Title

Incident Management with Advanced Traveller Information Systems

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Publication Date
1991-06-01

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PATH Working Paper
UCB-ITS-PWP-91-5

This work was performed as part of the Program on Advanced Technology for the Highway (PATH) of the University of California, in cooperation with the State of California, Business and Transportation Agency, Department of Transportation, and the United States Department of Transportation, Federal Highway Administration, and the National Highway Traffic Safety Administration.

June 1991

ISSN 1055-1417

ABSTRACT

Advanced Traveller Information Systems (ATIS) can be used to collect and disseminate dynamic information about travel times on highway links. One of the potential uses of these systems is to manage incidents. The objective of this research is to show under what incident conditions is it relevant to provide real time traffic information to travellers.

A model that uses graphical queueing techniques is utilized to define cases when ATIS is beneficial and cases when it is not, and to evaluate its benefits as measured by travel time savings. The model is applied to a simple road network with two parallel bottlenecks. We analyze an off-peak incident scenario where a user optimal strategy is implemented to disseminate information only to vehicles equipped with ATIS. The different cases of queue evolution that can result are described, benefits to guided and unguided travellers and the sensitivity of benefits to relevant parameters are also analyzed.

It is found that once equilibrium is reached between alternate routes, the rate of diversion from one to the other has to be decreased to maintain it. The implication is that during equilibrium some guided travellers will be diverted to the alternate route, while others will be asked to stay on the route where the incident has occurred. It is also found that as long as the fraction of vehicles equipped with ATIS is below a critical value, p_c, then the benefits to a guided traveller are maximum and are not affected by the amount of guided traffic. However, benefits to a guided traveller decline when the fraction of guided traffic becomes larger than p_c. The critical value, p_c, does not depend on incident parameters but is a function of capacity of the alternate route and corridor demand. System benefits also increase to a maximum as the fraction of guided traffic approaches p_c and become constant when this fraction is larger than p_c. Therefore, under the user optimal strategy, if the fraction of vehicles equipped with ATIS is equal to p_c benefits to guided traffic and to the system are maximized simultaneously. There is a need to develop a methodology which can find practical estimates of p_c for use in large scale simulations of real life networks.

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ACKNOWLEDGEMENTS

This research is part of the California Program on Advanced Technology for the Highway (PATH) which is funded by the California Department of Transportation.

The authors would like to acknowledge the helpful discussions with Professor Gordon Newell which resulted in using his graphical queueing techniques as the tool of analysis in this study.

INTRODUCTION

Advanced traveller information systems (ATIS) have gained worldwide interest as a promising technology for improving the efficiency of urban networks and reducing congestion. It is generally anticipated that the provision of route guidance information to travellers will help them avoid congested links in the network, thereby reducing congestion by spreading traffic over space, and possibly time. This proposition has been so well received that technology for ATIS is being developed and tested in numerous locations around the world. There remains, however, a paucity of analysis to demonstrate that the implementation of ATIS will in fact have a significant impact on congested urban networks, and to estimate the magnitude and distribution of its potential benefits. This paper is concerned with an important application of ATIS technology: the management of incidents. Using an idealized traffic corridor and deterministic queueing methods, we identify conditions under which route guidance information is useful and estimate its benefits in non-recurring congestion, or incident conditions.

Background

There have been numerous efforts during the last decade to evaluate the benefits of ATIS (see, for example: Kobayashi [8]; Tsuji et al. [10]; Jeffrey [6] and [7]; and Al-Deek et al. [2], [3], [4], and [5]). The results to date suggest that, by and large, the benefits of route guidance are marginal under conditions of recurring congestion. Experienced travellers, who make up the major portion of traffic in congested urban networks, have sufficient information to manage their route choice under conditions of recurring congestion. This has often been reflected in the estimates of potential benefits from ATIS in the vicinity of 10% savings in total travel time. These results suggest that ATIS is likely to be more useful under conditions of non-recurring 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 vis-a-vis the rest of the network would leave the traveller insufficiently informed to make appropriate route choice decisions. Furthermore, by extending ATIS information to potential travellers long before they approach incident locations, it may be possible to further reduce potential congestion by altering trip patterns including departure times, thereby spreading traffic over time in addition to space.

In the following paragraphs we describe a deterministic queueing model of a simple corridor in which we simulate the occurrence of incidents of various locations, durations, and severity. We use the model to analyze the benefits from ATIS, and we study the sensitivity of these benefits with respect to some parameters, most important among them is the percentage of vehicles that have ATIS equipment on board. In simulating the application of ATIS technology, we assume that it is possible to estimate the flow and the travel time on each link in the network using data collected via traffic surveillance. It is also possible to detect the occurrence of an incident, to estimate its duration and the capacity reduction caused by it. It is assumed in this analysis that vehicles with ATIS will always follow directions to divert to a shorter route. This assumption is not necessary for the model used here and can be easily relaxed.

CORRIDOR MODEL WITH INCIDENT

We consider a simple corridor as shown in Figure 1.

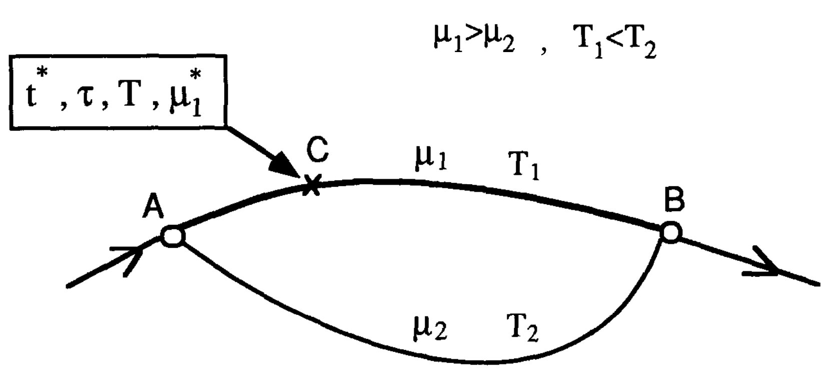


FIGURE 1 - NETWORK AND INCIDENT PARAMETERS

The corridor consists of two routes connecting points ***A*** and ***B.*** The first route is a freeway with capacity μ_1 and free flow travel time T_1 and the second is an alternate route with free flow travel time T_2 and capacity μ_2, where $\mu_2 \leq \mu_1$. We further consider that $T_1 < T_2$, and we assume, following Kuwahara and Newell [9], that these times are independent of flow except under queueing conditions. Thus, in the absence of queues, route 1 is always preferred to route 2.

To simulate an incident we need to set down some conditions of the network. First we consider the off-peak case in which the flow, Q, of traffic arriving at ***A*** is less than the capacity of the freeway μ_1. We also assume that the location of the incident is such that there is sufficient queueing space upstream of it so that the queue does not back up into junction ***A.*** Once travellers pass point ***A,*** information from ATIS becomes irrelevant since they would already be committed to one of the two routes. ATIS information will therefore be directed at traffic as it approaches point ***A*.** Finally, to simulate and analyze the occurrence of an incident we construct a deterministic queueing diagram for this corridor, as shown in Figure 2. The incident occurs at point C and reduces the capacity of route 1 from μ_1 to μ^*_1. The incident occurs at time t* and lasts for a duration ***T.*** As illustrated in Figures 1 and 2, point C is τ units of travel time away from ***A*** along route 1, and $0 < \tau < T_1$.

EVOLUTION OF QUEUES WITHOUT INFORMATION

In the absence of ATIS, or any other information about the incident or its impact on travel times, travellers will continue to choose between routes 1 and 2 on the basis of their ***non-incident*** experience. As mentioned above, this means all traffic at point ***A*** will choose route 1. As long as the back-up caused by the incident does not reach point ***A, the*** queue will evolve as shown in Figure 2. Traffic arrives at point ***A*** according to the arrival curve A(t), and τ units of time later at the incident point C according to curve A,(t). Note that the

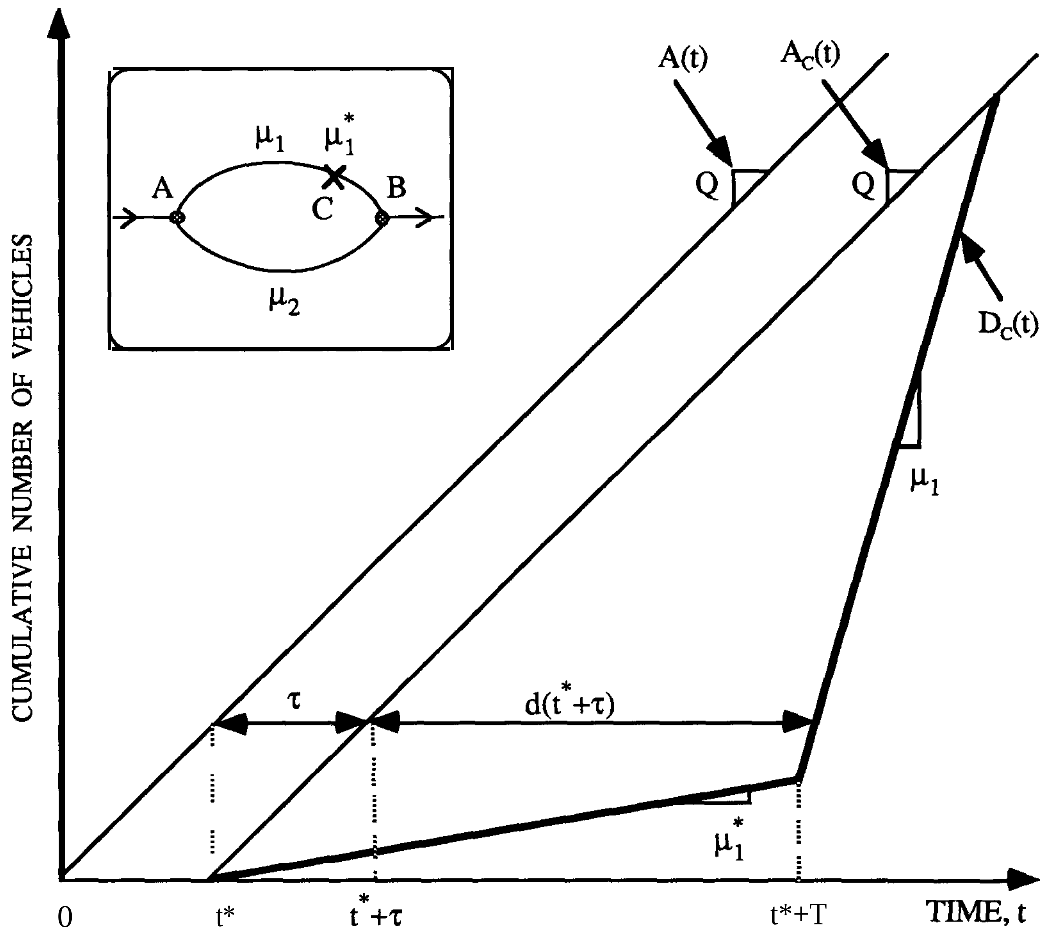


FIGURE 2 - OFF-PEAK INCIDENT SCENARIO WITHOUT INFORMATION
CASE-I $d(t^*+\tau) > T - \tau$ and $d(t^*+\tau) > T^*$

slope of both of these curves is Q, the traffic flow rate. The departure curve D,(t) shows the departure from the bottleneck. The departure flow rate is initially μ^*_1, the reduced capacity of the bottleneck, and then after the incident is cleared at time T+t*, is the restored capacity μ_1. Note that Figure 2 illustrates the evolution of the queue for one of a number of possible cases. This case is described by the following conditions:

$$d(t^*+\tau) > T - \tau,$$

and

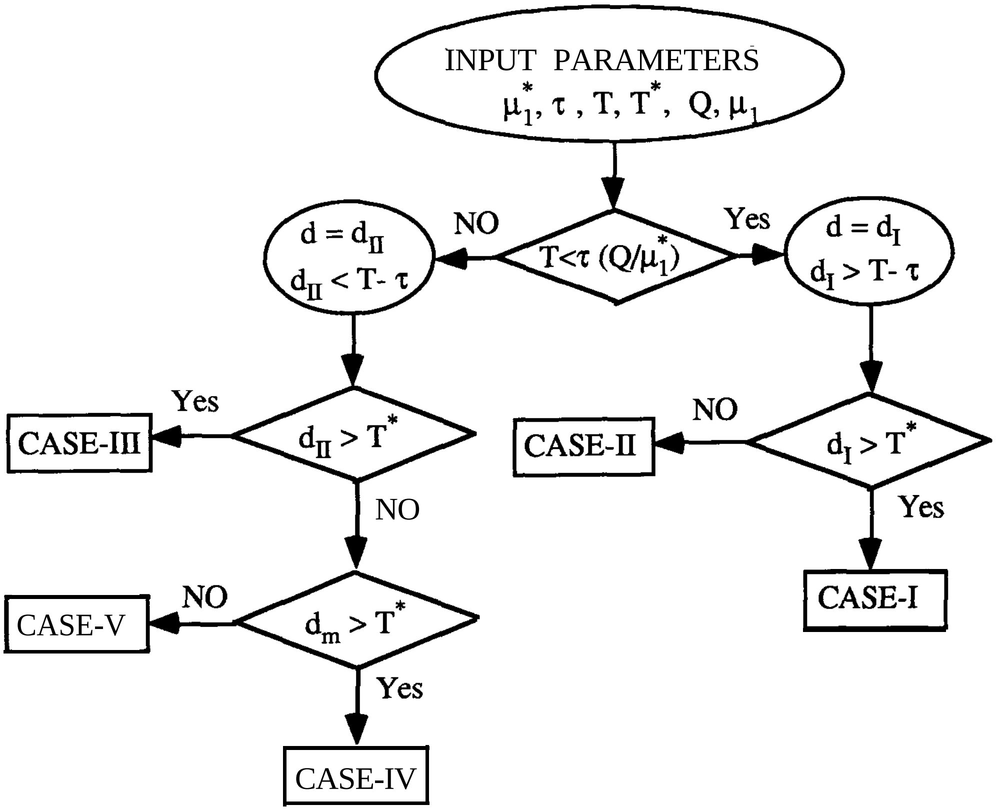
$$d(t^*+\tau) > T^*$$

where $d(t^*+\tau)$ is bottleneck delay for a traveller who arrives at A at time t^* (when the incident occurs) and uses the freeway to go from ***A*** to ***B***, and T^* is the difference between free flow travel times on the two routes, $T_2 - T_1$. The implication of the first condition is that a traveller who arrives at ***A*** when the incident occurs is expected to depart from C after the incident is cleared. The second condition implies that if information is available in this case, diversion during some time interval can result in benefits to guided traffic. The origin of the graph in Figure 2 is selected such that all vehicles that experience queueing delay are included in the calculation of corridor total travel time. For simplicity, we will use d from now on to denote $d(t^*+\tau)$.

The process for identifying cases of queue evolution without information under this incident scenario is illustrated in Figure 3. It is obvious that guided travellers will not gain anything if they divert to the alternate route in Cases II and V, because the delay never exceeds T^* in these two cases. Therefore, if it is available, information is relevant in three out of five possible cases: Cases I, III, and IV. These are used in this study to analyze the benefits from ATIS.

EVOLUTION OF QUEUES WITH ATIS

If a user optimal strategy is used in Case-I to instruct equipped traffic to divert, then there will be two possible outcomes: either 1) the fraction of equipped vehicles is large



$$d_I = T\left(1 - \frac{\mu_1^*}{\mu_1}\right) + \tau\left(\frac{Q}{\mu_1} - 1\right)$$

$$d_{II} = \tau\left(\frac{Q}{\mu_1^*} - 1\right)$$

$$d_m = \text{Maximum Delay} = T\left(1 - \frac{\mu_1^*}{Q}\right)$$

FIGURE 3 - CASES OF QUEUE EVOLUTION FOR AN OFF-PEAK INCIDENT SCENARIO WITHOUT INFORMATION

enough so that diverted traffic will cause a queue on the alternate route; or 2) there is not a sufficient number of ATIS equipped vehicles to divert and cause a queue. Cumulative arrival and departure curves are drawn in Figure 4 when there is no queue on the alternate route and in Figure 5 when there is. A,(t) denotes arrivals at ***A*** at time ***t*** of traffic using route 1 (the freeway), A*,(t) denotes arrivals at the incident bottleneck C when there is diversion to the alternate route, and $A_2(t)$ denotes arrivals to the alternate route. In the first case, shown in Figure 4, all equipped vehicles are instructed to divert to the alternate route for a period of time, K, after which the freeway reverts to being faster than the alternate route. The length of diversion period, K, is a function of ***p,*** the fraction of vehicles equipped with ATIS, with diversion expected to last longer for smaller values of ***p. In the*** second case, shown in Figure 5, all equipped vehicles are diverted to the alternate route for a period of time ***K*** until equilibrium is achieved. In order to maintain equilibrium, the rate of diversion has to be decreased. The fraction that should be diverted to maintain equilibrium was derived by Al-Deek [1] and is given by:

$$p' = \frac{\mu_2}{\mu_2 + \mu_1} \qquad \text{Eq (1)}$$

Note that this fraction is not a function of ***p.*** However, if equilibrium is to be achieved, then clearly ***p*** must equal or exceed ***p.*** This implies that some equipped travellers will be selected to divert to the alternate route while other will be asked to remain on route 1. This is a non-trivial task, but it is anticipated that this task can be achieved with in-vehicle ATIS where communication can be established with individual vehicles as they route in the network. There are nonetheless important implications of this for policy regarding the distribution of information and consequently the benefits of ATIS. Equilibrium lasts for a time period of ε after which the freeway becomes faster and no more equipped travellers are diverted. Application of user optimal strategy to all cases in Figure 3 results in a total of

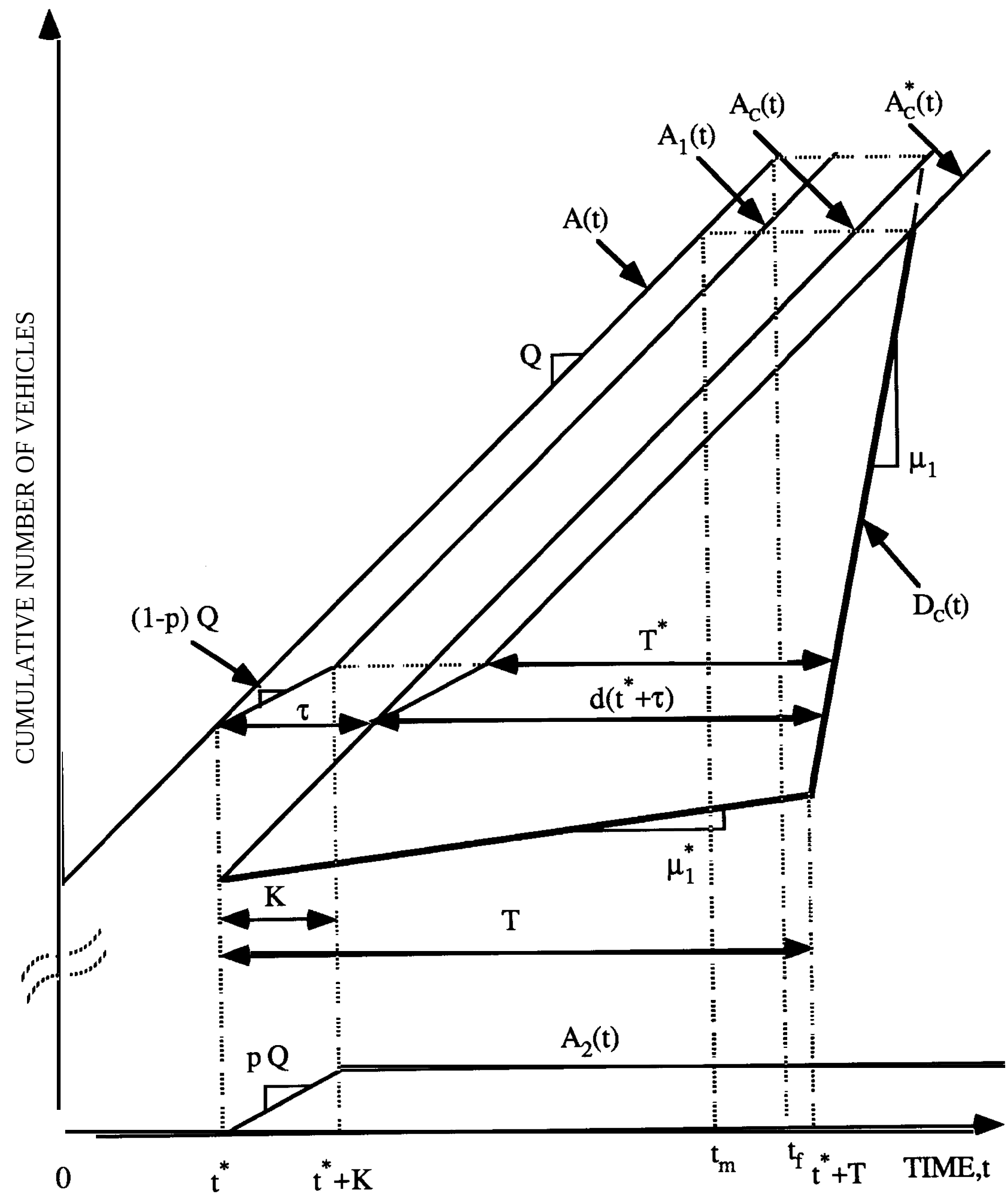


FIGURE 4 - OFF-PEAK INCIDENT WITH ATIS (NQ-CASE-I)

$p < (\mu_2/Q)$, $d_I > T^*$, and $d_I > T-\tau$

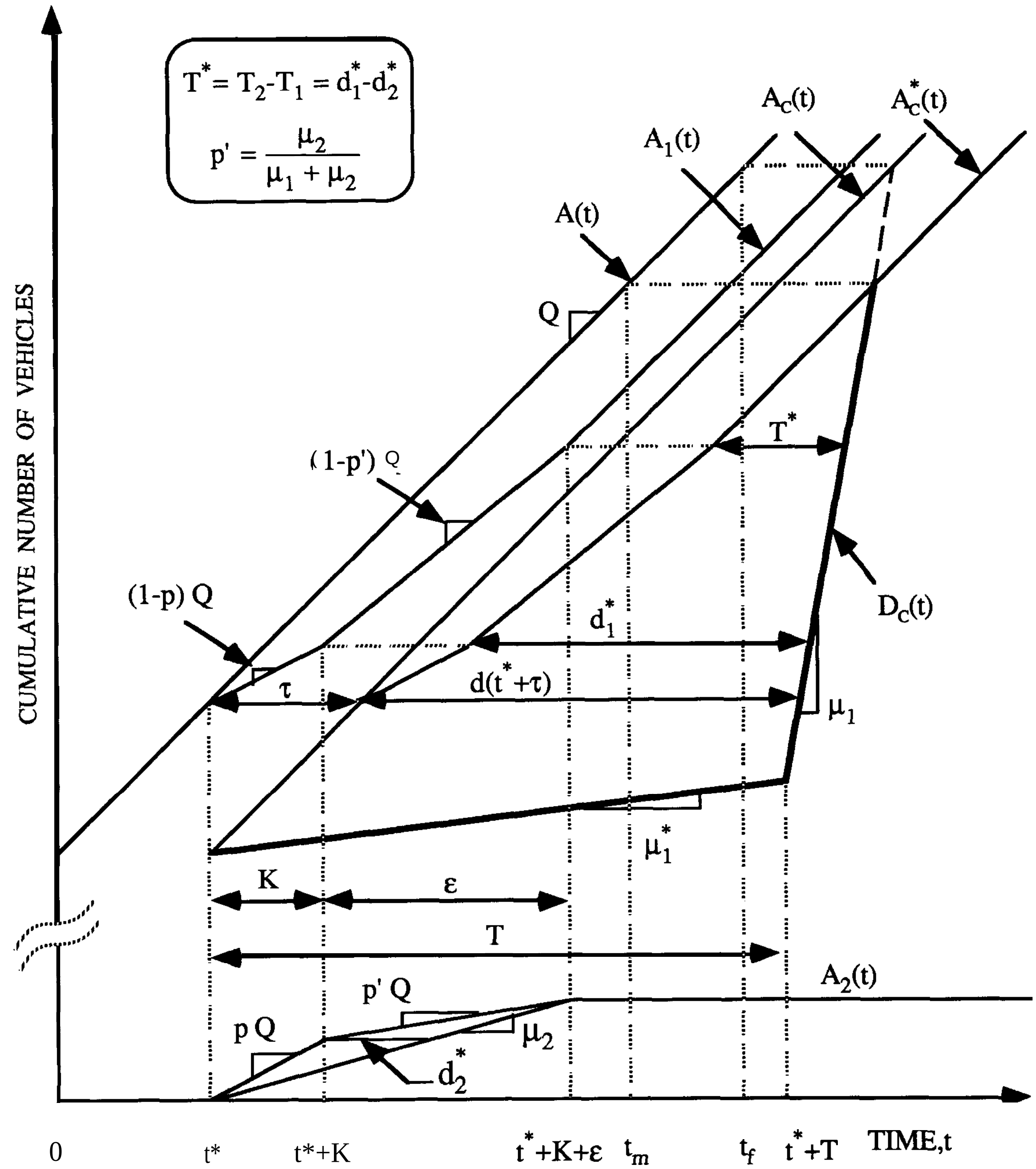


FIGURE 5 - OFF-PEAK INCIDENT WITH ATIS (Q-CASE-I)

$p > (\mu_2/Q)$, $d_I > T-\tau$, and $d_I > T^*$

twelve cases of queue evolution, illustrated in Figure 6. The large number of possible cases is a result of adding another input parameter, ***p***. The twelve cases are classified into three sets. In the first set, ***p*** is large enough so that the rate of diversion to the alternate route, pQ, causes a queue. There are five cases in this set, with names that start with the letter Q; this set will be referred to as the Q set. In the second set, which also contains five cases, there is no queue on the alternate route, even if all equipped vehicles are diverted to that route. The cases in the second set, the NQ set, are identified by the prefix NQ. Within each of the sets, cases are determined by threshold values of ***p*** such as z and z'. These thresholds determine how soon equilibrium can be achieved after the start of diversion. The threshold values for ***p*** that separate between these various cases are derived in Al-Deek [1]. For example, in Q-CASE-III equilibrium can be achieved before the incident queue starts to discharge because the fraction ***p*** is larger than threshold z, where z is the minimum fraction needed to initiate equilibrium and is given by:

$$z = \frac{\mu_2}{\mu_2 + \mu_1^* \left(\frac{T - \tau - d}{T - \tau - T^*} \right)} \qquad \text{Eq (2)}$$

EVALUATION OF ATIS BENEFITS

In this section we analyze the benefits to guided and unguided traffic and evaluate the total system benefits. We illustrate this with a numerical example, and we consider a three lane highway with a lane capacity of 30 vehicles per minute (total capacity μ_1 is equal to 90 vehicles per minute). The alternate route has a capacity μ_2 of 40 vehicles per minute. Demand Q is equal to 80 vehicles per minute. Trip time from ***A*** to ***B*** using the freeway, T_1, is 15 minutes, while T_2 is 25 minutes. An accident occurs on the freeway at point C at time t^* during off-peak conditions. It takes 10 minutes to travel from ***A*** to C when there is no queue between ***A*** and C, $\tau=10$ minutes. The accident blocks two out of three lanes and results in a 75% loss in capacity of the freeway. Furthermore, it is estimated that it will

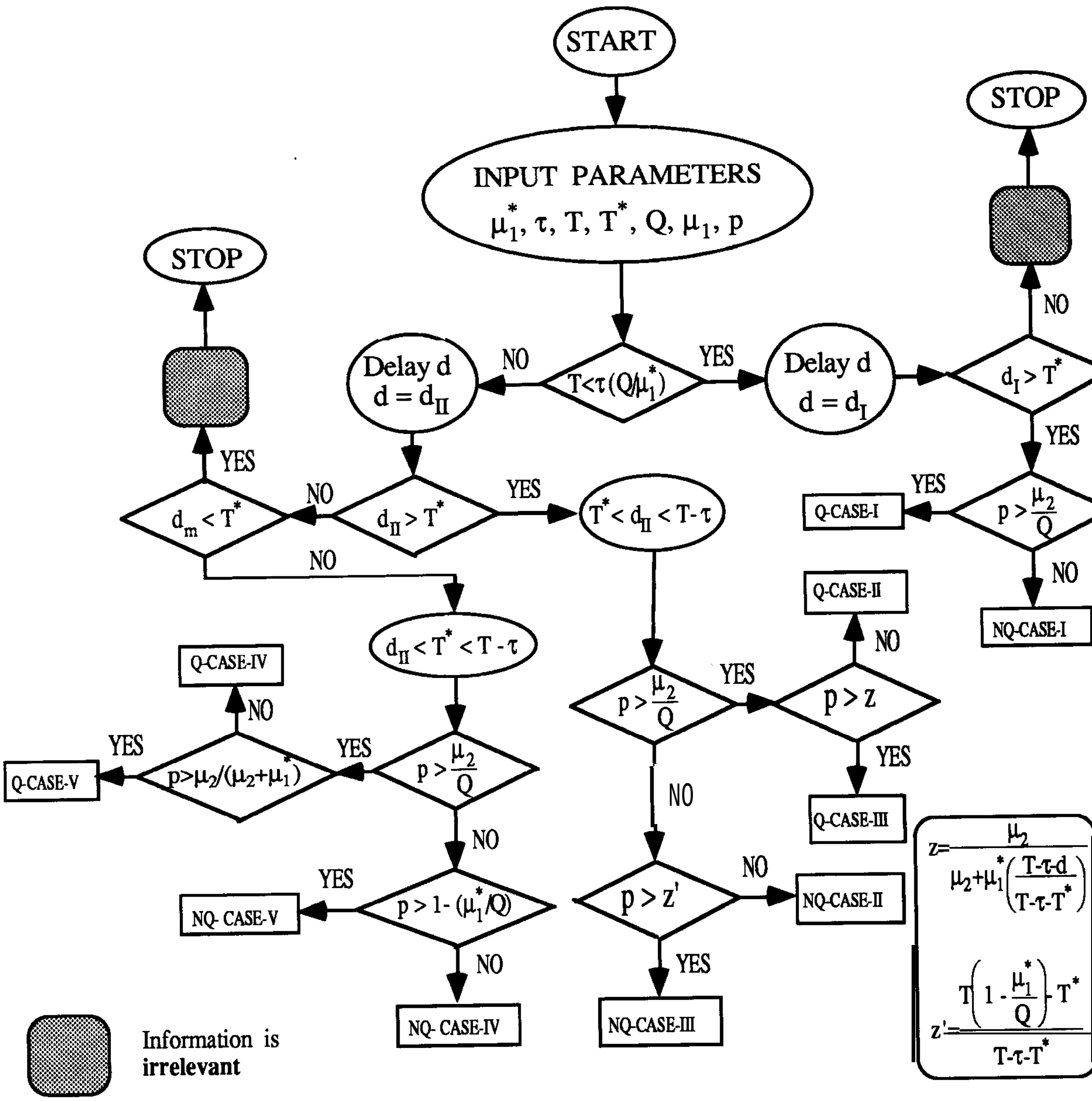


FIGURE 6 - CASES OF QUEUE EVOLUTION FOR AN OF-PEAK INCIDENT WITH ATIS

take 30 minutes to clear the accident, T=30 minutes.

Following the procedure described in Figure 6, we identify two possible cases of queue evolution for this numerical example: NQ-CASE-I and Q-CASE-I.

NQ-CASE-I

The time saved by a traveller is a function of the arrival time at point ***A***. This is illustrated in Figure 7 for NQ-CASE-I, which is valid for $p < 0.5$. Trip time from ***A*** to ***B*** under incident conditions and in the absence of ATIS is the basis for calculations of travel time savings. Therefore, Figure 7 shows a dynamic profile of travel time savings for both guided and unguided traffic. To explain the trend in time savings we refer to the queueing diagram of NQ-CASE-I shown in Figure 4.

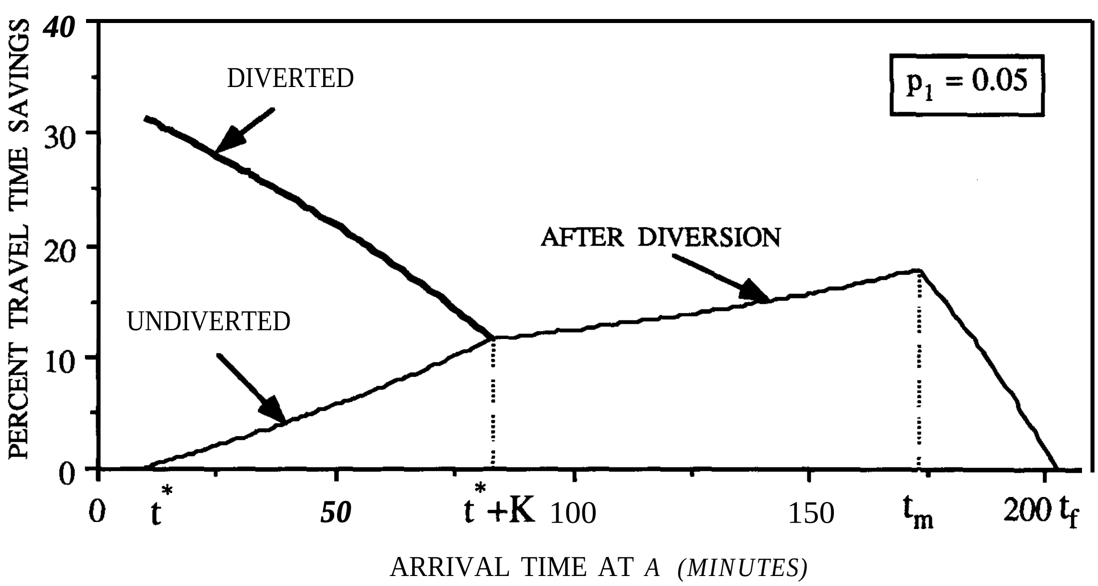


FIGURE 7 - BENEFITS TO DIVERTED AND UNDIVERTED TRAVELLERS (NQ-CASE-I)

All equipped vehicles are diverted for a period of time K. Benefits to diverted traffic decline to a minimum at the end of the diversion period. This is because diverted traffic is being shifted from the freeway, where the incident queue is diminishing, to the alternate route where there is no queue. Benefits to undiverted (or unequipped) traffic continue to increase to a maximum at the end of diversion period K. Throughout the diversion period K, the cumulative number of vehicles that divert to the alternate route increases causing the queue length and delay on the freeway to decrease. This is translated into time savings to those who continue to use the freeway. Queueing delay at the incident bottleneck is a function of the history of the arrival curve, At(t). This explains why benefits are not restricted to travellers who arrive during diversion time K, but also apply to travellers arriving after the diversion ends, regardless of whether they are equipped with ATIS or not. The queue discharges faster with ATIS than without it as shown in Figure 7 where the queue vanishes at time $\tau+t_m$ with ATIS and $\tau+t_f$ without it. As a result, delay on the freeway decreases at a faster rate and benefits to travellers arriving at A in time interval (t^*+K, t_m) increase to a maximum at time t_m. Since the queue would have diminished completely at $\tau+t_f$ anyway, no benefits are gained to travellers arriving at A beyond time t_f.

It should be noted that equipped travellers are always better off than unequipped travellers during diversion period K. The maximum length of diversion period K in this numerical example occurs when p is very small ($p\approx 0$) and is equal to 103 minutes, while the total time during which there are benefits ($t_f - t^*$) is equal to 193 minutes. The numerical example illustrates in this case that at best during 53% of the time guided travellers can be better off than unguided travellers.

The sensitivity of benefits to the fraction of vehicles equipped with information is illustrated in Figure 8. Since there is no queue on the alternate route, benefits to an equipped vehicle are not affected by how many equipped vehicles are diverted. On the other hand, benefits to undiverted traffic increase as the fraction of equipped (and therefore diverted) vehicles increases. The numerical example illustrates that maximum benefits are not necessarily gained by equipped travellers who divert to the alternate route; instead, the maximum benefits are gained by travellers arriving after diversion ends.

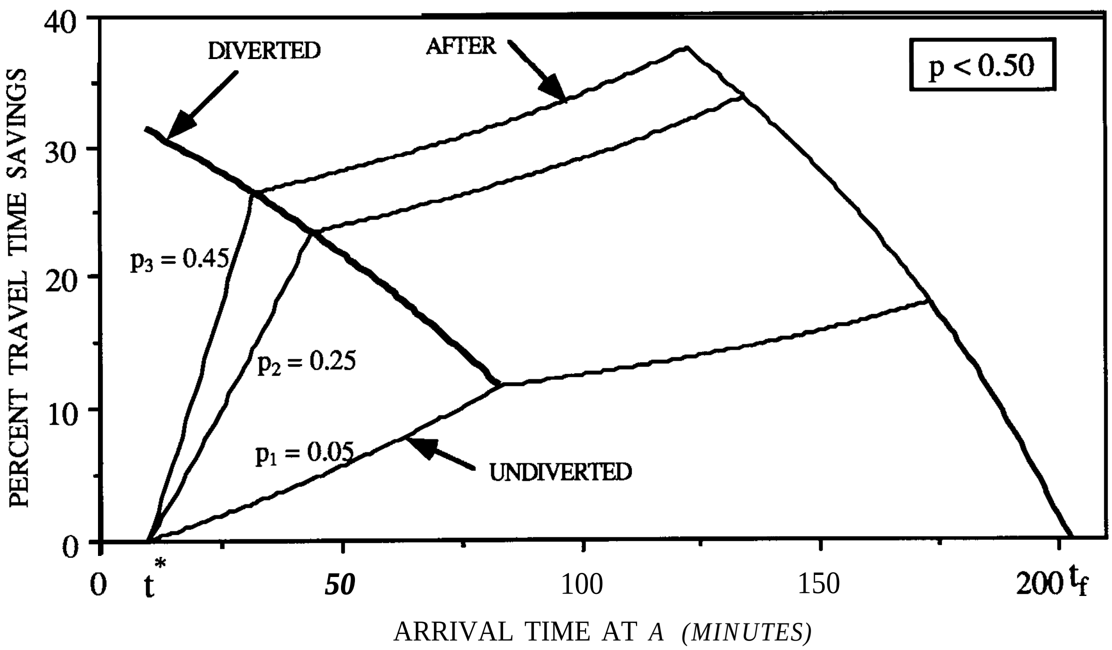


FIGURE 8 - BENEFITS TO DIVERTED AND UNDIVERTED TRAVELLERS FOR DIFFERENT LEVELS OF p (NQ-CASE-I)

<u>O-CASE-I</u>

This case applies when $\boldsymbol{p} > 0.5$ and is illustrated in Figure 9. There are two time intervals during which there is diversion: before equilibrium between the two routes is achieved, and during equilibrium. Diversion in the first interval is similar to that of NQ-CASE-I. Basically, all vehicles equipped with information are diverted to the alternate route for a period of time ***K.*** In this case, however, ***p*** is large enough to cause a queue on the alternate route creating a configuration of two parallel bottlenecks. Since a queue is forming on the alternate route, an increase in the fraction of diverted vehicles results in a decrease in the benefits to guided traffic. Once equilibrium is reached, benefits to guided and unguided traffic become identical during equilibrium and thereafter. Note that increasing ***p*** causes ***K*** to decrease and ε to increase such that total diversion $(K+\varepsilon)$ remains constant. Furthermore, the benefits to guided and unguided traffic during equilibrium and

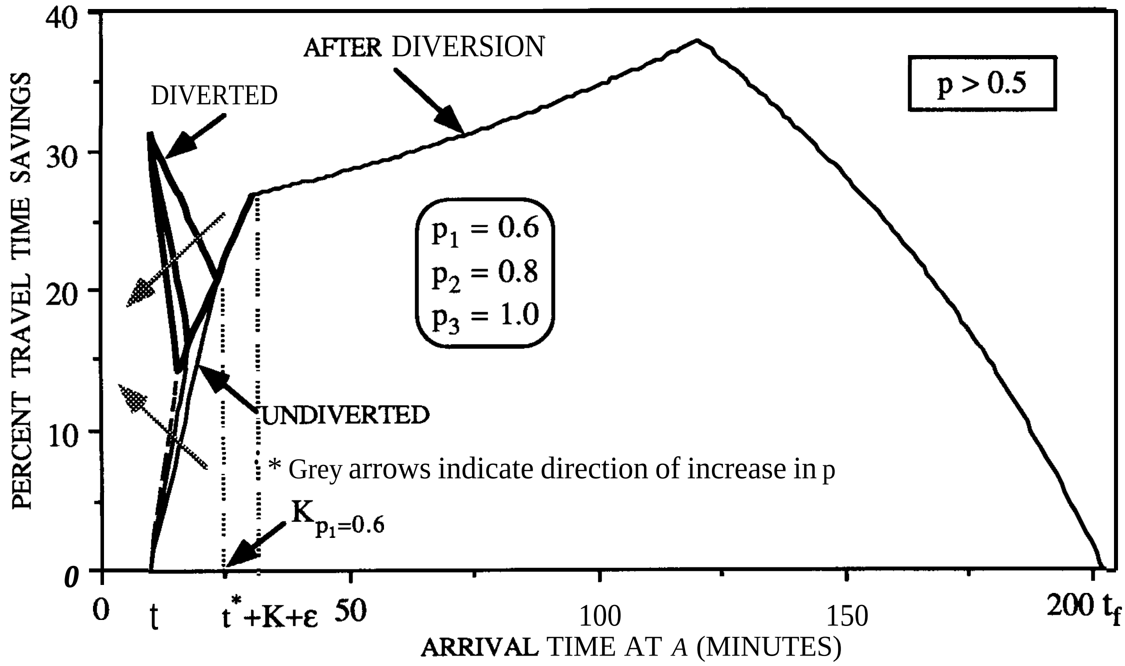


FIGURE 9 BENEFITS TO DIVERTED ANDUNDIVERTED TRAVELLERS (Q-CASE-I)

thereafter are not affected by an increase inp. Benefits increase during equilibrium because the queue on the alternate route discharges faster than the queue on the freeway. The dotted line in Figure 9 shows that even if all vehicles are equipped and therefore diverted to the alternate route during ***K,*** some benefit can still be gained by not diverting. This benefit is not as large, however, as the benefit of diversion. In a real life situation small amounts of time savings may not be sufficient to induce travellers to follow instructions to divert, given the possible inconvenience of diversion.

The maximum length of diversion time ***K*** in this case occurs when $p=0.5$ and is equal to 2 1 minutes, while the total time during which there are benefits $(t_f - t^*)$ is equal to 193 minutes. Therefore, in this case, at best during 11% of the time guided travellers can be better off than unguided travellers.

SYSTEM BENEFITS

It was found in the previous sections that equipped traffic gains maximum benefits as long as the fraction of diverted traffic does not exceed a critical value $p_c = \mu_2/Q$ (*0.5* in this numerical example). It was also noted that the time during which equipped travellers can be better off than unequipped travellers decreases drastically once a queue forms on the alternate route. In this section we investigate system benefits, that is, the total travel time savings in the corridor. Figure 10 depicts the trend of system benefits as the fraction of equipped vehicles increases from 0 to 1. The base value for percent travel time savings is the total travel time in the corridor from ***A*** to ***B*** when there is an incident but no ATIS.

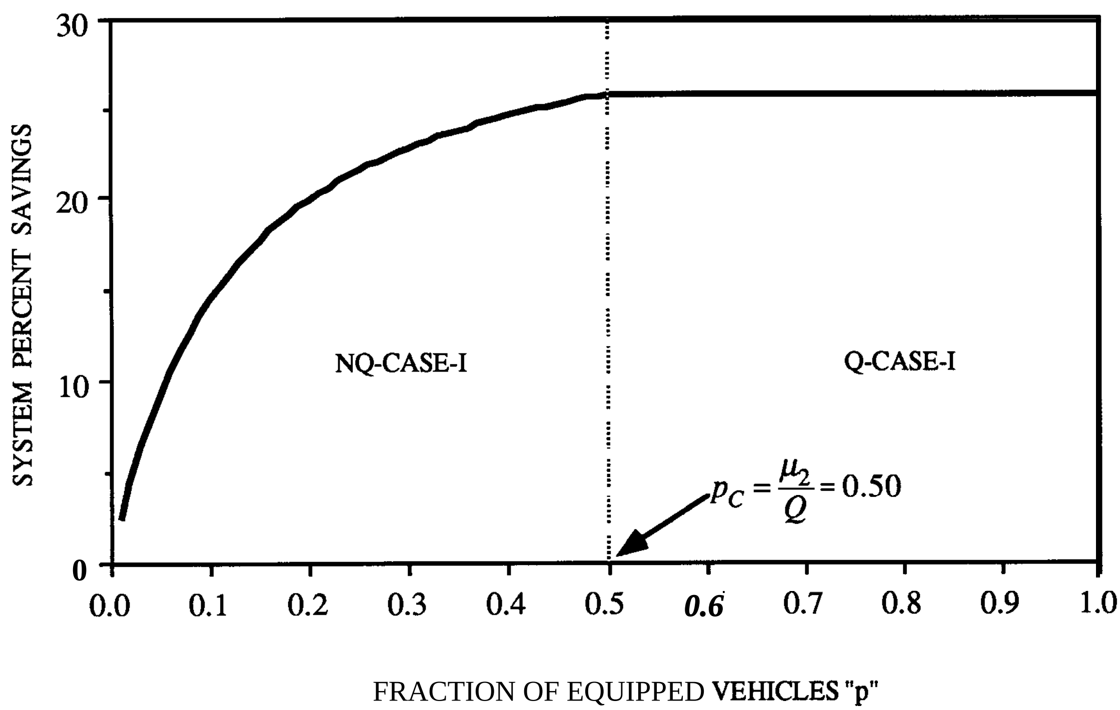


FIGURE 10 - SYSTEM BENEFITS VERSUS "p" (NQ-CASE-I AND Q-CASE-I)

Figure 10 illustrates that system benefits increase with p as long as p is less than p_C. System benefits become independent of p and stay at a constant level when p is larger than 0.5, or when a queue starts to form on the alternate route. This implies that system benefits are maximized when p is equal to p_C. Certainly, there is no more system gain if more than

p_c of the vehicles are equipped with ATIS.

This finding implies that a strategy can be applied where no more than p_c is diverted to the alternate route in all circumstances. Only then can one guarantee that benefits to the system and to equipped traffic under the strategy implemented are maximized simultaneously. However, if $p > p_c$ this strategy might be inequitable to those who are equipped but not diverted.

SENSITIVITY ANALYSIS OF BENEFITS

In this section we present the results of sensitivity analysis of system benefits to parameters other than p, using various numerical examples. These parameters are:

- incident parameters: duration, severity, and location
- corridor capacity: capacity of the freeway and capacity of the alternate route
- the critical value p_c
- travel demand in the corridor
- difference between free flow travel times on the two routes

It is clear that if the incident duration T increases, then system benefits from ATIS increase. However, the increase is nonlinear and diminishes for large incident durations as shown in Figure 11. Since NQ-CASE-I is valid for incidents with short durations, benefits are more sensitive to *Tin* this case than in NQ-CASE-II. It is also clear that there are no benefits, i.e., information is irrelevant, when the incident duration is short (less than 15 minutes in this numerical example).

System benefits increase nonlinearly with incident severity expressed as reduction in freeway capacity. ATIS becomes irrelevant for incidents with capacity reduction below 40% as shown in Figure 12. The iso-benefit contours shown in Figure 13 illustrate the sensitivity of maximum system benefits (i.e., $p=p_c$) to the incident duration and severity. When the severity is high (above 60%) and the duration is short (less than one hour) the benefits are more sensitive to duration than to reduction in capacity. Similarly, when the

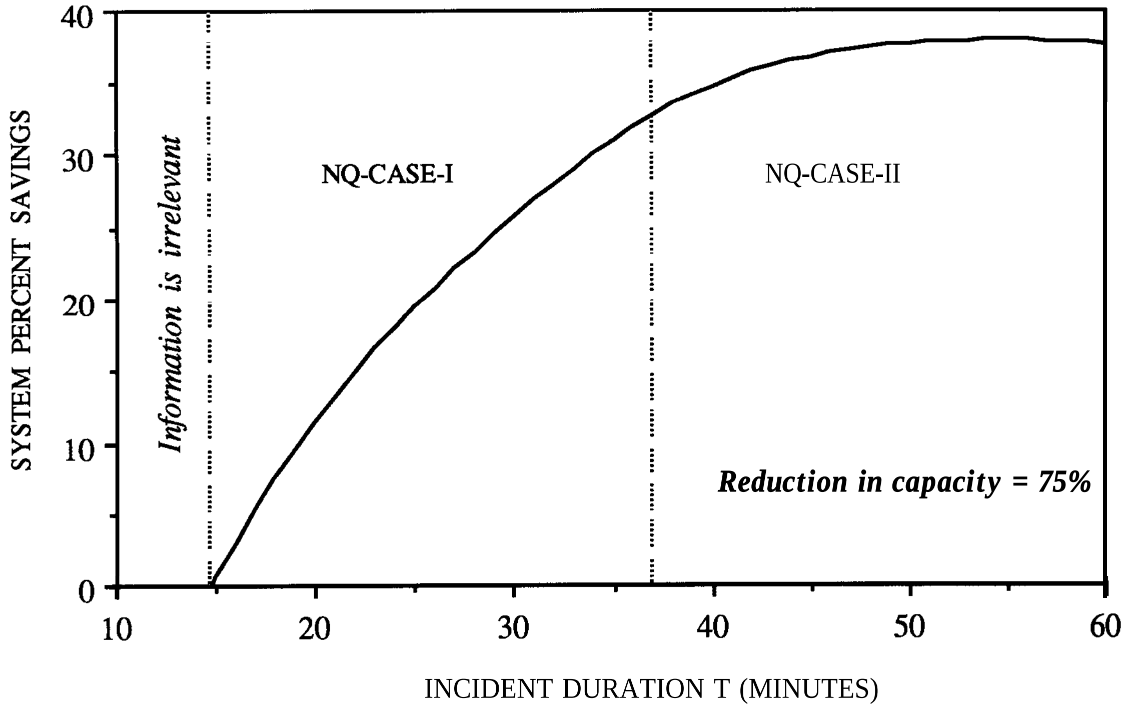


FIGURE 11 - SENSITIVITY OF SYSTEM BENEFITS TO INCIDENT DURATION (T)

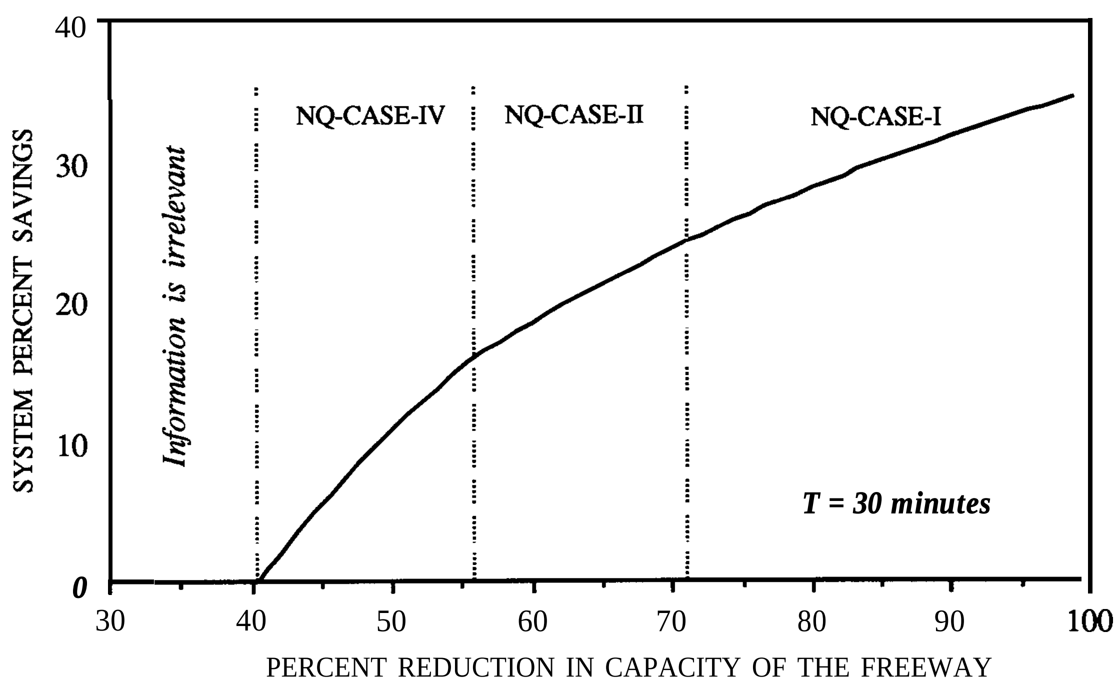
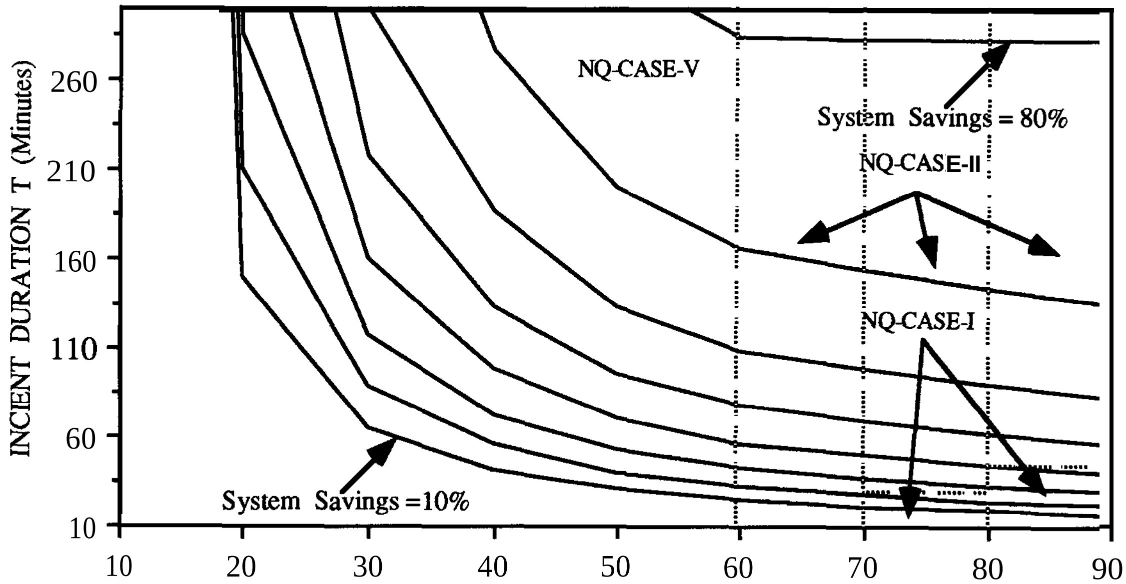


FIGURE 12 - SENSITIVITY OF SYSTEM BENEFITS TO REDUCTION IN FREEWAY CAPACITY



PERCENT REDUCTION IN CAPACITY OF THE FREEWAY

(P, = 0.5)

FIGURE 13 - ISO-BENEFIT CONTOURS - INCIDENT SEVERITY AND DURATION-

reduction in capacity is low (say, less than 40%) and duration is long (more than one and a half hour) the benefits are more sensitive to reduction in capacity than they are to incident duration. Generally, the sensitivity of benefits to both parameters diminishes when both are very large.

As is to be expected, the further the incident location is from point ***A,*** the smaller the benefits are. This is shown in Figure 14. In other words, the further point C is from point ***A,*** the more traffic there is in between which cannot make use of information. The iso-benefit contours shown in Figure 15 illustrate the sensitivity of system benefits to the capacities of the two routes normalized by demand. The value of ATIS information declines as the freeway capacity is improved. Incident management using ATIS is an alternative to expensive capacity improvement projects for freeways. On the other hand, improving the capacity of the alternate route enhances the role of ATIS in incident

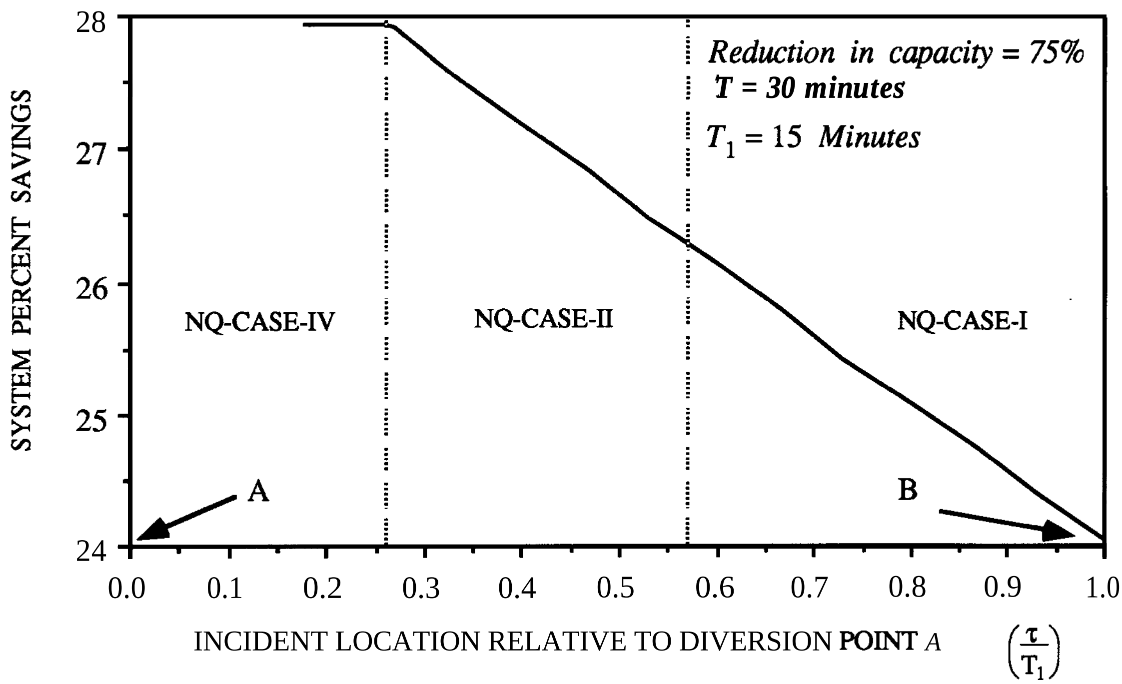


FIGURE 14 - SENSITIVITY OF SYSTEM BENEFITS TO THE INCIDENT LOCATION

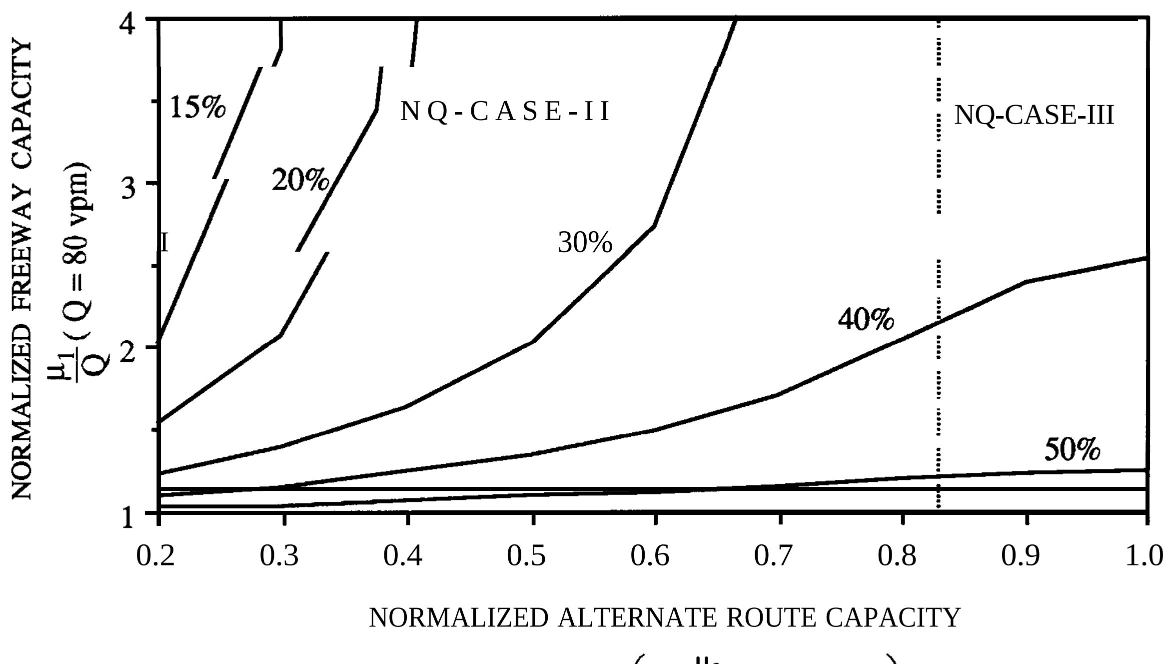


FIGURE 15 - ISO-BENEFIT CONTOURS - IMPROVEMENT IN ROUTE CAPACITIES -

management. Therefore, it may be said that ATIS is an alternative to expensive capacity improvement projects for freeways, but not to overall corridor capacity enhancement. The increase in corridor demand means a larger incident queue on the freeway and therefore an increase in potential savings from ATIS as shown in Figure 16. There is a certain level of demand below which there is no system gain from ATIS.

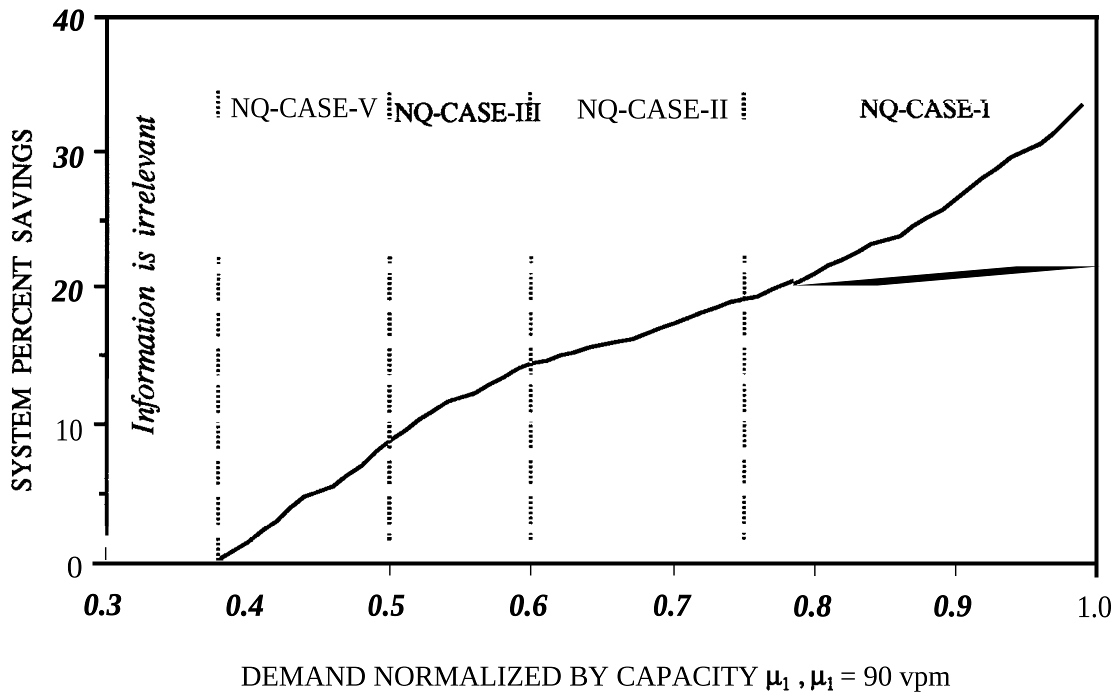
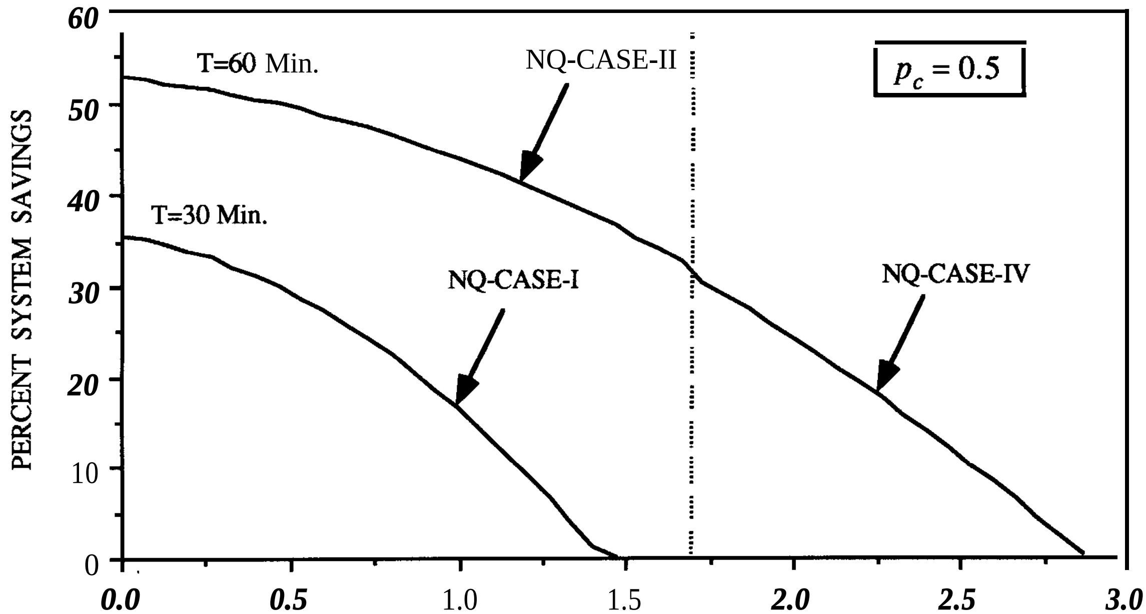


FIGURE 16 - SENSITIVITY OF SYSTEM BENEFITS TO CORRIDOR DEMAND

Finally, we look at sensitivity of the benefits to the difference between free flow travel times on the two routes, ***T*,*** as shown in Figure 17. There is an upper limit of ***T**** which defines relevance of ATIS information. When the alternate route is very long, it is as if it does not exist. When T^* decreases, diversion continues for a longer period of time and consequently diverted as well as undiverted traffic has a better chance to save time. Therefore, system benefits are expected to increase as ***T**** decreases and are maximized when the two routes are identical.



NORMALIZED T* , $\frac{T^*}{T_1}$ (T_1 = 15 MINUTES)

FIGURE 17 - SENSITIVITY OF SYSTEM BENEFITS TO T*

CONCLUSIONS

A deterministic queueing model is used to predict cases when ATIS is beneficial and cases when it is not beneficial, and to evaluate the benefits of ATIS. The model is applied to a simple road network with two parallel bottlenecks under an off-peak incident scenario. Different cases of queue evolution that can result when a user optimal strategy is implemented are described and benefits to guided/unguided traffic and to the system are analyzed.

It is found that once equilibrium is reached between alternate routes, the rate of diversion from one to the other has to be decreased to maintain it. The decreased rate is a function of capacities of the two routes. The implication is that during equilibrium some equipped travellers will be diverted to an alternate route while others will be asked to stay on the route where the incident has occurred.

It is also found that as long as the fraction of vehicles equipped with ATIS is below a critical value, p_c, then all equipped travellers can be diverted and all diverted travellers can still gain the maximum possible savings. In addition, diversion of all equipped vehicles will not increase travel times of the equipped vehicles using the alternate route when diversion occurs in this case. Since system benefits are also maximized at p_c, it is not recommended to divert more than p_c to the alternate route in all circumstances. This is reasonable as long as the market penetration of ATIS is below p_c. It is important to have an idea of how many units can be sold in a certain geographical area while savings are still guaranteed to be at maximum. It is also important to have a reasonable estimate of the parameter p_c so that traffic engineers can determine how to operate their system optimally under incidents without over-diverting traffic to city streets. The question then is how to find a reasonable estimate of p_c in real life urban networks. It was easy to answer this question in the simplified problem where p_c is equal to μ_2/Q. Fortunately, p_c does not depend on incident parameters but does depend on two corridor parameters, the capacity of the alternate route μ_2 and the travel demand in the corridor Q. In a real life corridor feasible alternate routes should be identified. It is not sufficient for an alternate route to be operationally feasible, but it also needs to be institutionally feasible. In testing a few real life corridors for this purpose, one may find that there are not that many routes that qualify. The capacity that is used in calculating p_c should be the total unused or available capacity of all the feasible alternate route(s). One of the tasks for an ATIS demonstration experiment is to find an empirical estimate of p_c. While it is not feasible to set up demonstration experiments in every corridor where the technology might be applied, a challenging task remains: to develop a methodology for estimating p_c from a base of simple queueing models such as the one used in this study and to extend it to large scale simulation models.

This study did not analyze incidents that occur during the peak period. During the peak period, the alternate routes are usually congested. If an incident occurs during the peak period and ATIS vehicles are diverted, they join the existing queues on the alternate routes. Therefore, system benefits during the peak conditions are reduced because of the disadvantage caused to travellers originally using the alternative routes where guided traffic is diverted. Thus, it can be concluded that system benefits under the off-peak conditions represent an upper limit for the benefits of en-route guidance. This suggests that ATIS en-route guidance is more useful in the management of off-peak incidents, when uncongested alternate routes are likely to be available. During the peak period, however, the alternate routes are usually congested, and consequently there is a need to spread traffic over time rather than space. This can be achieved through departure time switching rather than route switching. Here, the role of ATIS is thought to be more useful at home or before starting a trip rather than en-route. Pre-nip traffic information permits the most flexible decisions to trip makers. Travellers can switch routes, departure times, and possibly modes. This area is yet to be investigated and is an interesting subject for future research.

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