Motorist Information Systems and Recurrent Traffic Congestion: Sensitivity Analysis of Expected Results

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Urban traffic flows have increased dramatically in recent years, causing alarmingly high levels of congestion. A widely held belief is that the construction of new facilities alone will be unable to alleviate this congestion. In this context, motorist information systems based on modern information technology may play an important role in reducing traffic congestion and improving traffic flows and safety. A methodology that is based on a stochastic traffic assignment model is proposed for assessing the effectiveness of motorist information systems in reducing recurrent traffic congestion and for examining the interactions among important parameters of the problem such as level and amount of information provided, percentage of users and access to information, and congestion levels. The methodology is applied to a small suburban network.

Urban traffic flows have increased dramatically in recent years, causing alarmingly high levels of congestion. In 1985, 61 percent of rush-hour traffic on urban Interstates was rated as congested compared with 40 percent in 1975. The number of cars owned in the United States tripled between 1960 and 1986 and the total annual vehicle-miles increased from 719 to 1,861 billion in the same period. A widely held belief is that the construction of new facilities alone will be unable to alleviate this congestion. Therefore, planners are looking to improve the use of existing facilities with improved traffic management schemes.

Various authors, such as Jeffery (*1,2*) and Kobayashi (*3*), indicate that a certain percentage of urban trips are poorly designed and result in unnecessary delays. Hence, the potential exists to improve traffic conditions on urban and freeway networks by using information technology. Better use of existing facilities may be realized by providing information to motorists with respect to alternative paths to their destinations and actual traffic conditions on links of interest using a combination of sideways signals and on-board systems. In this context, motorist information systems that are based on modern information technology may play an important role in reducing traffic congestion and improving traffic flows and safety.

Various methods exist for relaying information to users, each with substantially different technical requirements, implementation costs, complexity, and capabilities in providing information. Examples of motorist information systems include pretrip information systems, roadside displays, traffic information broadcasting systems, and electronic route guidance systems. The Bureau of Public Roads (BPR) of the U.S. Department of Transportation is credited with the first attempt at developing a comprehensive electronic route guidance system in 1967 (*4*). The project, which terminated prematurely in 1970, concluded that systems that provide real time traffic information are promising, but more research is needed to overcome significant challenges in hardware and software.

However, the past few years has been a period of advancement and development in computer, communications, and general information technology. Main characteristics of these technological advances are reduced costs (capital and operating) and increased capabilities making possible efficient collecting and processing of large amounts of data for detailed and sophisticated analysis and control. These advances in information technology, along with the pressures arising from increased congestion, have spurred renewed interest in motorist information systems. Various projects (AUTOGUIDE in England, ALI-SCOUT in Germany, AMTICS in Japan, and PATHFINDER in the United States) demonstrating the feasibility of these systems are currently under way.

The hypothesis of the research presented is that provision of information to motorists can reduce traffic congestion, but that there are diminishing marginal returns as more information is provided. In testing this hypothesis, interactions among various important parameters of the problem are examined. These interactions are important because understanding the interactions among parameters will help determine the most appropriate hardware configuration for obtaining and transmitting information and the identification of conditions under which motorist information systems may be most effective.

RELATED STUDIES

Kobayashi (*3*) presents some results from a feasibility study of the comprehensive automobile traffic control system (CACS) project. He developed a simulation model to examine the effectiveness of alternative guidance methods and applied the model using data from a pilot area in Tokyo. Factors such as road length, number of lanes, and number of left and right turns were assumed to be the most important attributes that

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affect route choice for unguided vehicles, whereas shortest-path criteria were used for route selection by the guided vehicles. The results indicate that total travel time in Tokyo, with the introduction of motorist information systems, could be reduced by 6 percent and fuel consumption by 5 percent.

Jeffery (*1*), on the basis of an analysis of times and distances involved in a sample of journeys made in the United Kingdom, suggests that about 2 percent of all driver journey costs, in principle, could be recovered by an efficient route guidance system on the basis of historical information (journey costs include fuel costs, other vehicle running costs, and driver's time).

Tsuji et al. (*5*) investigated the effectiveness of route guidance systems by using a mathematical model in a case study in the Tokyo area. Measures of effectiveness used were the probability that guided vehicles arrive at their destination before unguided vehicles and the percentage of travel time reduction for guided vehicles. On the basis of this model, guided vehicles arrived at their destination earlier with probability 0.85 and experienced an 11 percent reduction in travel time. However, to be able to apply this model to real data several simplifying assumptions were made, including

1. Flow of guided vehicles does not affect the remaining traffic flow,
2. Travel times on alternative routes are mutually independent,
3. Only two alternative routes exist and each route is used only by the guided vehicles or only by the unguided vehicles,
4. Travel time and predicted travel time are normally distributed and are independent, and
5. All users follow route recommendations.

As a result, the suggested model suffers from several drawbacks—the model is not sensitive to the type of information transmitted to users, does not include interactions between guided and unguided vehicles, and is insensitive to the percent of guided vehicles.

Jeffery (*2*) combined the results reported by Tsuji et al. (*5*) with earlier results on the effectiveness of static motorist information systems (*1*) and concluded that drivers who have cars appropriately equipped could realize, on the average, benefits up to 10 percent if route guidance systems operating in real time are implemented.

Al-Deek et al. (*6*) estimated potential benefits of in-vehicle information systems in the context of the PATHFINDER project. They conducted a survey to identify routes typically used by commuters in a portion of the SMART corridor in Los Angeles. Traffic along that corridor was simulated and FREQ8PC and TRANSYT-7F were used to determine travel times on the network links. For a combination of four origin and three destination intersections, the cost of different routes was estimated on the basis of shortest path, freeway-biased route, and arterial-biased route. The study assumed that drivers with perfect traffic information would follow the shortest path to their destination. On the basis of these assumptions, savings in travel time estimates based on the differences between the shortest path and other paths are insignificant (less than 3 min for a 20- to 25-min trip) for the case of recurring congestion.

Under the assumption that an incident on the freeway does not affect travel times on surface streets, Al-Deek et al. (*6*) also estimated reduction in travel times under conditions of incident congestion. Under these conditions, maximum savings of 10 min may be realized for a 30-min trip.

Jones et al. (*7*) addressed the existence of opportunities to improve traffic conditions by providing real-time information to motorists. Data on travel times were collected along three alternative routes for different departure times for a given origin-destination pair on a corridor in Austin, Texas. On the basis of the differences in travel times along these routes, travel times may be reduced by 15 to 30 percent through route change and by 10 to 22 percent through departure time switching.

Gartner and Reiss (*8*) examined, through simulation, an approach to traffic control in a corridor. This approach incorporated roadside motorist information systems and dynamic setting of traffic signals and ramp metering. Parameters for this integrated system, which was tested in Long Island, New York, were set so that some user-specified performance function is optimized (on the basis of predicted corridor usage). Results indicated small improvements when no accident occurred in the corridor and more substantial benefits, especially with respect to delays and queue length, in the presence of incidents. However, the contribution of the motorist information component of the system (as opposed to the contribution of the dynamic setting of signal and ramp metering parameters) was not clear in this study. Furthermore, the applicability of the conclusion drawn by this study to more general networks was also not clear.

The results of previous studies with respect to the potential role of motorist information systems in reducing congestion and travel times are promising. However, in most cases these results were specific and limited to the data they were generated from while ignoring system-wide impacts and the important interactions among the users of the system. Furthermore, these results provide little insight to the sensitivity of the expected benefits to the parameters and characteristics of the problem.

METHODOLOGY

Detailed simulation models are necessary for accurate evaluation of the expected benefits from motorist information systems and for fully assessing their potential. A macroscopic model is presented that provides a good understanding of the interactions among the various parameters of the problem and facilitates sensitivity analysis of the expected benefits. However, this model does not account for all the details.

Characteristics of the Problem

Parameters recognized as important in the application of motorist information systems include users of traffic systems and their behavior, system objectives, congestion characteristics, characteristics of information provided, and network characteristics.

Motorists

Traditionally, traffic flows in urban networks have been the subject of mandatory control policies, such as traffic signal systems, which aim at improving system throughput and safety. However, motorist information systems differ from traffic control devices because these systems are a passive form of traffic control. Users receive information about traffic conditions and recommended paths, but are not forced to follow the suggestions. Decisions are made on the basis of perceptions and information received. Consequently, traffic systems are used by a large number of individual units that act independently of each other with each unit having objectives. Hence, in studying motorist information systems the reaction of the users to the information provided needs to be considered. Other important considerations related to the users of urban networks include trip purpose, trip length, degree of user familiarity with the network, and the portion of the motorist population receiving traffic information.

System Objectives

Reduction of congestion, through better use of existing facilities, is the main system objective in providing traffic information to motorists. However, obtaining system-optimal conditions may conflict with individual user objectives. Therefore, information provided may either reflect actual traffic conditions accurately or be altered to indirectly force users to move toward system-optimal (as opposed to user-optimal) routing decisions. Hence, depending on system objectives, information to motorists may be used as a control variable to influence flow distribution toward ideal levels.

Congestion Characteristics

Congestion is characterized either as recurrent or incident congestion. Recurrent congestion is caused by the fact that the capacity of certain facilities is inadequate to serve the number of vehicles that want to use the particular link or facility. Incident congestion is caused by incidents that routinely occur in the highway system, for example car breakdown or accidents, that temporarily reduce the capacity of a link or a facility. Various studies (*9*) indicate that the contributions of recurrent congestion and incident congestion to total traffic delays are similar.

Motorist Information System Characteristics

An identification and examination of the basic characteristics of motorist information systems is important, especially with respect to services provided and effectiveness in contributing to better motorist decision making. The most important characteristics are (a) the ability to provide real time information; (b) type, level, extent, and timing of information provided; and (c) ability to address individual vehicles or groups of vehicles.

A basic distinction with respect to the ability to provide real time information is static versus dynamic systems. Dynamic systems provide real time information on the basis of current traffic conditions, whereas static systems only provide historic information. Therefore, only dynamic systems are useful in warning users about incident location and severity. Static systems are not effective in reducing incident congestion.

Information systems vary from descriptive to prescriptive. Descriptive systems provide information on certain links, or the majority of links around a corridor of interest, whereas prescriptive systems make suggestions on the best available route to follow. Furthermore, (dynamic) systems may provide information only at the beginning of the trip (pretrip information or trip planning services) or may be capable of providing updated information throughout the duration of the trip. The determination of how much information, as well as the type of information, to provide has important implications on the design of routing algorithms necessary for the operation of motorist information systems. For example, all users should not choose the same route on the basis of information provided because the results will be opposite to those desired.

The number of users that receive the same information at the same time is an important characteristic that distinguishes different types of motorist information systems. Systems that are capable of providing information tailored to the needs of a request from an individual vehicle are more flexible but require more sophisticated hardware and software requirements for effective operation.

Network Characteristics

Effectiveness of motorist information systems is affected by the type of physical network and associated traffic levels. Corridors consisting of freeways and arteries with excess total capacity and availability of alternative paths are potentially good candidates for the installation and successful operation of such systems.

Modeling Approach

The approach selected focuses on evaluating the expected benefits of motorist information systems on recurrent congestion only. In addition, a better understanding is provided of the interactions among the various parameters of the problem: level, amount, and extent of information; number of users who receive information; and congestion levels. In determining these interactions, a hypothesis was made that motorists who receive information on traffic conditions may alter their traffic patterns in the long run. On the basis of information provided continuously, users may realize, for example, that certain links or paths perform consistently better than the ones regularly used, and eventually may switch to those paths.

In order to proceed with development of the necessary models, an assumption was made that users choose routes to minimize some measure of cost (for example, travel time). However, depending on the information available, users have imperfect knowledge of the actual costs associated with alternative paths (links). Hence, decisions on which route to use are made on the basis of perceptions about travel times on various links in the network (and the relative attractiveness of alternative paths to their destination). Furthermore, available traffic information directly affects the perception users of the urban network have of the relative attractiveness of alternative paths to destinations. Hence, perceived travel times are modeled as random variables whose distribution is influenced by the available information on traffic conditions. Lack of information results in high travel time variance, whereas complete information results in deterministic travel times.

In light of this assumption, the problem can now be placed naturally into the more general class of traffic assignment problems (*10,11*). In general, two classes of models exist for traffic assignment: deterministic user equilibrium (DUE) and stochastic user equilibrium (SUE).

Deterministic traffic assignment models assume that travel times on the links of the network are deterministic and that users have exact knowledge of travel times and flows on every link. Therefore, these models can be used to represent the case where users receive perfect information from the motorist information system. Equilibrium conditions for DUE can be stated as follows: at DUE, no motorist can improve travel time by unilaterally changing routes.

Stochastic assignment models assume that users have different perceptions on costs along links (or paths) and make decisions (mainly route choice) on the basis of these perceptions. Differences in perceived costs among users are because of different perceptions of path characteristics and various levels of knowledge among users. On the basis of this assumption, perceived travel time on Link a is represented as

$$t_a = t_a(x_a) + \varepsilon_a \qquad (1)$$

where $t_a(x_a)$ is the link performance function (i.e., link travel time as a function of the flow x_a on the link) and ε_a the perception error with expected value $E(\varepsilon_a) = 0$. Thus, cost C_k on Path k can be expressed as

$$C_k = \Sigma t_a \delta_{a,k} \qquad (2)$$

where C_k corresponds to perceived travel time on Path k and $\delta_{a,k}$ is equal to 1 if Link a is on Path k and 0 otherwise.

Equilibrium conditions of SUE can be stated as follows: at SUE, no motorist can improve perceived travel time by unilaterally changing routes. Thus, the stochastic equilibrium conditions for a given origin-destination pair are given by

$$f_k = qp_k \quad \text{for all Paths } k \qquad (3)$$

where q is the origin-destination flow, f_k is the flow on Path k between the given origin-destination pair, and p_k is the probability of choosing Path k, given by p_k = probability ($C_k \leq C_m$) for all Paths m.

The value of p_k depends on the distribution of ε_a (link perception). Two distributions commonly used are the Gumbel distribution, which leads to a logit model for path choice, and the normal distribution, which leads to a probit model for path choice. The probit model formulation, although computationally more involved, is preferred. Logit-based route choice modes treat all paths as independent even if they share a large number of common links, whereas probit-based route choice models do not suffer from this limitation. Using the probit model, travel time on Link a is assumed to be normally distributed with mean $t_a(x_a)$ and standard deviation $\beta t_a(x_a)$, where β is the coefficient of variation.

The level of information provided by motorist information systems to the users can be incorporated into the model by different values of the coefficient of variation of the travel time. Given that $t_a(x_a)$ is the actual travel time on Link a (for a given flow x_a), then different perceptions of users on that value result in a probability distribution function centered around $t_a(x_a)$. Thus, large variance (expressed by a high value of β), corresponds to a situation in which perceptions of travel time differ considerably, whereas small variance indicates good knowledge of travel times (see Figure 1).

When traffic information is provided, the perceptions that users (who receive the information) have of travel times improve and become centered around true travel times. This phenomenon can be expressed by a reduced variance for users with

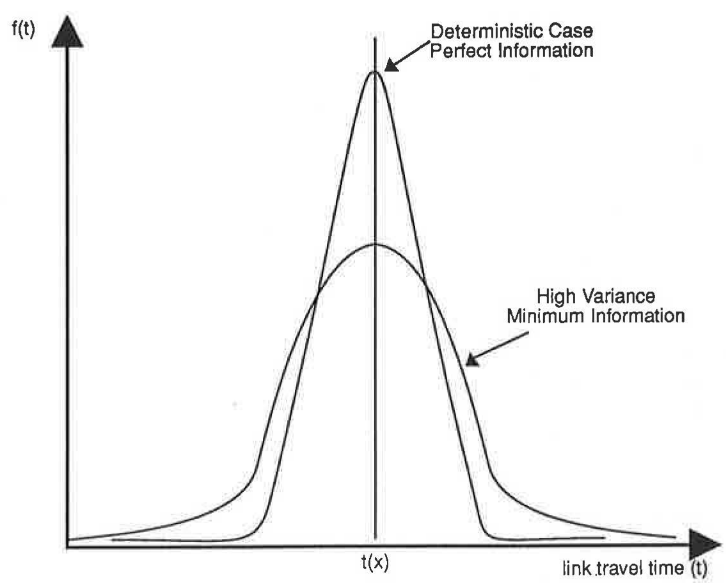

FIGURE 1 Perceived travel time distribution as a function of information availability.

access to information. The limiting case occurs when perfect information is available and all users know the true value of travel time. In this situation, the perception variance is zero. This analysis assumes symmetry of the probability distribution function both before and after provision of information.

Under this framework, different information systems and information availability can be modeled. In the previous formulation, actual link travel times are not stochastic (they are only perceived differently by the users). Therefore, the models presented cannot be used to address the problem of incident congestion (where the capacity of a link is temporarily reduced and the link travel time increases). Furthermore, incident congestion phenomena are highly dynamic in nature, whereas the traffic assignment model used in this study is static.

CASE STUDIES

In order to estimate potential benefits of motorist information systems and their sensitivity to various parameters, the model presented previously was applied under different scenarios of information availability and congestion levels on a relatively small suburban network using data from the city of Sudbury, Massachusetts, and a much larger urban network representing the Boston metropolitan area. Although the approach used is aggregate, the trends observed in the case study are indicative of the interactions among the various parameters of the problem and can be used for an initial assessment of the expected benefits from the introduction of motorist information systems.

Sudbury Case Study

In the town of Sudbury, the road network is characterized by three main routes that stretch from east to west: Routes 20, 27, and 117. The network consists of 204 nodes, 70 centroid nodes, and 578 links of which 214 are connectors joining the centroids to the network. A total of 12,247 trips per hour take place between origin and destination pairs of the network. The standard BPR equation was used for the link performance functions, i.e., travel time as a function of link flows is given by

$$t_a(x_a) = t_a^0[(1 + 0.15(x_a/\text{cap}_a)^4] \quad (4)$$

where t_a^0 is free-flow travel time on Link a, x_a is the flow on Link a, and cap_a is the capacity of Link a.

The practical capacity assigned to the performance function of each link was set at 800, 900, 1,000, and 1,100 veh/hr for 9-, 10-, 11-, and 12-ft lane width, respectively. The free-flow travel time t_a^0 was based on the measured length of the corresponding link and the maximum allowed speed.

In this case study, various scenarios were designed to examine the sensitivity of the expected benefits to the following parameters:

- Level and Amount of Information. Because the amount and level of information are modeled using the coefficient of variation β, the distribution of flow was compared for different values of β that varied from 0.0 (which corresponds to perfect information and deterministic assignment) to 0.5 (i.e., the standard deviation is equal to 50 percent of the actual travel time). Values of β between 0.0 and 0.5 represent intermediate levels of information provided. However, a value of 0.5 is rather high but is used in this study because the objective is to examine sensitivity of benefits to the various parameters of the problem.
- Extent (Spatial Distribution) of Information. Two cases were considered: (a) information is available for virtually all links in the network (e.g., the case of in-vehicle information systems) and (b) information is available only on major routes in the network (e.g., the case of radio broadcasting systems).
- Percentage of Informed Users. Two groups of motorists were used: informed users (i.e., those capable of receiving information) and uninformed users. The percentage of informed users varies from 0 to 100 percent. When a mixed population of motorists is assumed, the perception of uninformed users was modeled by using the highest value of $\beta = 0.5$.
- Congestion Levels. For the original origin-destination matrix, the average flow/capacity ratio was about 0.45. In order to examine the effect of congestion levels, the network was loaded using the original origin-destination matrix multiplied by factors equal to 1.5, 2.0, and 2.5 (resulting in average flow/capacity ratios of 0.67, 0.88, and 1.1, respectively).

Examination of all combinations of the various cases generated a large number of scenarios.

In order to compare the flow distributions obtained from the various scenarios, travel time per user (informed and uninformed) and total travel time for a given flow distribution were used as measures of performance. However, the data set did not include observed link flows. Consequently, an estimate was difficult to obtain for the value of the coefficient of variation β that best describes the current behavior of the users of the system. If data were available for observed link flows, then a value for β could be chosen that provides the best fit between link flows predicted by the corresponding SUE and observed link flows. This value of β could then be interpreted as reflecting the current level of information availability among the motorists.

Figure 2 presents results for the case where all users have the same perception of travel times. For each value of β, average path travel time and the corresponding average shortest path travel times are illustrated. A 4.4 percent reduction in average travel time was observed as the coefficient of variation decreases from 0.5 to 0.0. The time on the shortest path (i.e., the average travel time per user if all users follow the shortest path, at equilibrium, to their destination) increases as β decreases because as more information becomes available more motorists make intelligent decisions and follow the shortest path to their destination. However, as more motorists follow the shortest path, travel times (on the shortest path) increase because of the link performance functions used. This behavior of the average shortest path time also indicates that measuring expected benefits of motorist information systems, on the basis of the difference between travel times on the current shortest path (for a given origin-destination pair) and the travel time on alternative paths, overestimates the actual benefits (because this method ignores the interactions among users).

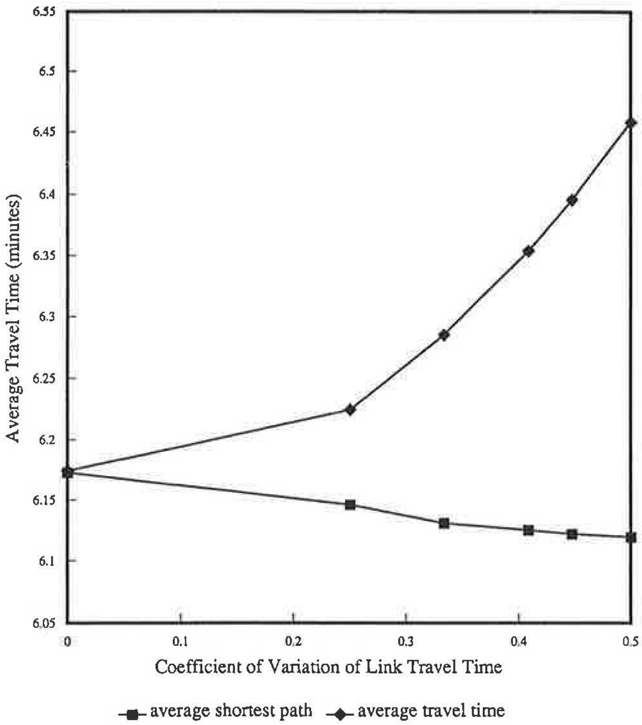

FIGURE 2 Path travel time as a function of information availability.

Table 1 presents the sensitivity of travel times to information for various congestion levels. Three levels of congestion are presented: the base case (load factor 1.0) and cases with load factors 1.5 and 2.0.

The results indicate moderate benefits from the introduction of motorist information systems. The percentage reduction in total travel time between the deterministic case and the case of limited information ($\beta = 0.5$) decreases slightly as the congestion level increases. In terms of average travel time per user, the greatest reduction in travel time is experienced when the load factor is 1.5. The benefits per user decrease as the load factor moves away from the value 1.5. Table 1 also indicates that additional benefits gained by moving toward a system-optimal allocation of flow are of similar magnitude as the benefits from improved information. Furthermore, these benefits increase with the congestion level (up to some point).

Figure 3 shows the sensitivity of system-wide travel time to the number of users who have access to information, for the base case of congestion levels. The coefficient of variation for uninformed users was fixed at 0.5, whereas the β value for informed users was set at 0.33, 0.25, and 0.0, respectively. In all cases, travel times decreased linearly with the number of informed motorists. This result is somewhat surprising because the rate of decrease in total travel time is expected to decrease as the percentage of informed users increases. The same trend was observed even when the network was more congested (load factors 1.5 and 2.0). However, when the β value of uninformed users becomes 0.45 (which implies that uninformed users have better perceptions than originally), the relationship between travel time and percentage of informed users behaves closer to the expected. Although initially the reduction is linear (but with a much smaller slope than before),

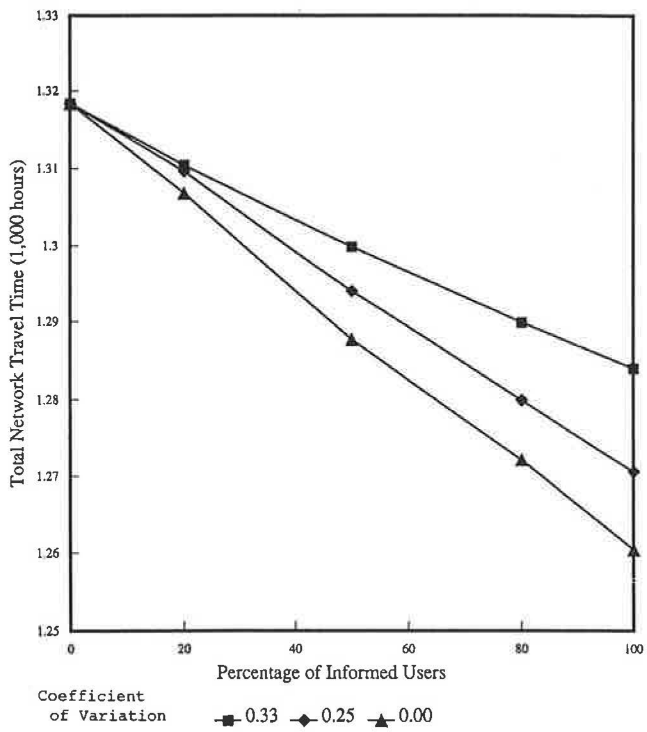

FIGURE 3 Sensitivity of travel time to percentage of informed users when the coefficient of variation for uninformed users is 0.50.

TABLE 1 SENSITIVITY OF TRAVEL TIME (hr) TO INFORMATION AND CONGESTION LEVELS

Coefficient of Variability β	Congestion Level (x/cap)		
	1.0 (.45)	1.1 (.67)	1.2 (.88)
SYSTEM OPTIMAL	111,810	130,871	155,614
0.00	114,815	136,926	159,974
0.25	114,986	135,905	163,151
0.33	116,957	138,172	165,807
0.41	119,854	140,621	168,715
0.45	120,975	142,127	170,428
0.50	123,545	144,703	170,642

the rate of reduction is lower and the curve tends to be asymptotically horizontal as the percentage of informed users increases. This observation supports the argument previously made that the β value of 0.5 used for uninformed users is too high and a lower value may better reflect actual conditions. Unfortunately, because of the lack of data (link observed flows), a proper value for β cannot be determined.

Figures 4 and 5 show the differences in travel times between informed and uninformed users. Figure 4 clearly demonstrates that, as expected, the difference between informed and uninformed users increases as more information becomes available to informed users (case with a load factor of 2.0). However, for all scenarios of information availability, the benefits experienced by informed users (over uninformed) decrease as the congestion levels on the network increase. Therefore, the value of information decreases as the network becomes more congested because the opportunities for identifying better paths decrease and both informed and uninformed users experience long travel times. Figure 5 shows the difference in travel times between informed and uninformed users as a function of the number of informed users. Jeffery (*1*) speculates that "additional sources of potential benefit that would accrue mainly to dynamic guidance systems include: (i) savings in congestion and delays, and hence time and vehicle operating costs, for non-equipped vehicles because equipped vehicles are diverted out of their way . . . ." However, this finding is not supported by the results shown in Figure 5 (at least for the case of recurrent congestion). Overall travel times for uninformed users, in general, increase marginally as the percentage of information-equipped vehicles increases. Similarly, because

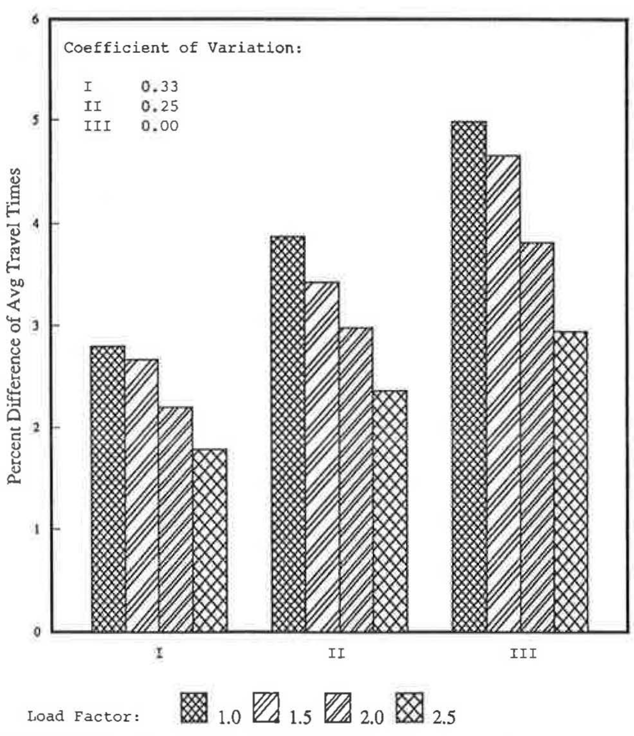

FIGURE 4 Comparison of average travel times between informed and uninformed users with 50 percent informed users when the β value for uninformed users is 0.50.

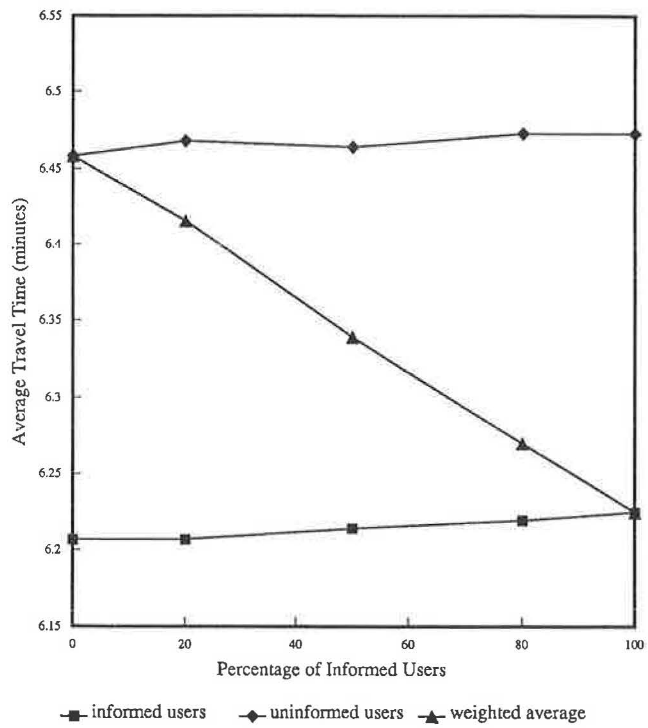

FIGURE 5 Sensitivity of average travel time to percentage of informed users when the β values are 0.25 for informed users and 0.50 for uninformed users.

of existing interactions, travel time for informed vehicles also increases. The difference in travel times is substantial enough that overall travel time decreases (see also Figure 3) as the percentage of informed users increases.

Given the probabilistic nature of the traffic assignment, to validate the results further, the hypothesis that link travel times for informed users are statistically less than the corresponding travel times for uninformed users was tested at the 95 percent confidence level. The hypothesis was accepted for all combinations of information availability and congestion levels (with the exception of the case in which the network loading factor was 2.5 and the corresponding average volume/capacity ratio was greater than 1).

Finally, Figures 6 and 7 show the results for the case where information is available only on selected routes in the network. In Figure 6, two cases are shown. In the first case, all users have the same information on all links in the network (see also Figure 2). The second case is identical to the first with the only difference that the information on the three major routes (Routes 20, 27, and 117) is perfect ($\beta = 0$). As expected, the difference in travel time between the two cases decreases as more information is available to the users. For all values of β, the benefits from the additional information on the three main routes are small. Figure 7 shows the differences in travel times for two cases: in the first case all users have information on the three major routes and no information ($\beta = 0.5$) on all other routes, whereas in the second case motorists have information on all routes. The level of information varies from $\beta = 0.5$ to $\beta = 0.0$. The results clearly demonstrate that the value of spatial information increases as

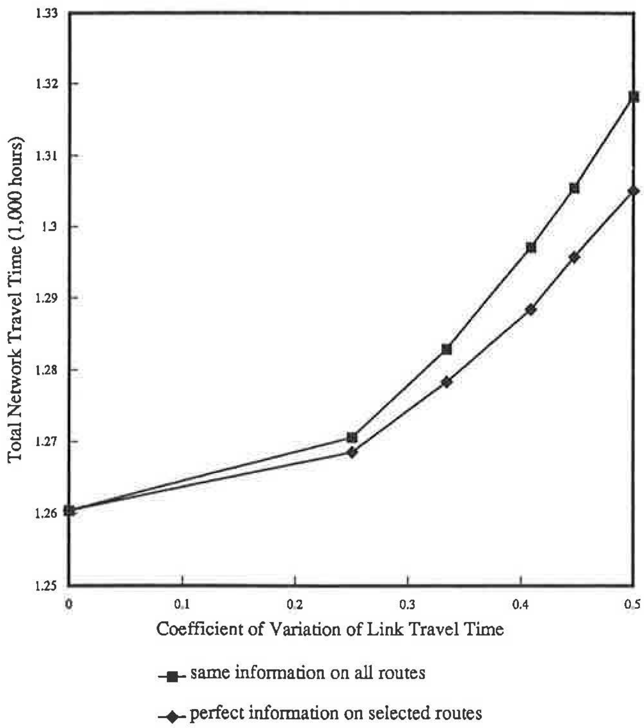

FIGURE 6 Effects of the provision of information on selected routes.

the level of information increases. When $\beta = 0.0$ (i.e., perfect information on the three routes in the first case, and perfect information on all links for the second case), travel time decreases by 4 percent as the spatial availability of information extends to all links.

Boston Case Study

The second case study was performed on a larger urban network describing the Boston metropolitan area. The network consists of 7,724 nodes; 239 centroid nodes; and 11,647 links, of which 1,064 are connectors with approximately 186,578 trips per hour. The Central Transportation Planning Staff (CTPS) in Boston provided the data used in this case study.

The BPR equation was used for link performance functions with a power of 6 for the flow/capacity ratio. The same scenarios as the Sudbury data were examined except extent of information, which has not yet been tested because of the size of the network and the existence of many major routes, some of which have nontrivial overlap. Because the Boston network is more congested than the Sudbury network, lower load factors of 1.1 and 1.2 were applied. Generally, the same trends were observed, but in some cases more insight was provided and some counter-intuitive phenomena that appeared in the first case study were addressed.

In Figure 8, in which all users have the same perception of travel time, the same trends as in Figure 2 appear. However, the magnitudes are quite different. In the Sudbury data, average travel time reduction was 4.4 percent as β decreased from 0.5 to 0.0, whereas in the Boston data this decrease amounted

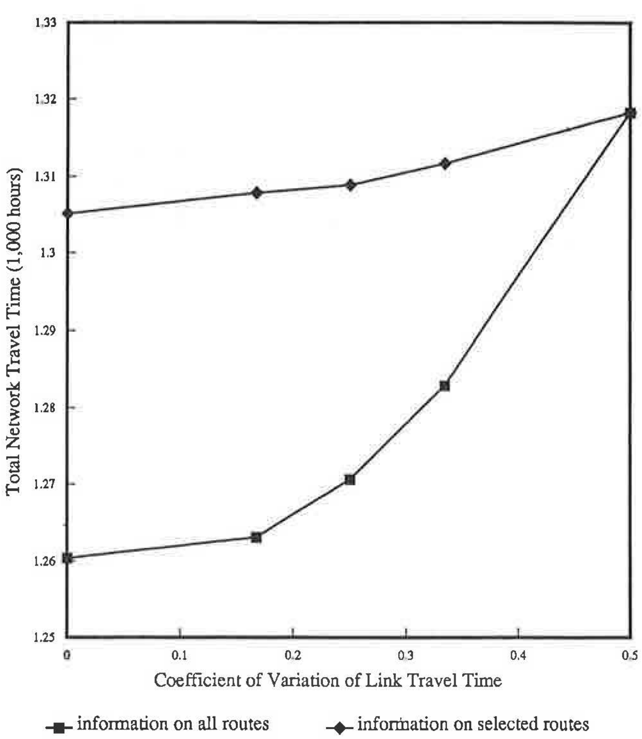

FIGURE 7 Average travel time as a function of spatial availability of information.

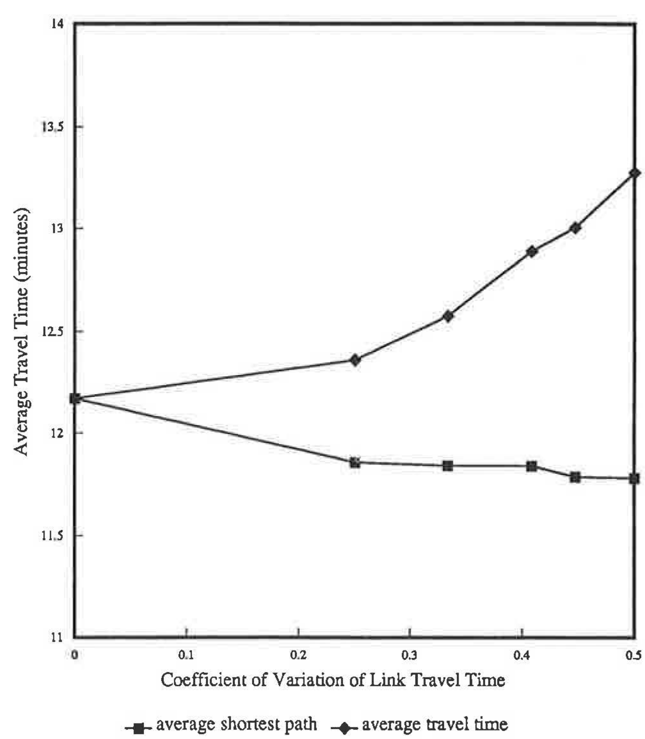

FIGURE 8 Path travel time as a function of information availability.

to 8.4 percent. On the other hand, average travel time along the shortest path increased by 0.8 percent in the Sudbury case study and by 3.2 percent in the Boston case study as β decreased. This result could be explained by the fact that the shortest path becomes congested faster because of the higher power of the flow/capacity ratio in the BPR function and the higher level of congestion in the network. The differences reported are for the two extreme values of the coefficient of variation. Unfortunately, the lack of observed link flows again does not allow the determination of a value for β that best represents existing conditions. However, a priori the true value is expected to be lower than 0.5. Furthermore, the average travel time reported does not include the time to traverse the connectors from or to the origin-destination centroids.

An interesting result is presented in Table 2 that compares total travel times in the network among the various scenarios of information availability and load factors. The total travel time under system optimal conditions is also given. Surprisingly, traffic conditions for the case of load factor equal to 1.1 (measured by total travel time) worsen when full information is provided compared with limited information availability (β = 0.25). The result, which suggests that information may not always improve travel times, needs further investigation because the difference observed is possibly caused by convergence effects of the model used rather than behavioral reasons (although in all other cases a monotone reduction in travel times is observed as more information is provided).

Figure 9 shows a more intuitive relation between total travel time and the percentage of informed users than Figure 3. For each of the three cases examined, a decreasing S-shaped function demonstrates that when a small percentage of users has access to information, total decrease in travel time is moderate. As more users gain access to information, travel time decreases at faster rates (when the percentage of informed users is somewhere between 30 and 70 percent). Finally, a small marginal decrease in travel time occurs when the percentage of informed users increases above a certain value. This pattern agrees more with the prior expectation than the linear rate of decrease that appeared in Figure 3 and supports the hypothesis that marginal benefits from providing information decrease as more users gain access to the same kind of information.

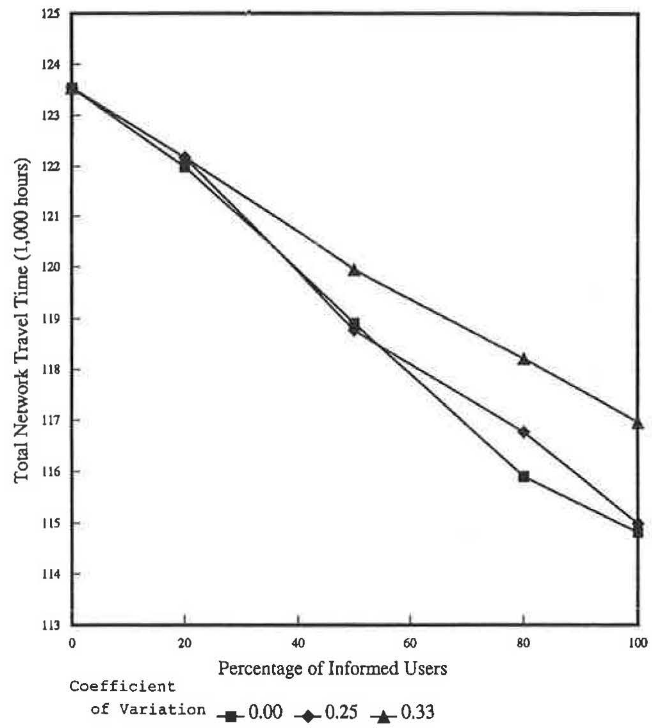

FIGURE 9 Sensitivity of travel time to percentage of informed users with a β value for uninformed users of 0.50.

Figure 10 shows additional information on the behavior of average travel time experienced by uninformed users as larger numbers of motorists have access to and use traffic information. Although in Figure 5 a general trend of increased travel time for uninformed users was observed, Figure 10 clearly shows nonmonotone behavior of the average travel time experienced by uninformed users. Travel time is lower when approximately half of the users in the system are informed. These results support the hypothesis that uninformed users may also benefit from the fact that informed users make better decisions, some of which involve route diversions. However, as the percentage of informed users increases beyond approx-

TABLE 2 SENSITIVITY OF TRAVEL TIME (hr) TO INFORMATION AND CONGESTION LEVELS

Coefficient of Variability β	Congestion Level (x/cap)		
	1.0 (.45)	1.5 (.67)	2.0 (.88)
SYSTEM OPTIMAL	1,249	2,082	3,352
0.00	1,260	2,139	3,503
0.25	1,270	2,155	3,523
0.33	1,283	2,169	3,546
0.41	1,297	2,191	3,585
0.45	1,305	2,204	3,608
0.50	1,318	2,222	3,637

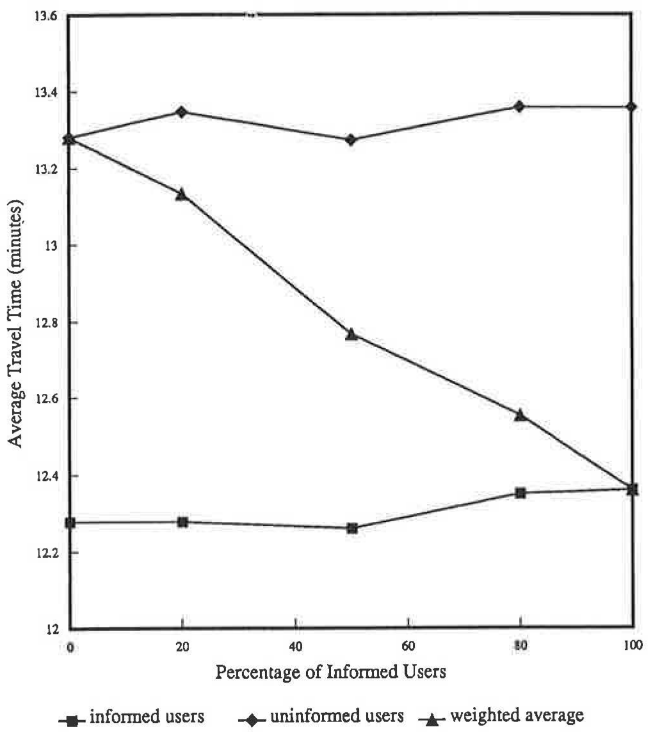

FIGURE 10 Sensitivity of average travel time to percentage of informed users when the β values are 0.25 for informed users and 0.50 for uninformed users.

imately 70 percent, informed and uninformed users start to experience an increase in their respective average travel times.

Finally, the results from the Boston case study should be interpreted with caution for various reasons: (a) analysis of the data is not yet complete, and (b) data obtained from CTPS was not in its original form but had already been calibrated to some extent.

CONCLUSION

A methodology to analyze long-term effectiveness of motorist information systems in reducing recurrent congestion was described. The methodology is based on the assumption that provision of information affects the perception users have on link travel times of a network and therefore improves their route choice. The model was applied on two networks (urban and suburban) and provided some understanding of the interactions among the most important parameters of the problem such as percentage of informed users and level and extent (spatial coverage) of information. The results show that motorists experience modest reduction in travel times because of the introduction of motorist information systems. The gains, though, are proportionally smaller than the ones estimated by other studies. However, these differences are attributable to the fact that previous studies have ignored interactions among users of the system.

From a theoretical point of view, the methodology presented has several limitations, and current research concentrates on relaxing the assumptions underlying the models used. Some of the most important of these limitations are as follows:

1. No formal link established by the research so far exists between the level and extent of information and the corresponding value of β. Such a link, if established, could be useful in measuring the value of information more accurately. Furthermore, this relationship could be used to evaluate the most appropriate hardware configuration.
2. The approach presented is only useful in assessing long-term benefits caused by reduced recurrent congestion from a motorist information system. Further work is necessary to capture similar effects under incident congestion conditions.
3. The models presented cannot be used directly to assess the benefits from using the information as a control variable to obtain flow distribution closer to the system-optimal distribution, in which use of the network is maximum, a goal that may be neither realistic nor feasible, anyway.
4. The model used is static and does not allow the study of other important effects, such as changes in departure times.

The resolution of these limitations—especially for evaluating benefits caused by a reduction in incident congestion—requires better understanding of user perceptions for route choice modeling. From a practical point of view, a need exists for conducting case studies using better modeling of link travel time perception and effects of information and examining the sensitivity of the results to other important parameters such as coordination of motorist information systems and traffic signals in a way similar to the Long Island study previously mentioned (*8*).

In summary, the modeling framework, despite limitations, has provided a means to incorporate information availability and its effect on traffic congestion, to identify important interactions among the important components of the problem, and to evaluate potential long-term benefits.

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