CHAPTER IV

PREDICTED AND CONSISTENT DYNAMIC MESSAGE SIGN STRATEGY

4.1 Introduction

The previous chapter explained the Dynamic User Class Model and some of its properties. This chapter presents one of the applications of the Dynamic User Class model in developing routing strategies for Dynamic Message Signs. Dynamic Message Signs (DMS) provide information to travelers about existing traffic conditions and incidents with various objectives including congestion reduction, incident management and route guidance. The effectiveness of dynamic message signs in achieving these objectives depends on the information strategies used. Some of the common information strategies used in research and in practice have been discussed in the literature review chapter. In order to address some of the limitations of the existing information strategies a Predicted, Consistent and Coordinated Dynamic Message Sign Strategy (PCDMS) has been proposed. In the PCDMS strategy, the following features have been addressed in providing information through Dynamic Message Signs:-

1. DMS provides information of a localized scope (referred to as the activation zone- the region from the DMS location to a fixed downstream point).
2. In the case of incidents, the users receiving information before the occurrence of the incident should not have knowledge of the incident, despite the use of predictive trip time information. This property is termed as consistency.
3. If both pre-trip and en-route information are provided, it would be desirable to coordinate the two sources of information to achieve better system performance, predictive ability, and information stability across the sources of information.

Consistency is extremely important for DMS as without consistency people starting before the occurrence of the incident are provided paths which are optimized for the occurrence of the incident. Hence users who start before the incident are assumed to have knowledge of the incident. Coordination is also essential when there are multiple information sources each of which have different scopes. Hawas and Mahmassani(1995) have found that when there are multiple information sources each providing information in its zone of influence without considering the presence of others, then the system performance deteriorates significantly under the no incident scenarios. The need for coordination between information dissemination sources is stressed upon by McDonald et. al.(1998).

The next section explains the three properties: prediction, coordination and consistency. The solution procedure for developing a Predicted, Consistent and Coordinated strategy for Dynamic Message Signs is then provided. Computational tests are conducted to study the impact of Prediction, Coordination and Consistency. The performance of the PCDMS is studied under various incident scenarios.

4.2 Background

The motivation behind this study is to address the consistency and coordination issues associated with predicted DMS under incidents in the presence of predicted pre-trip information.

4.2.1 Predicted versus Prevailing Information:

A common DMS information strategy, used in practice, provides prevailing information to drivers accessing the DMS information. In the prevailing information strategy, the information is provided based on the instantaneous/current travel time on all downstream links. The effectiveness of prevailing information is limited since it does not account for i) congestion due to user response to information (e.g. overreaction, (Ben Akiva, 1991)), and ii) future time-dependent loading and demand on downstream links. Predicted information, in contrast, recognizes that the demand and travel times on downstream links may be different from instantaneous/current travel times, and thus can reduce information-induced congestion and potential overreaction to information. A key shortcoming of prevailing information is its inability to account for difference in travel times from downstream links from currently prevailing trip times. However, even if prevailing information is frequently updated, its predictive ability can be poor since it does not forecast future traffic conditions and hence travel times on downstream links. Despite these limitations, the prevailing information is used as a practical benchmark in this study, since it can be computed easily and directly from ITS data, obviating the need for sophisticated algorithms.

4.2.2 Coordination between Pre-trip and DMS Information:

In this study, it is assumed that two sources of information are present – pre-trip and en-route, both providing information based on predicted travel times. The following argument illustrates the need to coordinate pre-trip and DMS information.

The DMS routing strategy is influenced by the arrival/loading pattern of vehicles at the DMS start node. The arrival pattern of vehicles, in turn, is affected by the pre-trip information and the resultant spatial distribution of vehicles on the network. Therefore, there is a need to account for the dependence of DMS information on the pre-trip information strategy. The DMS strategy also affects the pre-trip information, since the batch diversions at the DMS location can alter network traffic dynamics. This, in turn, changes the nature of least trip time paths recommended by pre-trip information. Consequently, predicted pre-trip information must explicitly recognize the influence of DMS information. In this study, DMS and pre-trip information are considered to be fully coordinated if the pre-trip information strategy accounts for the time-dependent network dynamics resulting from the DMS information and vice-versa.

This notion of coordination of DMS and pre-trip information is illustrated using some examples below. Suppose pre-trip information is based on pre-specified paths and DMS diversion is based on prevailing information, the two sources of information are not fully coordinated, since the 'pre-specified' pre-trip strategy does not account for DMS diversion policies. On the other hand, if both pre-trip information source and DMS provide prevailing information, then the two information strategies are naturally coordinated but only partially. In this case, pre-trip paths that passing through the vicinity of the DMS account for prevailing times on DMS links. However, prevailing DMS travel times do not fully account for the time-varying routing strategy recommended by pre-trip information. Note that this issue of coordination assumes importance when there are multiple sources of real-time information, each seeking to provide predicted information. In this context, several studies do not consider this issue of coordination given their focus on information from a single source (pre-trip or en-route information, Chiu et. al. 2001, Valdez-Diaz et. al., 2000).

Coordination is also particularly important given the fact that the DMS information is limited to a local area termed as the activation zone, as shown by the following example. A simple network is considered in this example, as illustrated in Figure 4.1 This network consists of four nodes s, 1, 2, t, and 4 links A (s to 1), B (1,2 on the highway), C(1,2 on alternative route), and D(2,t) and one O-D pair (s,t). Suppose that the travel times are time-dependent on this network and consist of two components (queue free components, and link turn penalties due to queuing). Assume that the queue free portion of the travel time on a link x, for a vehicle departing from the link's head at time k, is given as: $T_x(k)$, the turn-penalty in going from link x to link y for departure at time k from the tail of link x, is represented by $T_{xy}(k)$. Assume that pre-trip information is provided at the origin s and en-route information is provided through DMS at node 1 (for path from node 1 to node t).

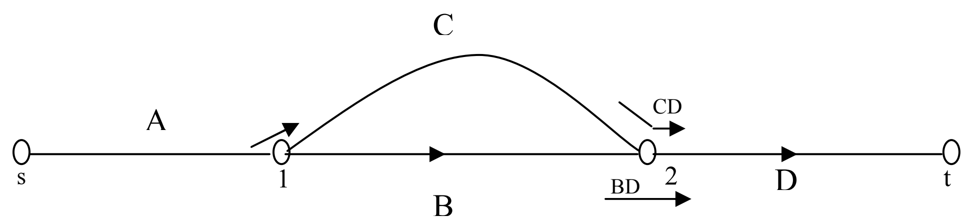

Fig 4.1: A small 4 link network .

In this figure, assume that the time-dependent link travel times are as follows:

$T_A(7{:}50)$ = 10 minutes	$T_C(8{:}00)$ = 5 minutes
$T_A(8{:}00)$ = 10 minutes	$T_B(8{:}00)$ = 8 minutes
$T_C(8{:}00)$ = 5 minutes	$T_D(8{:}10)$ = 4 minutes
$T_B(8{:}00)$ = 8 minutes	$T_D(8{:}08)$ = 8 minutes
$T_{CD}(8{:}05)$ = 3 minutes	$T_{BD}(8{:}08)$ = 2 minutes

Thus, $T_A(7{:}50)$ denotes the travel time experienced by a traveler on link A, departing from the starting node of link A(1) at 7:50 A.M, while $T_{CD}(8{:}05)$ refers to the time-dependent movement penalty (also in minutes) to turn from the link C to D at 8:05 A.M. There are two paths P_1 (A-B-D) and P_2(A-C-D) available for vehicles traveling from s to t on this network

The travel time on path P_1(A-B-D) = $T_A(7{:}50) + T_B(8{:}00) + T_{BD}(8{:}08) + T_D(8{:}10)$

$= 10 + 8 + 2 + 4 = 24$ minutes.

The travel time on paths P_2(A-C-D) = $T_A(7{:}50) + T_C(8{:}00) + T_{CD}(8{:}05) + T_D(8{:}08)$

$= 10 + 5 + 3 + 8 = 26$ minutes.

For vehicles that reach node 1 at 8:05 a. m., two sub-paths P_3(B-D) and P_4(C-D) are available. The travel times on these sub-paths are 8 and 5 minutes respectively.

Under these conditions, the least trip time path provided by pre-trip information corresponds to the path P_1(A-B-D). On the other hand, the shortest trip-time path en-route at node 1 (DMS location) corresponds to the sub-path P_4(C-D). This example underscores two important points:

1) the travel time on a sub-path (between the nodes 1 to t) corresponding to the optimal path from the origin to destination (s-t) may not be optimal as far as travel between nodes 1 and t are concerned.

2) if a user takes the optimal path (P_4) for the sub-path between 1 to t, there is no guarantee that the overall path from the origin to destination is optimal.

Assuming that the two information sources try to provide the least trip time path to the user corresponding to their network reach, the pre-trip information provides the shortest trip-time path from s to t and the en-route information source provides the shortest path from 1 to t. Note that for a given vehicle reaching the node 1 at a given time (e.g. 8:05 a.m. in this example), it is possible the pre-trip and DMS information recommend different paths, despite their objective of minimizing trip-time for the user.

The implications of this example for providing information through DMS in practice are two-fold: i) The DMS, in general, should not recommend a route which forms a part of the optimal time-dependent path (pre-trip) from s-t (even if it passes through the en-route location 1), since it could be sub-optimal with respect to the DMS objective (travel time from 1 to t), ii) It is reasonable for the DMS to provide guidance based on the shortest path corresponding to its local scope (1 to t) instead of the sub-path along the path (s-t) even if it passes through the DMS location. Providing routes based on the latter through the DMS is not desirable as it can result in lower compliance with the DMS information (due to sub-optimal path), and the fact that the pre-trip information was computed some time prior to the vehicle reaching the DMS.

Given their different objectives, the two sources would provide different sub-paths from 1 to t. Note that both sources of information are likely to affect the path choice of informed users. Consequently, the shortest pre-trip path (or associated trip times) from s to t given that a DMS is active may be different from the shortest path for the same O-D pair when the DMS is absent or inactive. In other words, a pre-trip shortest route solution that is computed without considering the presence and localized scope of the DMS information (shortest paths) is likely to be a sub-optimal pre-trip path (from s to t).

Therefore, each information source, while determining the routes as per its objectives, must explicitly recognize the presence and objectives of other information sources, and the resultant flows on the network. To further illustrate this idea, suppose that the pre-trip shortest paths are determined by solving a time-dependent user equilibrium assignment (in the absence of DMS). When the DMS is active, it is likely to divert some users in its localized scope (1 to t), thus changing the network flows from the equilibrium state. As a result, a new set of paths become optimal for pre-trip information, which results in a change in the network flows. This, in turn, changes the shortest DMS paths, and the iterative cycle continues until an equilibrium is reached between the flows on the network, and the shortest paths recommended by the DMS and pre-trip information are in mutual consonance.

When the flows and paths have converged to this state, the DMS and pre-trip information are referred to (in what follows) as being fully coordinated. In contrast, when the shortest paths and flows and resulting equilibrium as computed by one source (say the pre-trip information) completely disregards the presence of other sources, the resultant information strategy is referred to as an uncoordinated strategy. Note that when uncoordinated information is provided by pre-trip information (say by solving for a time-dependent equilibrium solution), then the resulting path flows are unlikely to be in equilibrium (paths are unlikely to be optimal) when the DMS is active, because of the lack of coordination. Coordination is therefore particularly important for compliance with information, and stability of network flows.

4.2.3 Consistency of Information:

While providing predicted information, it is also important to recognize and address the issue of information consistency with respect to unplanned non-recurrent and incident conditions. More specifically, predicted information must be 'consistent' with users' state of knowledge regarding the incident. Although, predicted information should be able to anticipate future network dynamics on the given day in general, it should not provide users with foreknowledge of the incident. In this paper, 'user having knowledge of the incident' means the paths provided to users correspond to the incident scenario and does not necessarily imply that the user is actually aware of the incident.

To illustrate, consider the following simple example. Suppose an unplanned incident occurs on an urban network between (8:00-8:30 a.m.) during the morning peak period (7:00-9:00

a.m). Consistency of predicted information implies the following information characteristics. If a user receives pre-trip or en-route information before the occurrence of incident, then this information should correspond to the no-incident scenario. Similarly, a user who receives information post-incident should receive predicted information that accounts for knowledge regarding the occurrence of the incident. Therefore, this information consistency aspect assumes importance in the context of: i) predicted information and ii) occurrence of unplanned incidents.

One popular predicted information strategy is the time-dependent user equilibrium(TDUE) solution in which the vehicles between a particular origin-destination pair at a specified departure time are provided with paths that are equal and minimal. Note that if predicted information strategy is provided based on the time-dependent user equilibrium (TDUE) solution, then this information will be inconsistent as the users starting before the incident are provided paths which correspond to the incident scenario. In the TDUE, all users (even those starting before the incident) are assumed to be aware of the incident. Consequently, this information strategy is not consistent with informed user's state of knowledge in the real-world, where some informed users will be aware of the incident and other informed users will not be aware of the incident. A potential alternate approach to address the stated consistency issue is to use the Rolling Horizon approach, in which the incident information is not known in the stages prior to incident start time. The incident is realized in stages starting after the incident start time. This Rolling Horizon approach is equivalent in the sense that it tries to capture the consistency aspect. However, the RH approach is different from the DUC in two respects: a) the optimality/equilibrium conditions are not guaranteed (Peeta et. al., 1995), and b) it is computationally more cumbersome (Peeta et., 2001).

We clarify that this notion of consistency is different from others used in the ATIS literature (for e.g. Bottom et al., 1999, discuss consistency between reported and experienced trip time, whereas, Ben Akiva et al., 2001, highlight consistency between simulation performance metrics and observed real-world flows). It is also noteworthy that the issue of consistency discussed here is of relevance in the context of incidents and predicted information, whereas, the issue of coordination may arise even under recurrent congestion.

To account for predicted, consistent and coordinated DMS information under incident scenarios, a Predicted and Consistent DMS strategy (PCDMS) is proposed and implemented by solving a two-stage Dynamic User Class assignment problem as discussed in the next section.

4.3 Solution Procedure

For the sake of illustration of the algorithm, we consider that there is only one DMS and one incident on the network on a given day. The arguments may be generalized to the cases of multiple DMS and multiple incidents in a straight-forward manner, but at considerable notational expense and increase in the number of solution stages. The PCDMS information strategy provides predicted, consistent and coordinated information at pre-trip and en-route (through DMS). To provide predicted information, both pre-trip and DMS strategies are based on time-dependent shortest paths which recognize that travel times on downstream links vary from the current travel time. The pre-trip information provides this information corresponding to each user's origin (say VehOrig) and destination (say VehDest), whereas, the en-route DMS provides the time-dependent shortest path between the DMS origin (say DMSO) and DMS destination node (say DMST). These time-dependent shortest-paths are computed subject to the network dynamics between multiple and dynamic user classes, in a manner that accounts for coordination and consistency, as described below. The following user classes are defined for the analysis conducted:

(i) User Class 1a: These vehicles depart from their origin before the incident occurrence and receive pre-trip information corresponding to the no incident scenario. In addition, the routes of vehicles belonging to this class do not pass through the DMS and hence they do not receive DMS information.

(ii) User Class 1b: The vehicles belonging to user class 1b receives pre-trip and DMS information corresponding to the no incident scenario. The initial routes provided to class 1b vehicles through pre-trip information pass through the DMS. Vehicles belonging to user class 1b start from their origin and arrive at the DMS before the incident occurrs and receive information corresponding to the no incident scenario.

(iii) User class 2a: Vehicles belonging to class 2a, depart from their origins after the occurrence of the incident and their initial routes do not pass through the DMS. These vehicles receive pre-trip information corresponding to the incident scenario and do not receive DMS information.

(iv) User class 2b: Vehicles belonging to class 2b, depart from their origin after the occurrence of the incident and their initial routes pass through the DMS. These vehicles arrive at the DMS after the occurrence of the incident. These vehicles receive both pre-trip and en-route information corresponding to the incident scenario.

(v) User class 2c: Vehicles belonging to this class start from the origin before the occurrence of the incident and reach the DMS after the occurrence of incident. Users belonging to this class receive pre-trip information corresponding to the no incident scenario and DMS information corresponding to the incident scenario.

Note that the information class to which a given vehicle belongs depends on the initial path chosen and the time of arrival at the DMS. The initial route chosen and the arrival time at the DMS, in turn, depend on the travel time and congestion on network links. As a result, different users will in general belong to different information classes, depending on the network dynamics.

4.3.1 Coordination

To model coordination for the no incident scenario, users are divided into two main classes: class P(receive pre-trip information only) and class R(receive pre-trip and en-route information. Note that class P consists of information Classes 1a and 2a above, and class R consists of information classes (1b, 2b, and 2c).

To ensure coordination between pre-trip and DMS information, the DMS information provides the time-dependent shortest paths between DMSO and DMST, given the network level dynamics due to the pre-trip information and vice-versa. The DMS information provides time dependent shortest path between DMSO and DMST given that the pre-trip information source provides time dependent shortest path between the various network level origins and destination. Similarly the pre-trip information assigns vehicles to time-dependent shortest paths between the user origin and destination taking into account the fact that the DMS assigns vehicles to time dependent shortest paths between DMSO and DMST. An algorithm to solve for coordination is provided in section 3.4 in the previous chapter. In the algorithm for users belonging to class P, retain their pre-trip shortest paths from their origin to destination. Users belonging to class R, traverse the pre-trip shortest path from their origin to DMSO and from DMST to their destination. Between DMSO and DMST they travel along the en-route shortest path from DMSO to DMST.

4.3.2 Consistency

To model consistency, information provided to users before the occurrence of the incident should reflect lack of knowledge about the incident. The paths provided to user's either pre-trip or en-route should be for the no incident scenario. To model this scenario, all the five user classes defined in section 4.3 – 1a, 1b, 2a, 2b and 2c are considered. As per consistency constraints, vehicles from user class 1a, 1b should not have knowledge of the incident (i.e. the paths provided to user class 1 should not take into account the occurrence of the incident).

On the other hand users from class 2a, 2b and 2c will be aware of the incident. Here awareness of incident implies that their paths (pre-trip and/or en-route) are reflective of the incident induced dynamics. Consequently, for user class two, the ATIS information (time-dependent paths provided) reflects i) knowledge of the incident, and ii) the network dynamics which results from the routing decisions of user class 1 above.

An informed user can belong to class one or two depending on the time of arrival at the DMS. The route choice of user class 2a, 2b and 2c depends on the route decisions made by user class 1a and 1b. The travel times on routes followed by user class 1a, 1b depend on the route choice of user class 2a, 2b and 2c. Since these user classes are dynamic, these dynamic interactions cannot be adequately modeled using standard multiple user class equilibrium models, where the user classes are static and exogenously defined. To account for these dynamic interactions, a two stage dynamic user class equilibrium model is proposed as follows. In stage one (referred to as the Dynamic User Class (DUC-1) sub problem), the pre-trip and en-route information strategy for user class one are obtained by solving a time-dependent user equilibrium problem with a coordination constraint (explained below) for the no incident scenario. In stage two (referred to as the Dynamic User Class (DUC-2) sub problem), a dynamic multiple user class equilibrium model is solved for the incident scenario to obtain the pre-trip and en-route information strategies for user class two given the routing decisions of user class one.

4.3.2.1 Algorithm

As explained in the previous section, coordination is achieved by solving the Dynamic User Class problem in two stages. An algorithm to solve for consistency is given in this section.

Stage 1: Solve the coordinated Dynamic User Class problem for the no incident scenario using the algorithm provided in section 3.4. In the descent direction finding step of the algorithm, if the time-dependent shortest path between any origin destination pair is found to pass through DMSO and DMST, then the sub-path of the original path between DMSO and DMST is replaced by the time-dependent shortest path between DMSO and DMST. Store the DMS and pre-trip paths computed for the no incident scenario.

Stage 2: Solve the coordinated Dynamic User Class problem for the incident scenario by assuming the 5 user classes which were defined in previous sections. It is assumed that all users are perfectly compliant with information (this assumption is relaxed later in this chapter). The DUC-2 sub-problem then solves for a time-dependent equilibrium between the user classes such that no user from classes (2a, 2b, and 2c) can improve their travel times by unilaterally switching routes while following the class route choice rules stated above. Note that the use of two-stages ensures consistency as the class one users are unaware of future incident occurrence.

The two advantages of this formulation in practice which could enable improved system performance compared to the prevailing and a priori TDUE strategy include :1) First,the vehicles which may depart pre-trip prior to incident occurrence, will be re-optimized at least locally at the DMS. 2)Further, users receiving pre-trip information after the occurrence of incident can benefit not only by the use of predicted information after the incident has occured, but can also reduce the loading pattern(vehicle arrivals) at the DMS through pre-trip information. This coordination can lead to reduction in overreaction and overconcentration problems. The overall solution from the PCDMS algorithm gives a solution close to a time-dependent equilibrium across the dynamic user classes. Given the complex time varying non linear dynamics existing in the system it is difficult to guarantee the existence of such an equilibrium. However in the empirical studies conducted here, convergence was always observed.

4.4 Experimental Design

In order to empirically study the performance of the proposed strategy computational experiments were conducted using DYNASMART - a dynamic traffic network assignment tool developed at University of Texas at Austin.

4.4.1 Simulation Model

These experiments are conducted using a mesoscopic dynamic simulation model, DYNASMART, developed at the University of Texas, Austin (Jayakrishnan,1994). This dynamic network assignment simulation model consists of the following components: traffic flow model, path processing algorithm, driver behavior model, and information supply model. This traffic simulation model moves individual vehicles on network links according to prevailing traffic theoretic relationships (e.g., Greenshield's model) and yields time-dependent traffic performance measures (trip times, densities, flows). This model captures within-day dynamic traffic features such as signal delays, queue formation, dissipation, and spillbacks. The resultant network congestion and supply conditions, in turn, influence user decisions (within-day) by affecting users' travel experience (congestion, travel time). User decisions and supply conditions, in turn, trigger changes in the information provided to drivers.

4.4.2 Network Structure

The traffic network chosen for the study is a part of the urban traffic network for the Fort Worth area in Dallas (refer Figure 4.2). The traffic network consists of 180 nodes and 440 links. Vehicles are loaded on to the network using time-dependent O-D trip desires and vehicle path files. The central corridor on the network connecting nodes 116 and 117 represents the freeway (IH 35).The DMS was assumed to be located on the freeway (link connecting node 41 to node 37).

4.4.3 Experimental Factors and Levels

This section gives an overview of the experimental runs conducted and their objectives.

(i) Impact of Prediction: In order to quantify the benefits of prediction, the performance of prevailing pre-trip and DMS strategy was compared against the performance of the two predicted strategies- TDUE and PCDMS under incident scenario and no incident scenarios. The incident attributes were fixed at the levels given below -two incident locations (freeway and arterial), incident start time (peak time), long incident duration and high incident severity.

(ii) Impact of Coordination: To determine the impact of coordination, the system performance under the TDUE strategy was compared against the system performance under coordinated but not consistent strategy. In the coordinated but not consistent strategy, the information provided to all users, through DMS and pre-trip correspond to the incident scenario. Hence all users are assumed to have foreknowledge of incident. The system performance was compared for the incident and no incident scenario. Under the incident scenario, the following attributes were assumed for the incident: locations (freeway and arterial), incident start time (peak time), long incident duration and high incident severity. Market penetration refers to the number of people who have access to pre-trip information devices. Two levels of market penetration were considered in this analysis: low and high. Under low market penetration, 40 % of the people had access to pre-trip information devices. Under high market penetration, all the users had access to pre-trip information. Compliance levels refers to the number of people who comply with the DMS information. Two different compliance levels were considered: low and high.15 % and 100 % of the users comply with the DMS information under low and high compliance levels respectively. The tests were conducted for moderate and high congestion levels.

(iii) Impact of Consistency: To determine the impact of consistency alone, the system performance under the TDUE strategy (neither consistent nor coordinated) was compared against the performance of the consistent but uncoordinated strategy. To implement the consistent but uncoordinated strategy, the pre-trip information strategy is solved in two stages. In the first stage, the pre-trip information for the no-incident scenario is calculated. In the second stage, the information strategy for the incident scenario is calculated. To ensure consistency in the second stage, the vehicles which depart before the incident occurrence are provided with paths corresponding to the no incident scenario obtained from stage 1. As there is no DMS, this strategy is not coordinated. The tests were conducted for low and high market penetration and compliance levels. High and moderate congestion levels were considered.

(iv) Impact of Coordination and Consistency: To determine the impact of coordination and consistency on the system performance, the performance of the PCDMS (both consistent and coordinated) was compared against the performance of a TDUE (neither consistent nor coordinated) strategy. The incident was assumed to be located on the freeway. Two different compliance and market penetration levels were considered – low and high. The system performance under moderate and high congestion levels was compared.

(v) Impact of DMS: In this experiment, the additional value of en-route information through DMS is compared when pre-trip information is provided to all users. This analysis is performed for two scenarios: no incident scenario and incident scenario. In order to compare the impact of pre-trip information over pre-trip and en-route information strategy, the system performance under PCDMS strategy was compared with the system performance under consistent pre-trip strategy. In the consistent pre-trip strategy, vehicles starting before the incident receive pre-trip information corresponding to the no incident scenario and the vehicles starting after the incident receive pre-trip information corresponding to the incident scenario. The system performance under low compliance, low market penetration and high compliance, high market penetration were studied.

(vi) Impact of Incident Scenarios:The performance of the PCDMS strategy is compared to the prevailing strategy and the a priori TDUE solution under several incident scenarios. The various incident scenarios are obtained by varying the following four attributes of the incident- location, start time, duration and incident severity. The experimental levels chosen for the various attributes are: 1) incident location –freeway, busy arterial located near the DMS and remote and uncongested arterial, 2) incident start time – early peak, peak, late peak and post peak loading profile,3) incident duration – short, medium and long clearance times, and 4) incident severity – blockage of one lane, two lanes and four lanes. The default value for the incident attributes are 1) freeway for incident location,2) incident start time corresponding to peak loading profile 3)long incident clearance time, and 4) incident severity corresponding to blockage of four lanes. While varying each attribute, the other attributes are held fixed at their default values.

The performance metrics used in analyzing the results was the average system travel time and/or relative to a benchmark information strategy (e.g. prevailing information) specified in each experiment.

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4.5 Computational Tests

Two main sets of computational tests were conducted using DYNASMART for the scenarios mentioned above and the results and insights are presented below. In the first set of tests (sections 4.5.1-4.5.5), the impact of prediction, coordination, consistency, coordination and consistency, and DMS information are empirically quantified. In the second set of computational experiments (sections 4.5.6), the performance of the system under PCDMS information strategy is compared with the performance of alternative strategies under a number of incident scenarios.

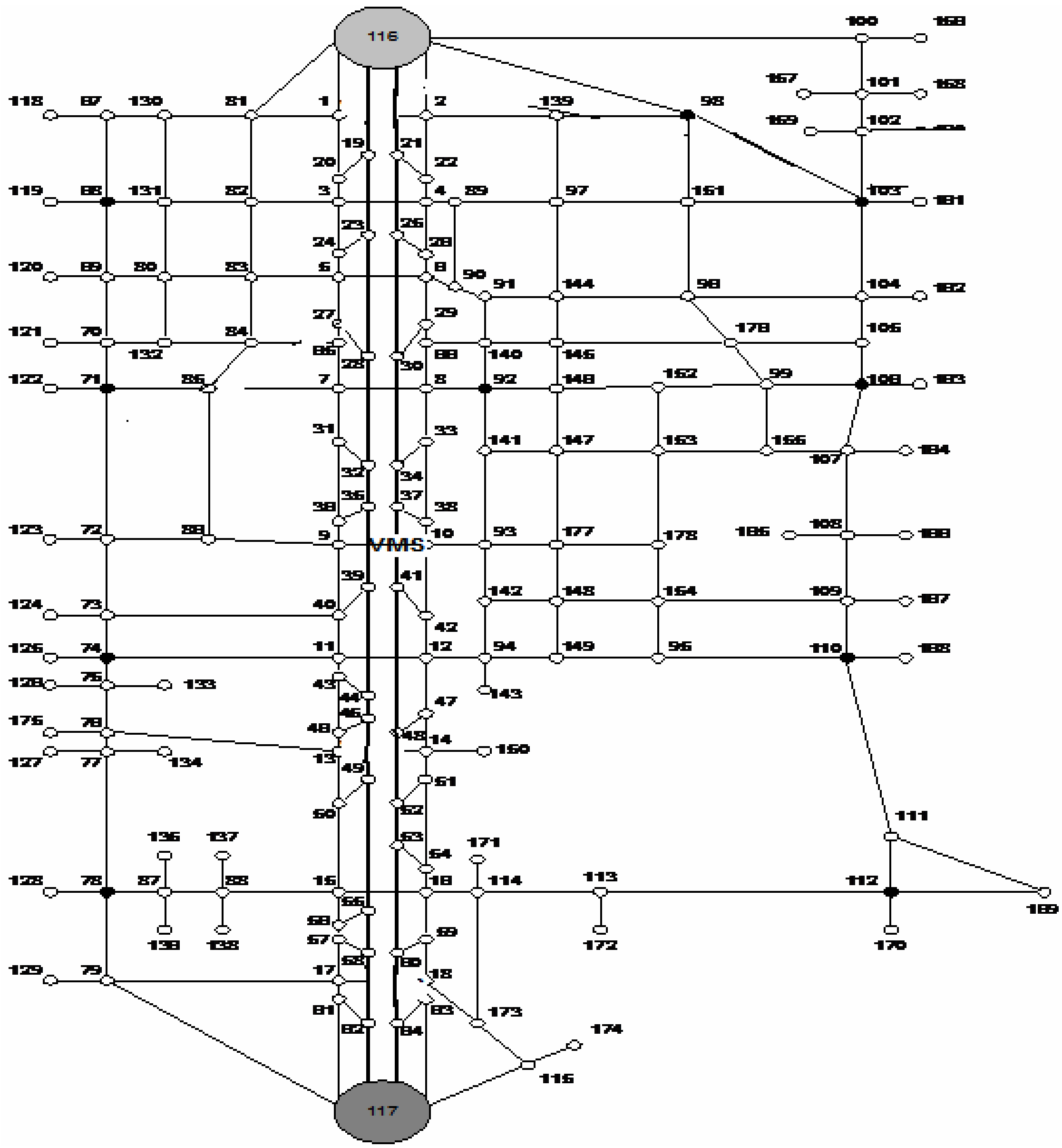

Fig 4.2: Fort Worth Network -Dallas

4.5.1 Impact of Prediction

The use of predicted information provides significant system improvements over prevailing information under all scenarios. Travel-time saving of up to 26.75 % was observed under predicted information over prevailing under the incident scenario and a 21 % improvement over prevailing strategy was seen under the no incident scenario. Predicted information provides a greater ability to redistribute vehicles as the future travel times and demand is anticipated and globally optimized. The PCDMS strategy offered greater trip time savings relative to the TDUE strategy under the incident scenario, than under the no-incident scenario.

Table 4.1: Impact of Prediction on Freeway and Arterial Travel Time

	Predicted Strategies		Prevailing strategy travel time (in mins)	Prediction Savings*	
	PCDMS strategy travel time (in mins)	TDUE strategy travel time (in mins)		PCDMS (%)	TDUE (%)
Arterial Inc	18.26	19.83	24.20	24.55	18.06
Freeway Inc	18.76	20.52	25.61	26.75	19.88
No Inci	17.92	17.98	22.73	21.18	20.91

Note: * refers to travel time savings over prevailing strategy.

4.5.2 Impact of Coordination

Coordination has a significant impact on the system performance under high congestion. Coordination is found to yield significant benefits over TDUE strategy under high compliance and high market penetration compared to the low compliance and low market penetration case. This is expected because the impact of coordination will be high only when users have to access to pre-trip information and comply with the en-route information devices. Also in this case, the benefits accrued are due to the favorable diversion pattern of the DMS. Higher densities are observed on alternate routes. When compliance with the DMS information is low and if many people do not have access to pre-trip information, then the impact of coordination is found to decrease under high congestion. The positive impact of coordination is higher under high congestion scenario than under low congestion scenario, when the compliance and market penetration levels are higher.

Table 4.2: Impact of Coordination (Moderate Congestion) on Average System Travel Time

Compliance	Market Penetration	Incident	Coordinated strategy travel time (in mins)	TDUE strategy travel time(in mins)	% savings*
Low	Low	One incident	14.88	14.96	0.53
		No incident	13.92	15.12	7.94
High	High	One incident	14.36	14.77	2.78
		No incident	12.96	12.96	0.00

Table 4.3: Impact of Coordination (High Congestion) on Average System Travel Time

Compliance	Market Penetration	Incident	Coordinated strategy travel time (in mins)	TDUE strategy travel time (in mins)	% savings*
Low	Low	One incident	26.26	19.94	-31.77
		No incident	19.90	18.17	-9.54
High	High	One incident	19.32	20.52	5.85
		No incident	17.92	17.98	0.33

Note:-* refers to travel time savings over TDUE

4.5.3 Impact of Consistency alone

When information is consistent, vehicles that leave before the incident have no knowledge of the incident. Consequently, their paths which correspond to the no incident scenario, may be seriously sub-optimal once an incident occurs. In contrast, in the TDUE strategy, the paths of all vehicles are optimized for the presence of incident (s). Therefore, one might expect that imposing consistency constraints can lead to an increase in system travel time compared to the TDUE strategy. Surprisingly, however, when all the users have access to pre-trip information, the system performance actually improves when information is consistent compared to the TDUE strategy (up to 9 %), when the incident occurs on the freeway. Consistent strategy is found to perform significantly better than the TDUE under high compliance and market penetration. However under low compliance and market penetration the benefits of congestion are found to decrease. Similar trends are observed under high and low congestion. Further disaggregate analysis of network dynamics revealed that this improvement was due to the following reasons: i) consistency did induce congestion at incident location and the upstream links, and ii) however, this local congestion lead to a time-dependent diversion of vehicles away from the predominantly congested arterials on the east west corridor, thus resulting in an overall decrease in system travel time. This finding is interesting because of the following practical insight. The result provides evidence that with two user classes (segmented based on their knowledge of incident), each following user-equilibrium based assignment strategies, the overall system performance can actually be better than a time-dependent User Equilibrium solution. Hence, under moderate congestion, consistency under freeway incident improves the system performance.

Table 4.4 : Impact of Consistency (Moderate Congestion) on Network Performance

Compliance	Market Penetration	Incident	Consistent strategy travel time (in mins)	TDUE strategy travel time (in mins)	% savings
Low	Low	Freeway	15.50	14.96	-3.60
High	High	Freeway	13.79	14.77	6.64

Table 4.5: Impact of Consistency (High Congestion) on Network Performance

Compliance	Market Penetration	Incident	Consistent strategy travel time (in mins)	TDUE strategy travel time (in mins)	% savings
Low	Low	Freeway	19.88	19.94	0.33
High	High	Freeway	18.69	20.52	8.92

4.5.4 Impact of Coordination and Consistency

The PCDMS strategy is found to significantly improve the system performance (up to 8.5 %) over the a priori TDUE strategy. The benefit of the PCDMS strategy is found to be higher under high market penetration and compliance levels. Due to consistency, vehicles which start before the incident do not have knowledge of the incident. As many vehicles are unaware of the presence of the incident, vehicles for whom the incident link is a part of the normal commute route travel along the same route. As the incident results in reduced capacity in their normal routes, there is queue formation on the incident link and the downstream link. However, routing of vehicles on paths corresponding to the no incident scenario results in decreased congestion along the east west corridor, thus improving the system performance. The DMS diversion also makes sure that the queue formation on the incident link is under check. Table 4 shows the impact of the interaction between coordination and consistency on system performance. The impact of the interaction between coordination and consistency is calculated by subtracting the benefit of pure coordination and the benefit of pure consistency from the benefit of coordination and consistency. Under moderate congestion, the interaction between coordination and consistency has no impact on system performance under low compliance and market penetration and a negative impact on system performance under high compliance and market penetration. However when the congestion levels are high, significant benefits are observed due to the interaction between coordination and consistency under low compliance and low market penetration.

Hence the interaction between coordination and consistency is found to have a negative impact on system performance under higher compliance and market penetration levels. However, the dis-benefit of interaction can be offset by the benefits of pure coordination and pure consistency as observed in the previous sections. The results also provides a strong argument in favor of the use of local control through information and/or control devices to alleviate network level congestion, and corroborates similar findings (Levinson, 2002) in the context of usage of DMS for variable speed limits.

Table 4.6: Impact of Consistency and Coordination on Network Performance

Compliance	Market Penetration	Congestion	PCDMS strategy traveltime (in mins)	Coordination strategy travel time (in mins)	Consistency strategy travel time(in mins)	TDUE strategy travel time (in mins)	Interaction (in mins)
Low	Low	Moderate	14.50	14.88(0.53)	15.50(-3.6)	14.96	-0.00(0.0)
		High	21.30	26.28(-31.77)	19.88(0.33)	19.94	-4.92(24.6)
High	High	Moderate	13.97	14.36(2.78)	13.79(6.64)	14.77	0.59(-4.0)
		High	18.76	19.32(5.85)	18.69(8.92)	20.52	1.27(-6.1)

Note- the term in parenthesis denotes the travel time savings over TDUE

4.5.5 Effect of pre-trip versus pre-trip and en-route information

Under low compliance and market penetration, the travel time performance is improved when information is provided using both sources. Pre-trip and en-route strategy is found to perform significantly better than the pre-trip only strategy for all the scenarios under low market penetration and low compliance. This can be attributed to the fact that the DMS locally reoptimizes the paths that have been provided through pre-trip information. This phenomena can be confirmed by the higher densities observed on the alternate paths of the DMS. The presence of DMS information is found to yield significant benefits under the no incident scenario than under the incident scenario. The presence of DMS is found to significantly improve the system performance under low market penetration (up to 8%) than when the market penetration is high. This is because under low market penetration majority of the people do not have access to pre-trip information. The DMS optimizes the path of these users locally and significantly reduces the system travel time. However under high market penetration, all the users have access to predicted pre-trip information. When all the users have access to predicted pre-trip information the impact of DMS is not significant. Hence the DMS is found to have a significant impact on system performance when majority of users do not have access to pre-trip information.

Table 4.7: Comparison of pre-trip vs pre-trip and en-route

	Incident	Pre-trip and en-route (in mins)	Pre-Trip alone (in mins)	% Savings
Low Comp/ Low market Penetration	Freeway	14.51	15.50	6.41
	Arterial	13.79	14.07	1.99
	No Inci	13.92	15.12	7.94
High Comp/ High market	Freeway	13.97	13.79	-1.31
	Arterial	14.77	14.07	-4.98
	No Inci	12.95	12.95	0.00

4.5.6 Role of Incident Attributes on System Performance

The three strategies were compared for the scenarios mentioned in the previous sections under low compliance and with low market penetration. The following general trends were observed in system performance for the various incident scenarios. 1) The system performance under PCDMS improves with increasing delay in incident start time. 2) The system performance under PCDMS worsens with increasing incident duration and severity. 3) Predicted strategies yield significant benefits over prevailing strategies with benefits ranging from 7% to 22 %.

PCDMS is found to significantly outperform the TDUE and the prevailing strategy for various incident locations. Under PCDMS, the worst system performance is observed when the incident occurs on the freeway. Even though more vehicles are affected by the incident when the incident occurs on the arterial, the holding of vehicles due to the incident is found to significantly reduce the congestion along the east west corridor. Hence due to the positive effect of consistency, maximum benefit of PCDMS over TDUE (11 %) is observed when the incident occurs on the arterial. The benefit of PCDMS over TDUE is observed to be minimal (around 1.5 %) when the incident occurs on the remote arterial away from the zone of the influence of the DMS. Similar trends are observed under the prevailing information strategy also. Maximum benefits by PCDMS over TDUE, are observed when the incident occurs near the zone of influence of the DMS.

Table 4.8: Impact of Incident location on travel time performance of Alternative Information Strategies

	PCDMS strategy travel time(in mins)	TDUE strategy travel time (in mins)	Prevailing strategy travel time (in mins)
Freeway	14.51	14.96	17.77
Arterial	13.79	15.49	15.90
Remote	13.59	13.83	15.81

The PCDMS strategy out performs the TDUE for various incident start times with maximum benefit being observed for peak incident start time. As the incident start time is delayed the performance of the system is found to improve. This can be attributed to the fact that as the incident start time is delayed lesser number of vehicles are affected by the incident. The system performance under PCDMS is found to worsen with increasing incident duration. This is expected as the number of vehicles being affected by the incident increases with increase in incident duration. The system performance under PCDMS is found to be better than the system performance under TDUE with maximum benefit being observed at moderate incident duration. As the incident severity increases, the benefit of using PCDMS over TDUE increases with maximum benefit being observed at higher incident severities. This can be attributed to the fact that the benefit of coordination and consistency is higher when the impact of incident increases. For all the incident scenarios considered, the PCDMS is found to significantly outperform the TDUE strategy. The benefit is found to increase when the impact of the incident increases (when greater number of users is affected by the incident).

Table 4.9: Impact of Incident Start Time on travel time performance of Alternative Information Strategies

	PCDMS strategy Travel time (in mins)	TDUE strategy Travel time (in mins)	Prevailing strategy Travel time (in mins)
Early Peak	15.85	15.44	17.04
Peak	14.61	15.53	18.96
Late Peak	14.51	14.96	17.77
Post Peak	14.45	14.72	17.17

Table 4.10: Impact of Incident Duration on travel time performance of Alternative Information Strategies

	PCDMS strategy travel time in min	TDUE strategy travel time(in min)	Prevailing strategy travel time(in min)
Freeway	14.509	14.964	17.766
Arterial	13.793	15.485	15.903
Remote	13.594	13.829	15.812

Table 4.11: Impact of Incident Severity on travel time performance of Alternative Information Strategies.

	PCDMS strategy travel time(in mins)	TDUE strategy travel time(in mins)	Prevailing strategy travel time (in mins)
1 lane	13.53	13.63	15.94
2 lane	13.45	13.91	15.95
3 lane	13.51	14.21	16.75
4 lane	14.51	14.96	17.77

4.6 Assumptions

The simulation based network assignment model - DYNASMART assumes perfect a priori knowledge of the origin-destination demands. It is also assumed that current conditions can be perfectly known without error or lag. Further detailed calibration studies using real world data must be conducted before implementing this strategy in any real world network. Despite these assumptions, the new strategy provides significant benefits over the prevailing strategy over a wide variety of real world scenarios. The results indicate significant promise in implementing PCDMS strategy in other real world networks also. The tests are conducted for one en-route information source (one DMS) alone. The framework presented in chapter 3 and the implementation methodology in this chapter can also be extended for multiple en-route information sources also.

4.7 Summary of Results

Significant benefits are observed when DMS information is provided when the market penetration of pre-trip information devices is low. Therefore there is significant scope for improving system performance using DMS alone. The benefit of using PCDMS over TDUE information is found to be significant under higher compliance and market penetration levels. The benefit is found to improve with increasing incident impact. Pure coordination is found to yield significant benefits under higher congestion levels under high compliance and market penetration levels (table 4.2). The location of incident is found to have significant impact on the performance of PCDMS. The results indicate that the relative benefits of the PCDMS over the TDUE strategy varies with spatial characteristics of the incident. This corroborates the earlier finding that the benefit of PCDMS increases with increase in the number of people being affected by the incident. This can be attributed to the positive impact of consistency. The system performance improves when the incident start times are staggered away (to the right) from the peak of the loading pattern. The system performance under PCDMS worsens with increasing incident duration and severity. This study suggests that the PCDMS can lead to significant travel time savings (up to 8%) over TDUE strategies, which may translate into substantial cost savings on a large network over a period of time. The use of PCDMS information strategy may also be practically useful in emergency evacuation and incident management contexts.

This work proposes an algorithm for consistent, coordinated and predicted DMS information for a fixed DMS source and sink. This study can be generalized to find optimal location of DMS. The DMS location problem is formulated as a bilevel problem in which the upper level contains a tabu list of DMS locations. The lower level evaluates the DMS location problem by finding the travel times under different incident scenarios. The PCDMS information strategy proposed above can be embedded in the lower level problem and used to evaluate the locations of DMS contained in the tabu list.