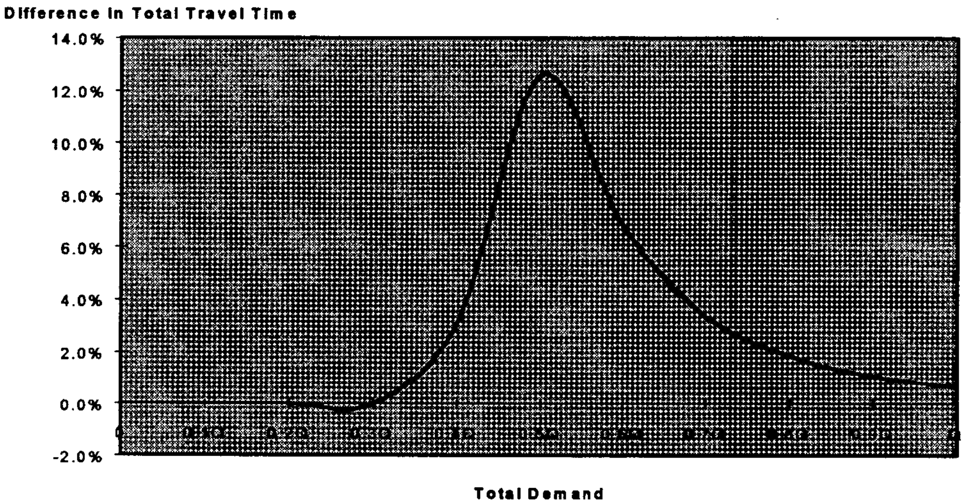


Figure 2.2 Differences between UE and SO routing

2.4 Comparison of UE vs. SO under Incident Condition

It is generally believed that DRGS will be more beneficial when the non-recurrent congestion caused by accidents or roadwork occurs. It is reasonable to believe that under normal traffic conditions, only a few drivers need to re-route themselves to keep the equilibrium state in the network; but under abnormal traffic conditions like non-recurrent traffic congestion, most of the driver will need the DRGS re-routing information to settle the disequilibrium status.

Therefore, it is a critical task to develop a DRGS routing strategy which maximizes the DRGS benefits under non-recurrent congestion. In this context, the research will focus on the quantitative evaluation of DRGS routing strategies under non-recurrent congestion.

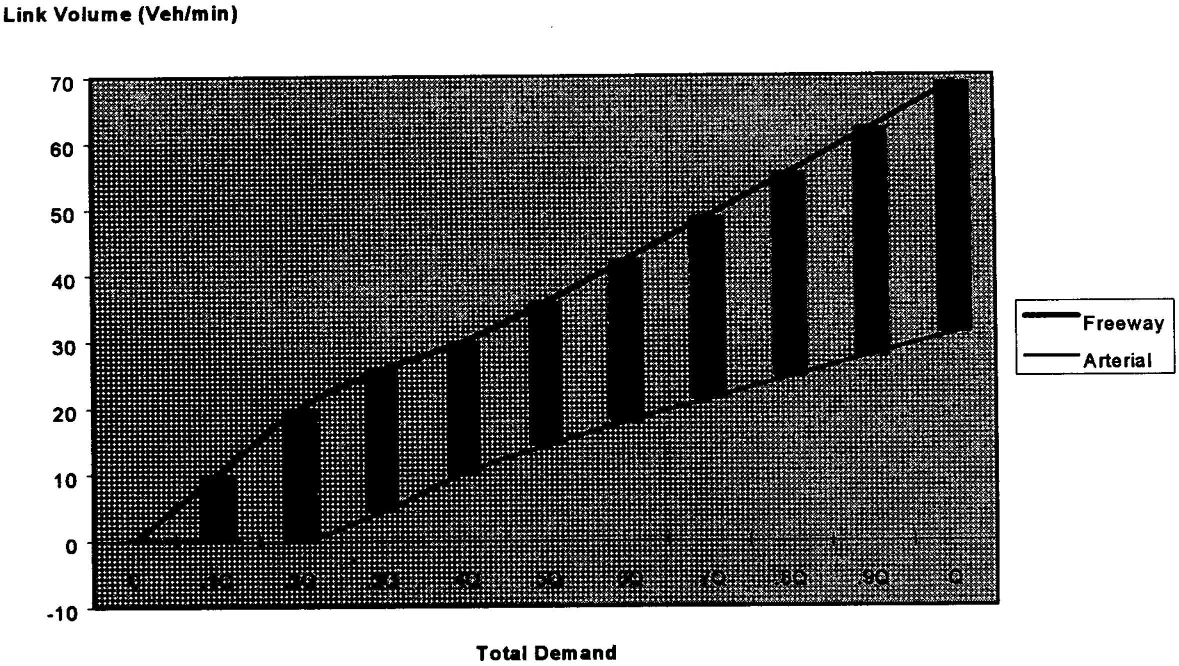


Figure 2.3 Distribution of System optimal routing

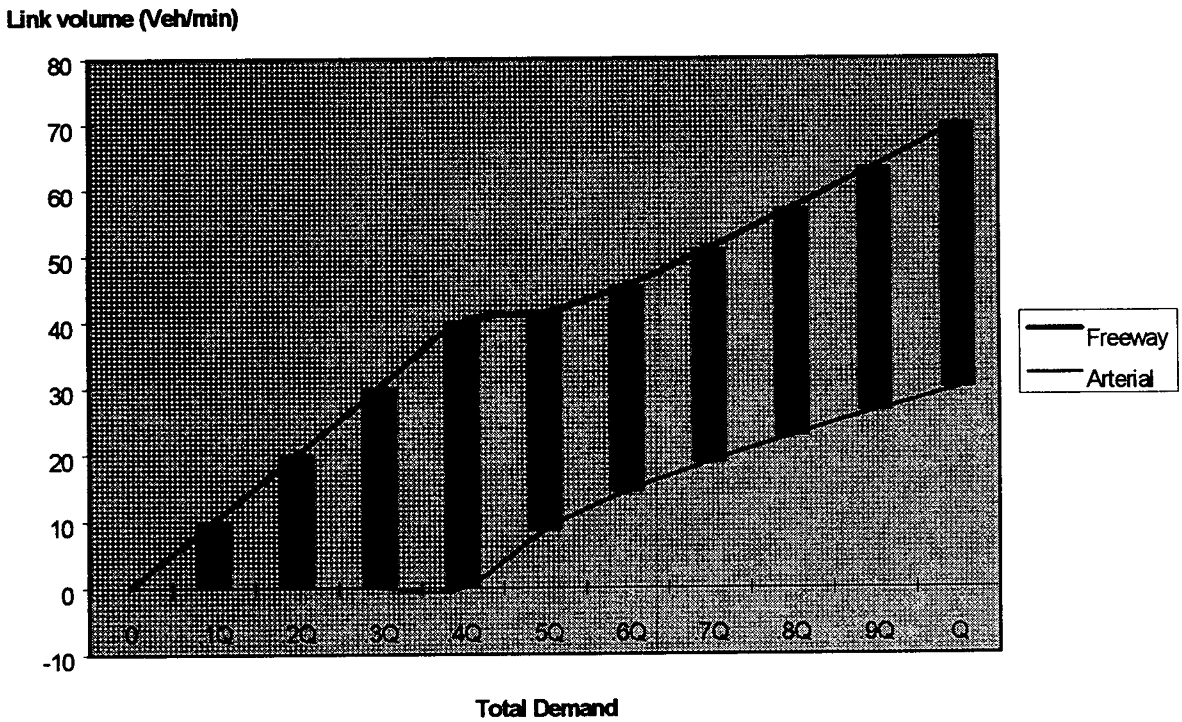


Figure 2.4 Distribution of User equilibrium routing

2.4.1 The Difference Between UE and SO under Incident Condition

Consider the following simple network with a incident on freeway.

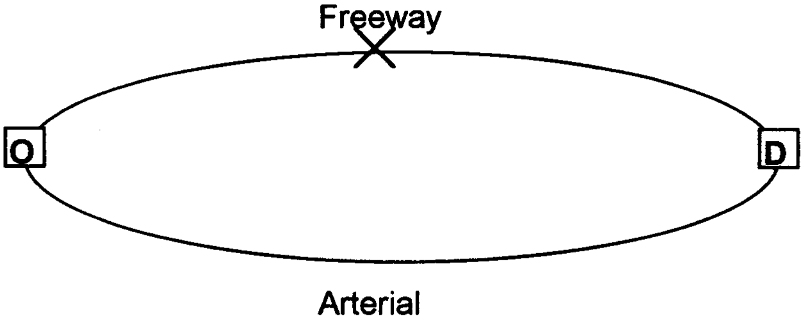


Figure 2.5 A simple network with incident on freeway

Without question, delays on the freeway with incident will increase more rapidly than on the freeway without incident because of the freeway capacity reduction due to the lane or shoulder blockage. The increased delays will result in more steep slopes both on link cost function (FLC') and link marginal cost function (FLMC') as shown in Figure 2.6. This demonstrates the hypothetical cost and marginal curves for the simple network with incident condition. It should be noted that the arterial traffic volumes of the new User Equilibrium (UE') and System Optimal (SO') status are increased by the incident effects, as compared to that of User Equilibrium (UE) and System Optimal (SO) status without incident.

2.4.2 The Sensitivity Analysis by Freeway Capacity Reduction

The sensitivity analysis of the differences between UE and SO route guidance strategies under incident situation are performed by changing the freeway capacity from 0 to 4000 vehicle per hour. Figure 2.7 depicts the 3-dimensional distribution of the differences in total travel time between the two strategies as total traffic demand and freeway capacity vary simultaneously. The graphic shows that there is no big difference between the two strategies if the level of capacity reduction lies between 50% and 100%. This is because there is not enough capacity to be utilized for system optimal route guidance in the system.

However, if the incident severity is low, the difference is relatively high, especially in the traffic demand. However, as the incident severity is alleviated , the differences increase and gradually decrease after it reaches its maximum point, which is in the mid-range of 3000 vph to 4000 vph of traffic demand. It should also be noted that the maximum point shift upward and maximum value increases as the capacity reduction decreases.

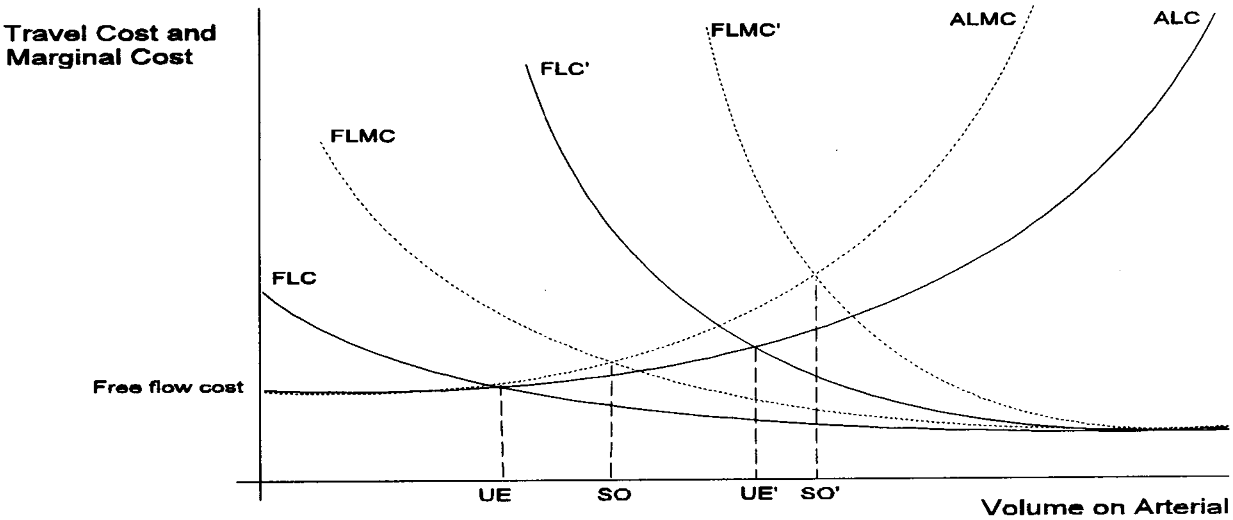
2.4.3 The Existence of "Braess' Paradox" under Incident Condition

It is a well-known fact that a failure to realize the fundamental difference between the SO and UE flow pattern can lead to pseudo paradoxical scenarios. The most famous of these is known as 'Braess Paradox'. The paradox occurs when the individual choice of route is performed without the consideration of the effect of the action on other network. We expect a total travel time reduction which is a system optimal perspectiveby adding a link while the drivers choose their route by UE criteria. Thus the resulting UE flow pattern does not necessarily reduce the total travel time.

It should be noted that the paradox does not always occur only with the addition of new link. It can also happen when the database of available links in the Route Guidance System network is expanded to the local roads. Furthermore, it can happen when we consider diversion routes under incident situation. (Van Aerde 1991)

Figure 2.8 shows the change of the difference between UE and SO strategies with multiple alternate routes by incident, that is capacity reduction in freeway. It is noted that the distributions of the differences of the two traffic conditions don't have the similar shapes. This implies that careful consideration should be given for determining route guidance strategies.

For example, there are no significant differences between the two strategies under normal condition, when the level of traffic demand lies between 60% and 80% of the system capacity. But once an incident occurs, the difference reaches its maximum within the same level of traffic demand. In other words, when the incident occurs with the steady-state traffic demand, we can save considerable total travel time by changing the routing strategies from UE to SO. This will be the basis in the following proposed methodology for determining optimal route guidance strategies under non-recurrent congestion.



FLC : Freeway Link Cost
FLMC : Freeway Link Marginal Cost
ALC : Arterial Link Cost
UE : User Equilibrium Flow Pattern
SO : System Optimal Flow Pattern

FLC' : Freeway Link Cost under Incident Condition
FLMC': Freeway Link Marginal Cost under Incident Condition
ALMC : Arterial Link Marginal Cost
UE' : User Equilibrium Flow Pattern under Incident Condition
SO' : System Optimal Flow Pattern under Incident Condition

Figure 2.6 Difference between UE and SO under incident condition

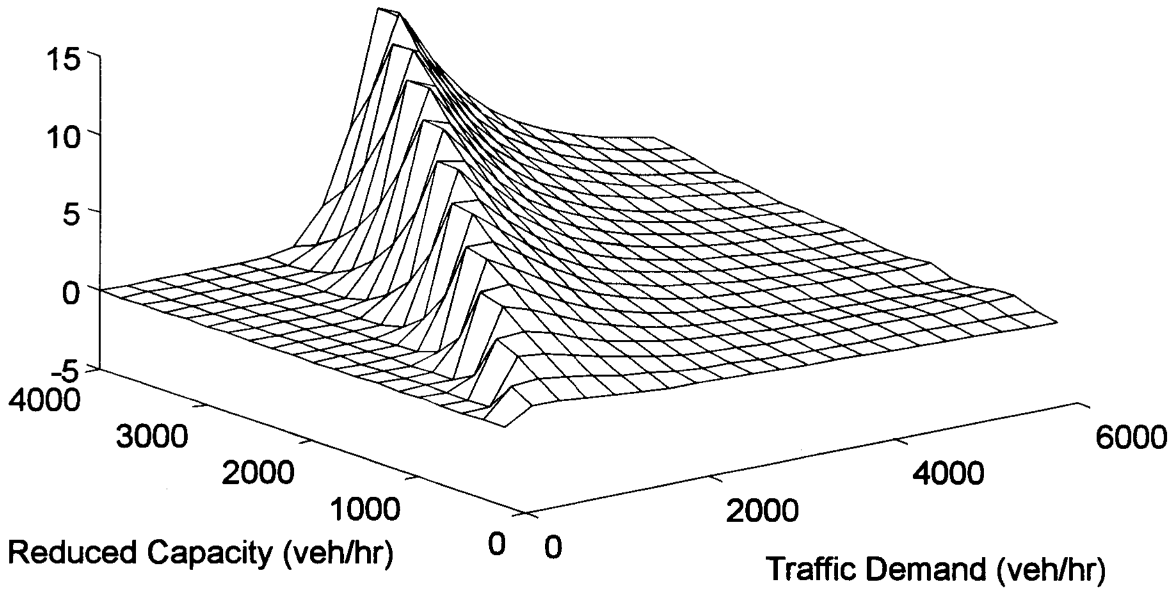


Figure 2.7 Difference Between UE and SO by freeway reduced capacity

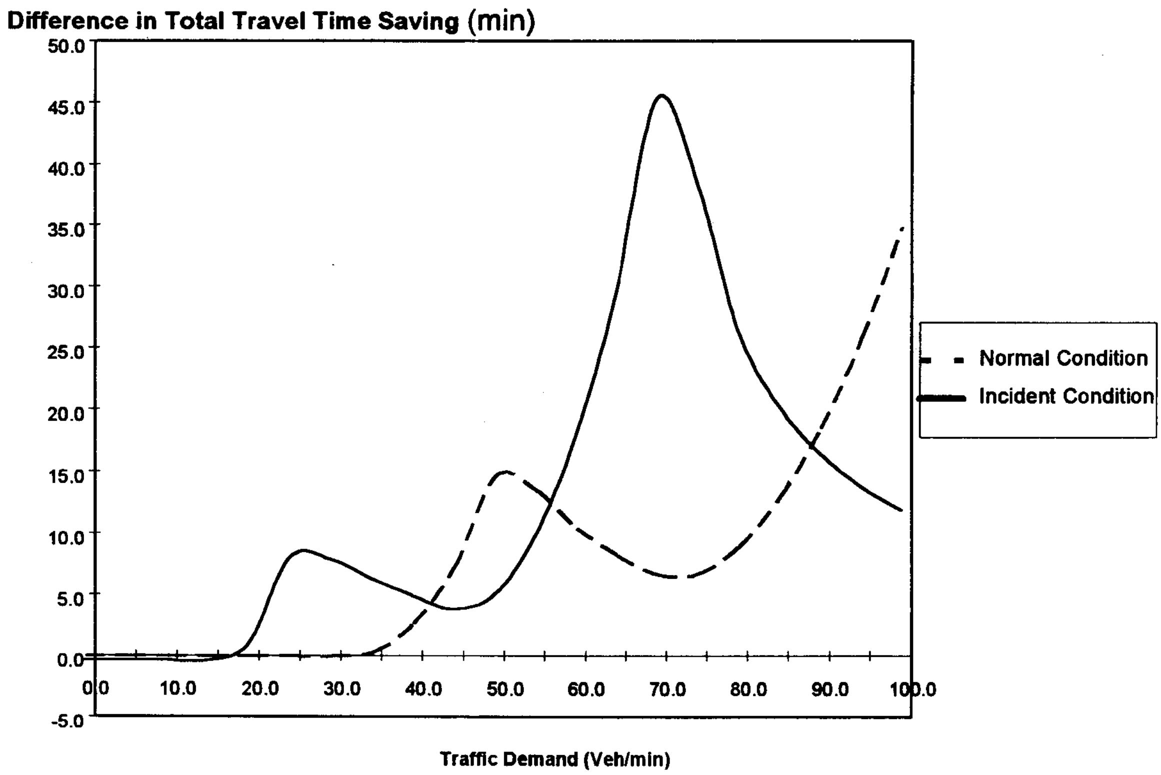


Figure 2.8 Differences between UE and SO with multiple alternate routes

III. ADAPTIVE ROUTING STRATEGY FOR DRGS

There have been numerous efforts during the last decade to evaluate the benefits of DRGS. These results suggest that the benefits of DRGS are marginal under conditions of recurring congestion. Experienced travelers, who make up the major portion of the traffic in congested networks, have sufficient information to choose their route under recurrent congestion.

It is thus expected that DRGS is likely to be more useful under conditions of non-recurrent congestion, as may be caused by incidents. Under these conditions, the lack of information about the severity and duration of an incident and its location would leave the travelers insufficiently informed to make appropriate route choice decision.

Furthermore, by extending DRGS information to potential travelers long before they approach incident locations, it may be possible to further reduce potential congestion by altering trip patterns including departure time in addition to space. Thus, providing reliable information about the incident and optimal route recommendation are essential to DRGS.

The travel time reduction by system optimal strategy over user equilibrium strategy varies with the traffic condition and network configuration. Therefore, an adaptive strategy which considers the variation of travel time saving is needed to provide efficient route guidance especially under non-recurrent congestion. Here, a discrete deterministic queueing model is developed to estimate delay dynamically caused by freeway incidents. Based on this, an adaptive dynamic route guidance methodology for incident management is proposed.

3.1 Dynamic Estimation of Incident Delay

Any freeway incident can cause delay either directly via lane closures or indirectly via "gawker block". The extent of incident impacts depend on the level of traffic demand during the incident, the duration of the incident, and the degree of capacity reduction. Here a discrete dynamic model for estimating incident delay has been suggested using deterministic queueing model.

3.1.1. Deterministic Queueing Model

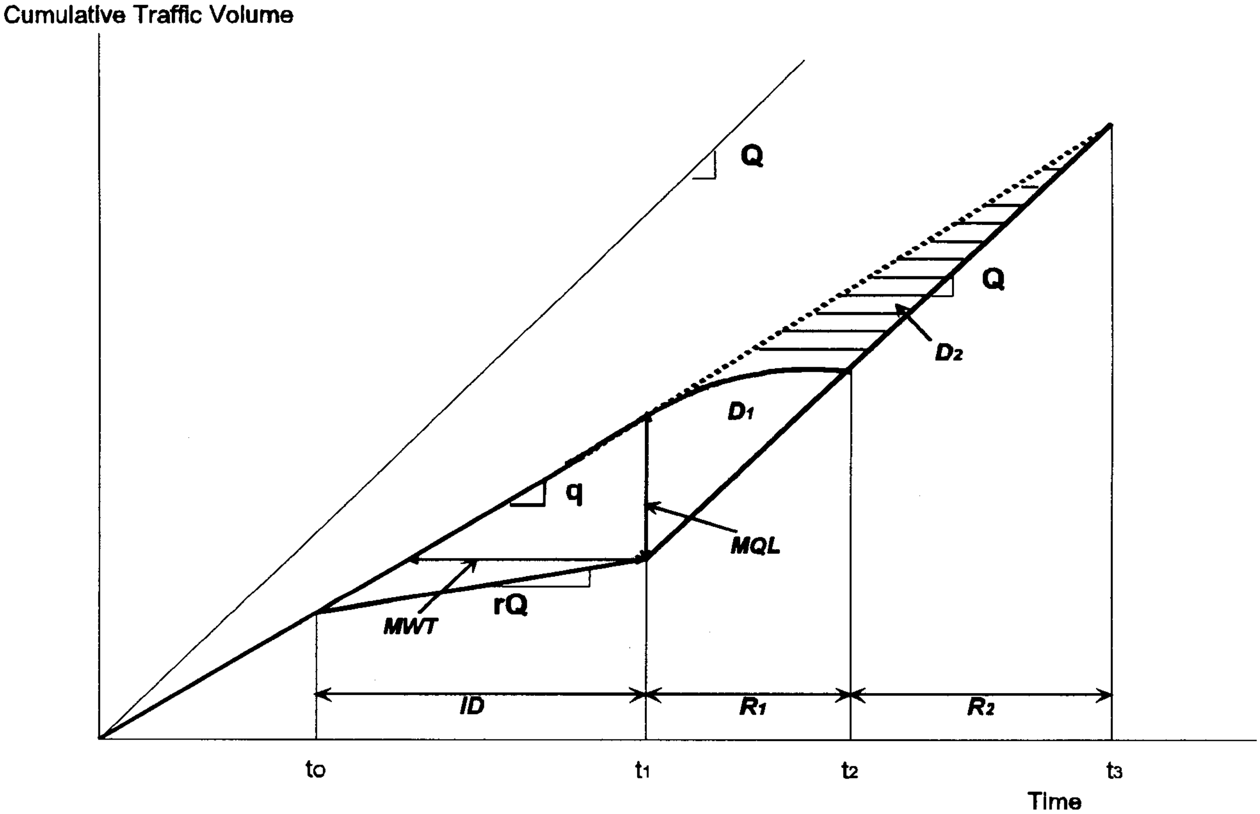
Deterministic queueing model which assumes uniform flow rate can give the information about the exact queue length and delayed time within a given time period. Figure 3.1 shows the process of incident occurrence and response with the time-varying length of the queue and delay due to incident.

The area, D_1, is the total delay with diversion due to the incident which depends on the incident duration (ID) and the reduced capacity (rQ) by the incident type and its severity. It also shows that reduction in incident duration reduces the total delay. Moreover, route guidance information about incident duration can allow individuals to divert to alternate routes before joining the queue. This would reduce the arrival rate and the incident bottleneck, which will save additional total delay caused by no diversion.

With the information about the duration and reduced capacity by the incident, we can get various incident data including the time to normal flow(t_3), maximum queue length (MQL) and maximum waiting time (MWT) and so on. [See May 1990]

3.1.2 Dynamic Delay Estimation

A discrete model for estimating dynamic incident delay is developed based on deterministic queueing model. The model will be a component of link performance function for the optimization problem. Figure 3.2 illustrates the dynamic variation of incident queueing delay with discrete time slice(Δt). Using geometry of the diagram, queueing delay under incident condition in the link performance function as follows;



Q : Capacity Flow rQ : Reduced Capacity Flow by Incident q : Demand Flow
ID : Incident Duration MQL: Maximum Queue Length MWT: Maximum Waiting Time
R_1 : Recovery Time with Diversion R_2 : Additional Recovery Time With No Diversion
D_1 : Total Delay with Diversion D_2 : Additional Total Delay with No Diversion
t_0 : Incident Started Time t_1 : Incident Cleared Time
t_2 : Time to Zero Queue with Diversion t_3 : Time to Normal Flow with No Diversion

Figure.3.1 Deterministic queueing diagram by incident condition
(Source: Cambridge Systematics, Inc. 1990)

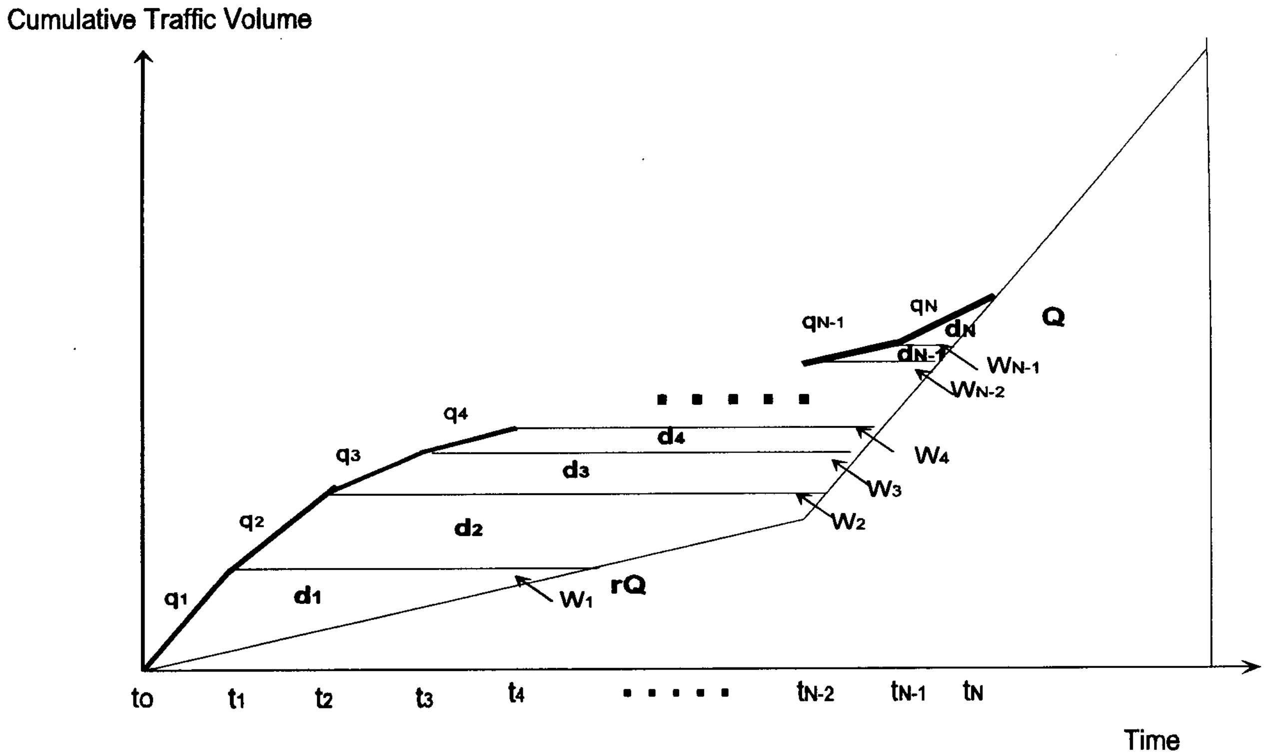


Figure 3.2 Discrete deterministic queueing model for estimating incident delay

$$C(x(t)) = \alpha + \beta x(t)^3 \qquad if\ a(t) = 0$$

$$or \quad C(x(t)) = \alpha + \beta x(t)^3 + a + bx \qquad if\ a(t) > 0$$

where,

$$a = W_{n-1} - \frac{1}{2}\Delta t$$

$$b = \frac{\Delta t}{2rQ}$$

Figure 3.3 illustrate the flow chart for dynamic delay estimation using deterministic queueing model. There are two equations for each incident situation as follows;

$$W_n = W_{n-1} + (\frac{q_n}{rQ} - 1)\Delta t \qquad \text{for } t_n^d < ID \qquad (4.2)$$

$$W_n = W_{n-1} + (\frac{q_n}{Q} - 1)\Delta t \qquad \text{for } t_n^d \geq ID \qquad (4.3)$$

where,

t_n^d *: the departure time for last vehicle arriving at time interval n*

ID : incident duration (minutes)

In the following section, an adaptive strategy for DRGS which has a step-wise feedback control loop is proposed to implement efficient real-time optimal route guidance strategy under non-recurrent congestion. The methodology utilizes the results of comparison of UE and SO strategies and dynamic queueing delay estimation model.

In addition to this, it is suggested that careful consideration should be given by adopting minimum travel time saving ratio, when SO strategy is implemented. The purpose of adopting minimum travel time saving ratio is to prevent improper use of system optimal strategy. It is believed that at least a certain percentage should be saved by implementing SO strategy, since SO strategy might lose its credit gradually by sacrificing the travel time of some of equipped drivers. Here 5% of minimum travel time saving ratio has been assumed.

3.2 An Adaptive Methodology for DRGS under Non-Recurrent Congestion

It is proposed that an adaptive routing strategy is required for efficient control of dynamic route guidance system especially under non-recurrent congestion. Figure 3.4 demonstrates the step-wise feedback methodology of adaptive routing strategy for DRGS. The detailed procedure is as follows;

1) Determine the exogenous variable
It is important to set up exogenous variables such as the user compliance ratio, minimum travel time saving ratio and the market penetration ratio. These values can be obtained by field surveys and interviews or lab experiments, which are out of scope in this research. Instead, sensitivity analysis will be performed for these variables in the next chapter using a simulation model.

2) Monitor real-time traffic situation
Using advanced traffic technology, a series of real-time traffic data which describe the current traffic situation are available for the traffic networks. Especially, real-time information about current traffic flow pattern and queue length during the incident process will play key roles in the proposed methodology.

3) Starting incident situation
Once an incident is detected, it will automatically trigger the dynamic incident delay estimation module using current traffic flow and basic incident information including the location of the incident, the number of blocked lanes, and incident type (e.g., accident or disablement). The information will be used for defining the incident duration and reduced capacity. Lindley suggested a table of average incident duration for freeway section based upon previous work done by Owen and Urbanek,1978.[see Table 4.1] He also provided the information about the fraction of freeway section capacity available under incident conditions. [see Table 4.2]. Using this table, the reduced capacity due to the incident can be computed.

4) Solve UE and SO route guidance strategies
As discussed in previous chapter, the UE and SO route guidance strategies will be obtained by using nonlinear programming method with the revised link performance function. User compliance ratio for system optimal strategy is applied before the two strategies are compared.

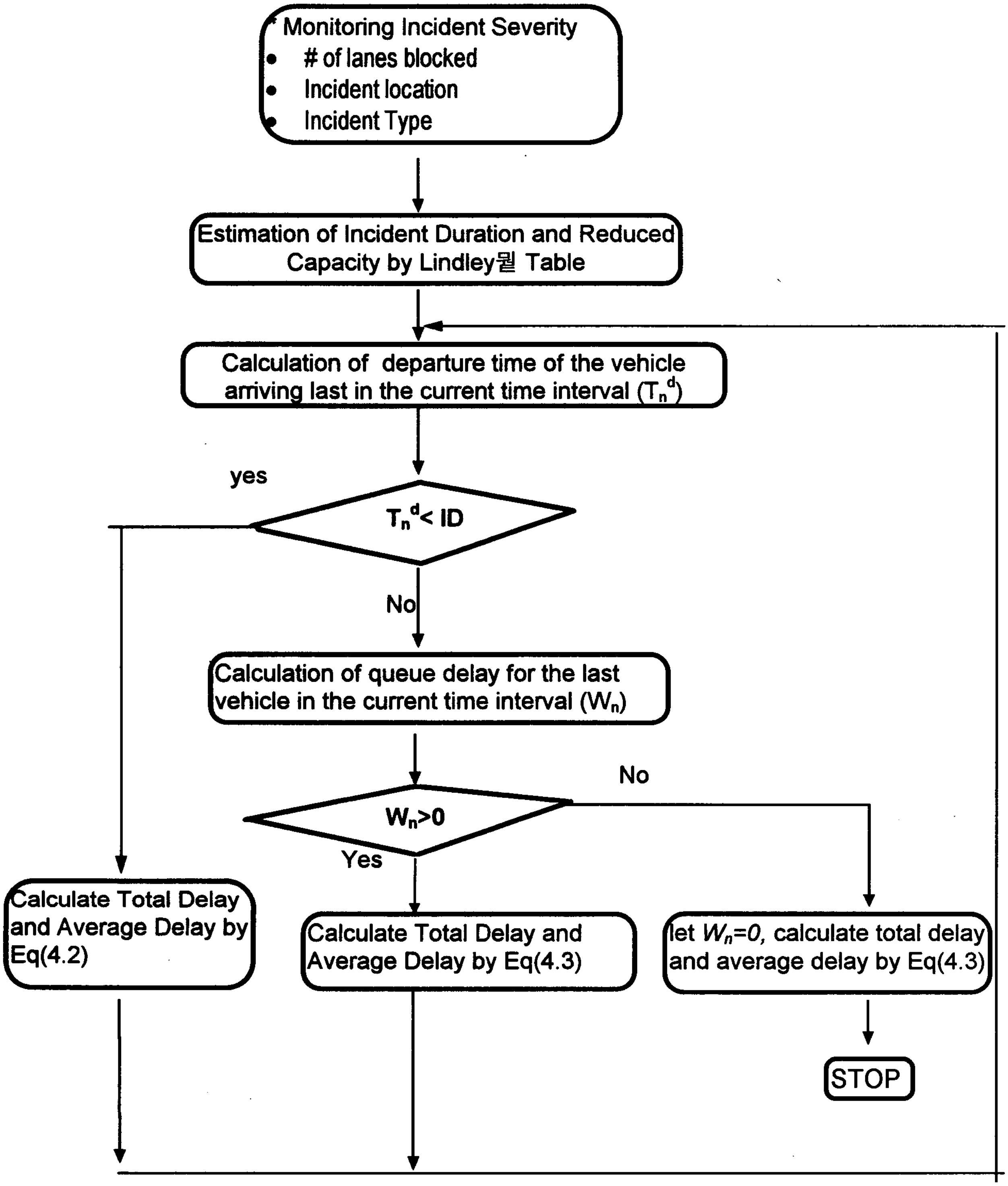


Figure 3.3 Algorithm for estimating incident delay

5) Comparison & selection
The difference in total travel time between UE and SO strategies will be the criteria for determining optimal strategy for current traffic situation. Minimum travel time saving ratio should be applied to system optimal strategy for the comparison. As noted in previous chapter, the difference varies due to the current traffic flow pattern, the severity of incident , the number of available alternate routes and its link characteristics.

6) Implementation
The selected route guidance strategy will be implemented promptly to the networks. The results of the implementation will be captured by the traffic monitoring system after one time slice passed. This adaptive routing strategy for DRGS will continue until the time to normal flow.

Table 3.1 Average incident duration times for freeways (Lindley 1987)
(min)

Existence of shoulder	Accident type	Location of the incident			
		Shoulder	Lane blocked		
			one	two	three
Shoulder	Disablement	30	40	45	NA
	Accident	40	50	60	70
No shoulder	Disablement	NA	30	45	NA
	Accident	NA	50	60	70

Table 3.2 Fraction of freeway section capacity available under incident condition
(Lindley 1987)

No. of freeway lanes in each direction	Shoulder		Lane blocked		
	Disablement	Accident	one	two	three
2	0.95	0.81	0.35	0	
3	0.99	0.83	0.49	0.17	0
4	0.99	0.85	0.58	0.25	0.13
5	0.99	0.87	0.65	0.40	0.20
6	0.99	0.89	0.71	0.50	0.25
7	0.99	0.91	0.75	0.57	0.36
8	0.99	0.93	0.78	0.63	0.41

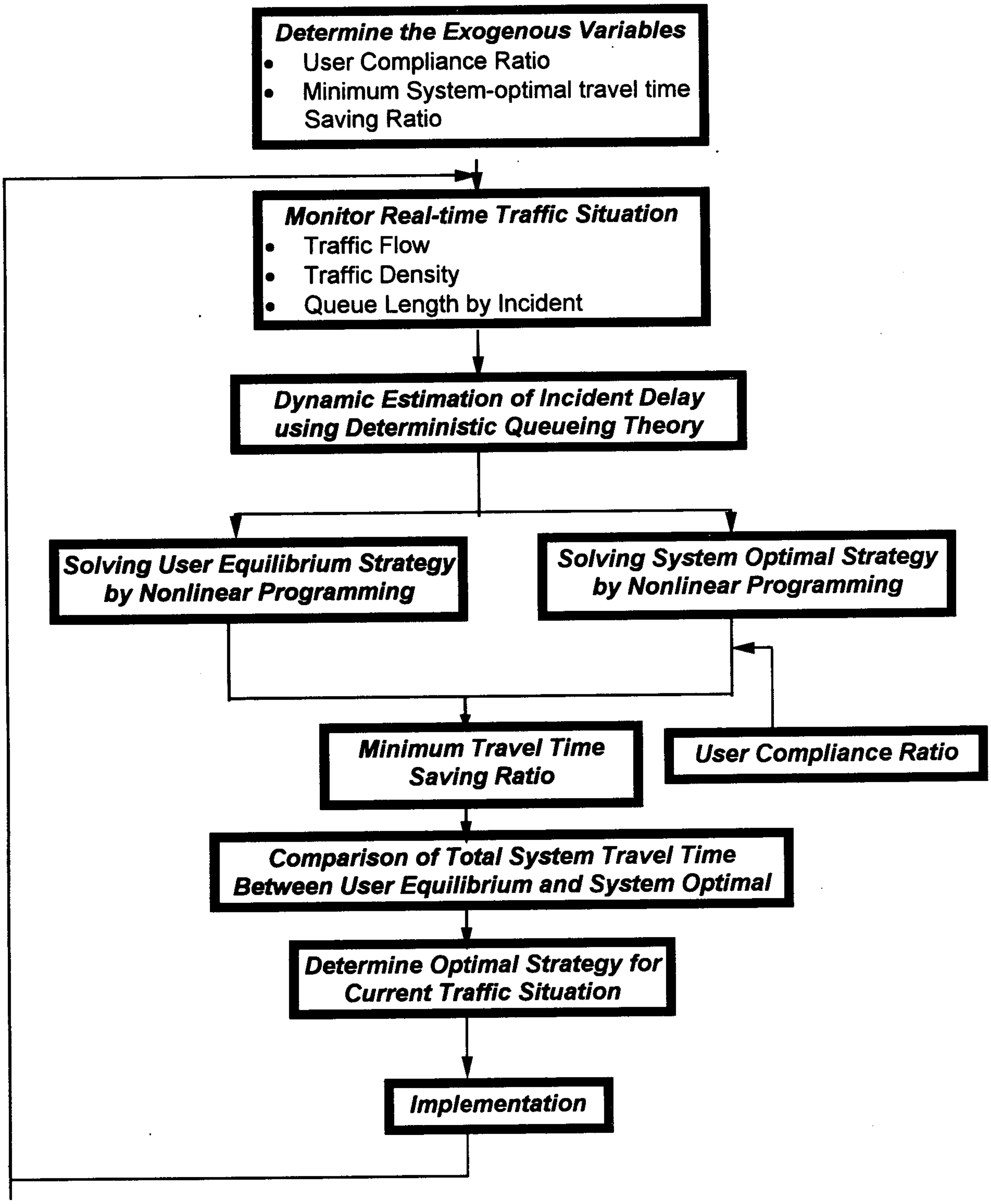


Figure 3.4 The Step-wise feedback methodology for DRGS under non-recurrent congestion

IV. STRATEGY EVALUATION

The evaluation of adaptive routing strategies for DRGS is presented by the utilization of a dynamic simulation model for Intelligent Transportation System (ITS), INTEGRATION under various non-recurrent congestion. The adaptive routing strategy is applied to the traffic diversion under non-recurrent congestion situation. The following alternative strategies for DRGS are evaluated :

(1) Diversion by the Adaptive Routing strategy.

(2) Diversion by the Instantaneous User Equilibrium Strategy

The Adaptive routing strategy employs traffic conditions during the occurrence of an incident and other road environment conditions to recommend efficient and effective diversion routes, while the user equilibrium strategy uses a real-time minimum travel time path for individual driver. In other words, the user equilibrium strategy unlike the adaptive routing strategy does not take into account the total system travel time saving in selecting diversion routes.

The comparison of the two methods were achieved by simulating various incident scenarios using the idealized network and Fairfax county road network. Several incident conditions by incident duration and traffic demand on freeway and arterial were investigated using each of the strategies. The simulation tool employed in the study is the INTEGRATION traffic simulation model.

4.1 Simulation with Idealized Network

4.1.1 Simulation Method

The evaluation of adaptive routing strategy for DRGS is performed with idealized network which has following configurations;

- Networks : 7 nodes and 8 links (one freeway and one neighboring arterial.)
- Freeway traffic demand : 3500 vph, 2500 vph
- Arterial traffic demand :600 vph, 1200 vph
- Freeway capacity : 4000 vph (2000 vph/lane)
- Arterial capacity : 2000 vph (1000 vph/lane)
- Incident severity : 1 lane blockage (65% capacity reduction)
- Sensitivity analysis by incident duration (30,60 min)

Four simulation categories have been identified by traffic demand on freeway and arterial as follows;

- Arterial Normal Freeway Normal(ANFN): Arterial V/C (0.3), Freeway demand(0.625)
- Arterial Normal Freeway Congested(ANFC): Arterial V/C (0.3), Freeway demand(0.875)
- Arterial Congested Freeway Normal(ACFN): Arterial V/C (0.6), Freeway demand(0.625)
- Arterial Congested Freeway Congested(ACFC): Arterial V/C (0.6), Freeway demand(0.875)

4.1.2. Simulation Results

Figure 4.2 shows that when the travel time saving ratio is maximum when both arterial and freeway have normal traffic demand under incident. As the demands increase, the travel time saving ratios decrease. It is noted that ACFN condition can save more total

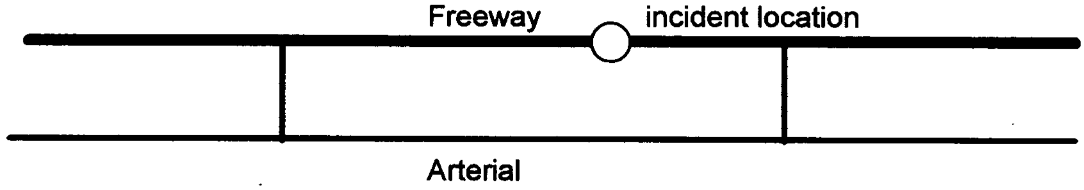


Figure 4.1 Idealized network for integrated traffic simulation

travel time than ANFC condition. This is because there is not enough capacity in arterial under ACFN condition to accommodate the system optimal routing that pursue the utilization of remaing capacity.

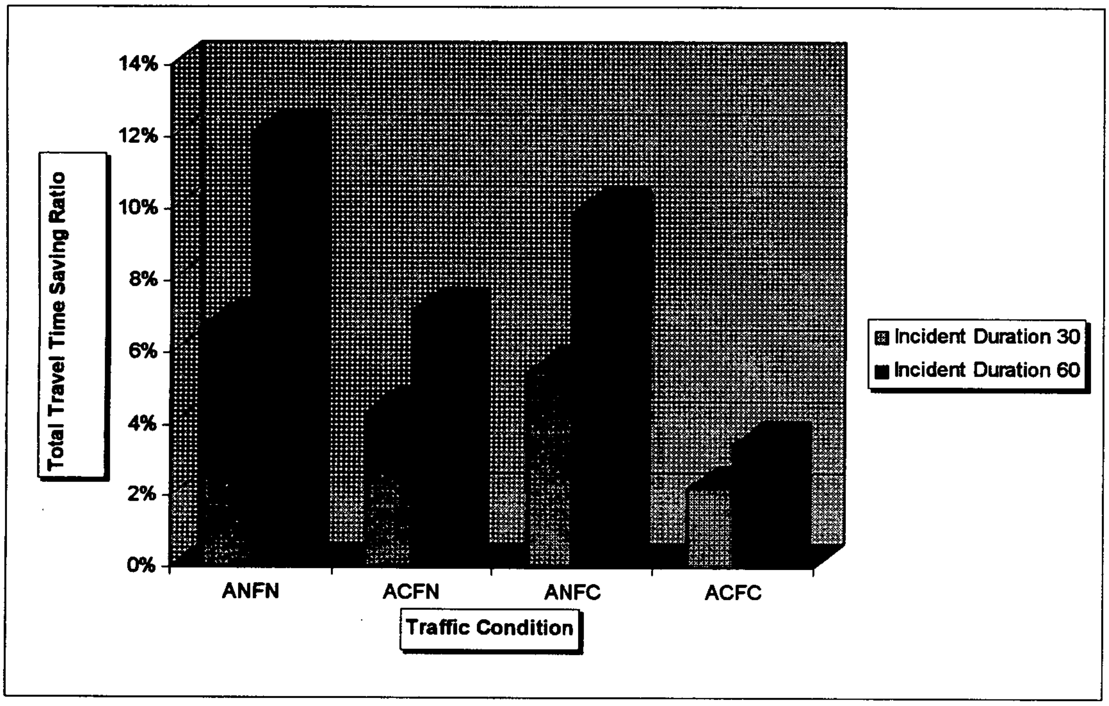


Figure 5.2 Total travel time saving by adaptive routing strategy over user equilibrium routing strategy under incident condition

Figure 4.3 The realistic network of fairfax county in Virginia

4.2 Simulation with Realistic Network

- Incident type : 65% capacity reduction (1 lane blockage)
- Traffic Assignment Algorithm : Fixed Multi-Path Assignment (update every 5 minutes)
- Incident duration : 15, 30, 45, 60 min (10 min ~ 70 min on simulation time)
- Total Simulation Time: 110 Min. (4.2 Hour)
- Incident locations on I-66
- Scenario I : Adaptive routing strategy
- Scenario II : Instantaneous user equilibrium routing strategy

4.2.1 Simulation Results

Table 4.1 shows that the adaptive routing strategy can reduce the total travel time within the range of 3% to 10%. As incident duration increases, the travel time saving ratio also increases.

Table 4.1 Comparison of traffic performance in realistic network

Incident duration	*Average trip times (min)*		
	User Equilibrium Routing Strategy	Adaptive Routing Strategy	Reduction Ratio(%)
15	15.49	14.96	3.4
30	17.70	16.69	5.7
45	20.34	18.65	8.3
60	23.95	21.43	10.5

V. CONCLUSION AND FURTHER RESEARCH

5.1 Conclusion

The high cost of traffic congestion which runs into several billions of dollars per year in the United States behooves upon traffic and transportation professionals, the responsibility to find solutions to alleviate them. Several methods are currently being developed to address incident related traffic congestion problems which account for about 60 percent of the total traffic congestion in the United States. However, it can not be overemphasized that whichever method is developed to address the problem, It should be effective and efficient.

Currently Dynamic Route Guidance Systems (DRGS) are being expected as a promising solution to traffic congestion. This research proposed an adaptive routing strategy for DRGS as an effective and efficient methodology. The research concludes with the following findings and recommendations for further researches.

Infrastructure based DRGS have advantage of pursuing system optimal routing strategy, which is more essential under abnormal traffic conditions such as non-recurrent congestion and natural disaster. However user compliance could be a problem under such a strategy, particularly when some of equipped drivers are urged not to choose minimum travel time path for the sake of improving the total network travel time. On the other hand, In-vehicle based DRGS can utilize the user-specified route selection criteria to avoid "Braess Paradox" under normal traffic conditions. However, it may be of little use under abnormal traffic conditions and high DRGS market penetration.

In conducting the comparative analysis between system optimal strategy and user equilibrium strategy, significant differences were found within the mid-range traffic demand. The maximum total travel time difference occurs when the level of traffic demand is half of the system capacity. At this point, system optimal route guidance strategy can save more than 11% of the total travel time of user equilibrium route guidance strategy.

According to the computation results, there is no need to implement system optimal routing strategy at the initial stage of the incident. However, it is critical to use system optimal routing strategy as freeway and arterial are getting congested and the queue delay in freeway increases.

The adaptive routing strategy is evaluated using Traffic simulation model, INTEGRATION. According to simulation results using an ideal network, the travel time saving ratio is maximum when both arterial and freeway have normal traffic demand under incident. In case of a realistic network, the adaptive routing strategy also proved to save the total travel time between 3% to 10% over the traditional user equilibrium routing strategy. The reduction of total travel time increases as the incident duration increases. Consequently, it is concluded that the adaptive routing strategy for DRGS is more efficient than using user equilibrium routing strategy alone.

5.2 Further Research

The following has been suggested as areas of further research to this dissertation.

- Sensitivity analysis with different user compliance ratio
- Sensitivity analysis with different market penetration ratio
- Sensitivity analysis with different information updating time interval
- Establishment of multiple user class optimization technique
- Application of the adaptive routing strategy to general route guidance scenarios based on radio based dynamic route guidance system

Incorporation with incident management algorithm to implement comprehensive incident management strategyE

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