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Stated and Reported Diversion to Public Transportation in Response to Congestion: Implications on the Benefits of Multimodal ATIS

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STATED AND REPORTED DIVERSION TO PUBLIC TRANSPORTATION IN RESPONSE TO CONGESTION: IMPLICATIONS ON THE BENEFITS OF MULTIMODAL ATIS

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ABSTRACT

The objective of this study is to evaluate the potential benefits of a multimodal Advanced Traveler Information System (ATIS). The propensity of auto commuters to switch to public transportation in response to unexpected traffic congestion is investigated using a detailed survey undertaken in the Golden Gate Bridge corridor in 1993. A stated preference analysis tied to the situation for which the commuting behavior was reported is used to estimate the propensity of travelers to divert to transit under a multimodal ATIS.

The current proportion of travelers switching to public transportation in response to congestion is limited. Few people switch to transit upon learning about unexpected congestion while en route, mostly because few opportunities to park their vehicle and switch mode are perceived as available. A larger but still limited proportion of commuters (1.6%) switch to public transit as a pre-trip response to unexpected congestion.

Eighteen percent of respondents stated that they would switch to public transportation if suggested to do so by a pre-trip ATIS device under unexpected congestion. 61% of these potential switchers might have saved some time by changing mode, assuming that transit travel times remain unaffected by unexpected congestion. The average time saving for all potential switchers amounts to 10.8 minutes, or $3.24 per trip, using the appropriate value of time for each commuter. When considering only the potential switchers that would save time by taking transit (7% of the total sample), the average annual benefit of ATIS-induced diversion to transit could be $108 per person. Prescriptive ATIS information thus has the potential to divert a certain segment of the population to mass transit under unexpected congestion. This potential is, however, limited to the population with greater transit accessibility.

1. INTRODUCTION

Advanced Traveler Information Systems (ATIS), a branch of the general Intelligent Vehicle Highway Systems or IVHS effort, are intended to help -people make more informed travel decisions. Computerized information systems could indeed support pre-trip decisions such as mode choice, departure time, and trip chaining sequence, as well as route selection and diversion while on the road.

There is an increased interest in expanding advanced traveler information systems into a multimodal data source providing information about a wide variety of travel options. ATIS devices could provide not only real-time information about traffic conditions, but also information about transit routes, schedules, and optimal itineraries on transit networks. Because reluctance to use public transportation is partly due to a lack of information about available transit services, a multimodal ATIS device could encourage a switch of travelers to public transportation, especially under unexpected congestion. What proportion of drivers could be affected? What benefits will accrue from this modal switch? Using the results of a detailed survey about commuting behavior, this study explores the impacts of a multimodal ATIS on mode choice and quantifies the user benefits of a switch to transit under unexpected congestion.

First, the conceptual structure underlying the study is presented. The distinction between pre-trip and en route information, the question of user and system benefits, the monetary value of time, and the concept of a multimodal ATIS are discussed. The methodology is then briefly summarized, followed by a description of the survey design and characteristics of the sampled population. Commuters' propensity to divert to public transportation without ATIS is then explored, using reported behavior from the survey. Two situations are considered: whether the commuter learned about the incident before the trip (pre-trip response) or while on the road (en route response). The core of the paper deals with a stated preference analysis of the diversion propensity to transit under incident conditions, when commuters are provided with pre-trip ATIS information. To address validity issues, stated preferences are compared with the corresponding reported behavior and a profile of the people who would switch to transit because of ATIS is presented. Then the time savings achieved by the switch to public transportation are calculated and expressed in money terms using an appropriate function for the value of travel time. Finally, conclusions are drawn on the effectiveness of ATIS in causing a switch to public transportation.

2. CONCEPTUAL STRUCTURE

2.1 Pre-trip and en route response to unexpected congestion

Travelers can learn about unexpected congestion on their usual route either before their intended trip or while on the road. This distinction is important because the behavioral response to the unexpected conditions is likely to be different in each case. When drivers learn about unexpected congestion while en route, they are restricted to relatively fewer options:

- Do not change travel plans;
- Divert to an alternate route;
- Park vehicle and switch to public transportation;
- Modify the trip chaining sequence, that is, add or cancel some intermediate stops.

When travelers learn about unexpected congestion before starting their trip, they have greater flexibility in adjusting travel plans. More options then become available:

- Do not change travel plans;
- Change route;
- Change the trip departure time, that is, leave earlier or later;

2.2.2 Transportation system benefits

Transportation system benefits of ATIS may include reductions in trip time, pollution, and energy consumption, as well as safer traveling. System benefits are more than the aggregation of user benefits. Indeed, certain impacts such as reduced energy consumption, less pollution, and lower probability of getting involved in an accident might be too small to be perceived at the user level, but become very important at the system scale.

This study focuses on the *user* benefits of a switch to public transportation. Although a wider definition of the user benefits of ATIS would be possible, only time savings to people with access to ATIS devices are considered. This approach is used because the switch to transit, no matter how beneficial for the system as a whole, will not occur unless the switchers themselves are made better off. It should nevertheless be recognized that switching people from their private vehicle to public transportation is primarily intended to bring system benefits: improved highway performance and, in the long run, increased transit level of service.

2.3 Value of time

The value of travel time has been investigated extensively, both from the theoretical and empirical points of view. Hensher (1976) provides a good summary of the issue. The most frequent methods to find out a value of travel time rely on econometric models of situations involving a trade-off between money and time. The value of time is generally accepted to be a function of the income, although a wide range of values have been suggested for the ratio of the value of time on the hourly wage (Heggie 1972; Cox 1983). The monetary value of travel time is a function of the trip purpose: time spent for work trips, for example, is more onerous than time spent on social or recreational trips (Thomas and Thompson 1971). It has also been accepted that the value of travel time savings depends on the amount of time freed for other purposes: a saving of a couple of minutes may be too small to be used productively (AASHTO 1978). These issues were considered when evaluating the time savings brought about by ATIS: the value of time was taken as a function of both the personal hourly income and the amount of time saved.

2.4 Multimodal Advanced Traveler Information Systems

Recent developments in telecommunications and information processing technologies are providing new opportunities to disseminate extended pre-trip information about a large variety of travel options. The integration of information about traffic conditions, transit itineraries and schedules, parking availability, and rideshare matching is expected to help travelers make wiser travel decisions and also to optimize the use of the transportation system. More comprehensive information is likely to influence traveler behavior and thus provides an opportunity for transit agencies to attract new ridership.

Pre-trip transit-related information is already available in various forms: computer-assisted telephone information services, automated telephone information systems, teletext systems, interactive audio/video systems, cable television, or personal computers (Khattak, Noeimi, Al-Deek, and Hall 1993). These media provide either real-time or historical information about schedules/departure times, fares, itineraries, trip chaining optimization, connection points, and transit vehicle location. Some of these systems can suggest an optimal itinerary based on criteria set by travelers, such as shortest time, lowest fare, maximum use of rapid transit, or least walking distance.

The objective of a multimodal ATIS is to integrate this information with reports on highway performance. The system could provide either descriptive information (travel times for both automobile and transit alternatives) and/or prescriptive directions, that is, suggest a particular option given the current traffic conditions. By providing a clear comparison of transit and automobile travel times, multimodal ATIS could induce a switch of travelers to public transportation, especially under non-recurrent congestion. The objective of this study is to measure the extent of such a switch under the provision of prescriptive information.

3. METHODOLOGY

The propensity to switch to public transportation when provided with pre-trip ATIS devices was assessed using stated preferences, because such devices are not yet widely available in the US (see Khattak, Koppelman, and Schofer 1993, for a review of literature on stated preferences). To increase the realism of the technique, the stated preferences were validated with reported response to unexpected congestion. Statistical tests and discriminant analysis were then performed to obtain both a profile of the potential switchers and the conditions most favorable to the modal switch. Time savings for each potential switcher were extracted from the survey and further converted into monetary value. The money value of time used was based on the personal income of each respondent and on the magnitude of the savings achieved. Annual benefits were estimated assuming that the frequency of incidents inducing diversion to transit would be inversely related to the time elapsed since the last incident reported. Finally, an upper bound to the potential travel time benefits was computed, assuming that all respondents who would save time by switching to transit would do so.

4. SURVEY CONTEXT

4.1 Survey design

The study is based on a survey about commuting behavior undertaken in the Golden Gate Bridge corridor, in the San Francisco Bay Area, in February 1993. This corridor, although not entirely typical, was chosen because of its good transit level of service, recurrent traffic congestion on the bridge, and the high cost of parking at destination (downtown San Francisco), all of which encourage the use of transit. The survey was part of a broader study (Khattak *et* al. 1992) intended to:

- Develop a taxonomy of ATIS dissemination technologies;
- Assess system impacts of ATIS technologies at highway bottlenecks;
- Evaluate impacts of ATIS technologies on traveler behavior; and
- Assess the impact of different information dissemination strategies on traveler behavior.

The questionnaires were distributed to peak period commuters crossing the Golden Gate Bridge in both the morning and the afternoon rush hours. There might have been a self-selection bias among respondents, since they had to mail back the questionnaire. Money incentives conditional on the completion of the survey were successful in achieving a good response rate: more than a third of the 9000 copies distributed were returned (see Khattak 1993, for the details of the questionnaire distribution). The questionnaires included a total of 62 questions; the following sections are relevant to this study:

1. *Normal travel patterns.* This part contains day-to-day commuting behavior description such as work schedule, schedule flexibility, normal and best alternate routes to work, and the presence of recurrent congestion.

2. Pre-trip response to unexpected congestion. This part of the questionnaire asks commuters to report an incident of which they became aware before beginning their trip. They are asked how they modified their travel plans in response to this unexpected congestion. Through a sequence of stated preference questions tied to the situation for which the behavior was reported, the survey also explores how ATIS could affect the pre-trip response to unexpected congestion.

3. En route response to unexpected congestion. This section is equivalent to the previous one except that respondents were asked to report an incident that they learned about while on the road. The stated preference questions explore how the provision of ATIS in-vehicle information could affect the decision to divert to an alternate route.

4. Socioeconomic profile. This part of the questionnaire asks respondents about socioeconomic characteristics such as gender, age, personal income, level of education, household size.

To reduce questionnaire length, the sample was divided into two groups: 1746 respondents filled out the pre-trip section (2), while the remaining 1492 people answered the en route part (3). Sections 1 and 4 were filled out by all 3238 respondents.

4.2 General characteristics and representativeness of the sample

Sixty four percent of the sample are males and the average age of the respondents is 46 years. Seventy-three percent of the respondents have at least a college degree; their major occupational fields are professional/technical (35%) and management (33%). The average annual income is $69,900, with 41% of the respondents earning more than $80,000 a year. Fourteen percent live in one-person households, while 43% reported a two-person household. Most respondents live in Marin County and work in San Francisco; this single O-D pair accounts for 59% of the sampled individuals. The sample represents therefore a middle-aged, well-educated, and wealthy segment of the population.

To evaluate the representativeness of the sample, it was compared to both census data and the Bay Area Travel Study (1990). Minor differences were found for the ratio of drive alone/car-pool, the average trip time to work, and the number of cars or persons per household (Khattak 1993). This was expected, given the method chosen to distribute the questionnaires. It was concluded that the sample, although it does not reflect the whole population of the area, provides a clear picture of the population commuting by car in the Golden Gate Bridge corridor. This analysis, however, does not preclude biases in other attributes or contextual factors. Finally, it should be pointed out here that daily commuters account for only a portion of the total traffic on the bridge during rush hours. This percentage, when estimated from the use of discount tickets, is around 60%.

4.3 Availability of transit services in the study corridor

The supply of transit services available in the study area is briefly described here, in order to place diversion to public transportation within context. The Golden Gate Bridge, Highway and Transportation District, whose aim is to maintain and operate the Golden Gate Bridge and ensure reasonable mobility within the corridor, provides transit services between the three counties of San Francisco, Marin, and Sonoma (GGBHTD 1993). Two ferry lines and a fleet of transit buses are operated by the district; no rapid rail transit line is available within the corridor.

Ferry service between Sausalito and San Francisco Embarcadero terminal is offered all year round, using a 575-passenger vessel with a seating capacity of 388 passengers. Eighteen crossings are offered on weekdays, 12 on weekends and holidays; two additional crossings are operated during the summer peak season. The travel time is 30 minutes and the minimum headway during peak period is 70 minutes. The base fare is

$3.75 with discounts available for senior, disabled and young patrons. Tickets providing substantial savings are also available for frequent users. Between Larskpur and San Francisco Terminals, service is provided year-round by a fleet of three 725-passengers vessels offering a trip time of 45 minutes and a peak headway of 30 minutes. Twenty-six crossings are offered during the week, and 10 during weekends and holidays. The base fare is $2.50 on weekdays and $3.25 on weekends and holidays. Ferry feeder bus lines are provided free of charge at both ends of lines to facilitate access to the terminals. A 1143-space park-and-ride lot is available at the Larkspur Terminal. In addition, a privately owned ferry service operates between Tiburon and San Francisco.

The district also provides a total of 1189 bus trips per weekday, on 61 bus routes forming a network of 524 directional route-miles. Four basic lines operate all day, 7 days a week, along trunk routes between the Transbay Bus Terminal and Civic Center in San Francisco and various suburban centers within Marin and Sonoma counties. In addition, 19 bus routes operate during rush hours between residential neighborhoods of Sonoma and Marin and employment centers in San Francisco. Thirteen routes also serve as ferry feeders and operate during peak hours on weekdays between certain residential areas of Marin County and the Sausalito, Tiburon, and Larkspur ferry terminals. Two routes provide ferry feeder service in the financial district of San Francisco. Golden Gate Transit also provides local bus service within Marin and Sonoma counties, as well as recreational and special shuttle services. Transfer facilities with other transit operators are located throughout downtown San Francisco.

Golden Gate Transit buses traveling to and from San Francisco are able to bypass most traffic congestion by using HOV lanes on Highway 101. However, these lanes do not extend to the bridge and buses do experience delay when the bridge is congested. Twenty-six park-and-ride lots provide capacity for 2682 vehicles (not including the ferry lots). Ten fare zones are established within the Golden Gate Transit service area. A 10-by-10 matrix based on the distance traveled is used to determine bus cash fares.

Reductions are available for senior, disabled, and young patrons and transfers are free. The highest frequency of both ferry and bus service is between the residential communities of East Mar-in and downtown San Francisco.

Annual ridership on the Golden Gate Ferry system was about -1.5 million unlinked passenger trips in 1992. Four million passengers took the bus between Marin and San Francisco in 1992; 900,000 between Sonoma and Marin; and 300,000 between Sonoma and San Francisco (GGBHTD 1993). According to census data, the modal share of transit for work trips in 1990 was 30.0% from Marin to San Francisco, 24.0% from Sonoma to San Francisco, 11.2% from San Francisco to Marin and 7.7% from San Francisco to Sonoma (MTC 1990).

Judging by the frequency and spatial distribution of transit services, as well as the presence of park-and-ride facilities, the Golden Gate Bridge corridor provides some opportunities to use or divert to public transportation, at least for the people working with regular schedules in downtown San Francisco. In the context of incident induced congestion, the opportunities would also depend on the spatial (location) and temporal dimensions of the incident.

5. REPORTED RESPONSE TO UNEXPECTED CONGESTION

This section explores the propensity to switch to public transportation under unexpected (incident-induced) congestion. Two types of reported behavior are considered: a switch to public transportation while on the road (en route response) and the decision to use public transportation while still at home or at work (pre-trip response).

For both pre-trip and en route cases, respondents were asked about unexpected congestion on their usual route. Sixty-three percent of the pre-trip respondents (N=1044) stated that, in the last three months, they did become aware of unexpected congestion on their usual route while at home or at work. On the other hand, 74% of en route respondents (N=1043) became aware of unexpected congestion while on the road during the last three months. Only the respondents who faced an incident answered to the remainder of the sections about unexpected congestion. All percentages are expressed as a function of these people. These respondents provided details about the length and cause of delay, the weather at that time, and the way they learned about the congestion. This information is summarized below.

Among the pre-trip respondents, 60% learned about the unexpected congestion while at work and 40% while at home. For en route respondents, 55% of the incidents occurred on their way from work to home in the evening, while 45% of them occurred on the way from home to work. The cause of unexpected congestion for both cases is presented in Table I. Adverse weather and accidents accounted for most of the unexpected delays. Thirteen percent of the incidents were caused by accidents due to bad weather.

TABLE I
Cause of unexpected congestion among respondents

Cause of unexpected congestion	**Proportion'**	
	PRE-TRIP RESPONDENTS	EN ROUTE RESPONDENTS
Bad weather	50.0%	36.2%
Accident	41.3%	36.2%
Some other reason	17.4%	13.5%
Unknown reason	7.5%	17.3%
Disabled vehicle	5.4%	11.8%
Construction or road work	4.2%	10.4%

[1]The percentages sum up to more than 100% because some incidents may have more than one cause

Most unexpected delays occurred during rainy weather, as shown in Table II. A larger proportion of incidents occurring under inclement weather was reported by respondents who learned about the congestion before the trip than by those who learned about it during the trip. Since both groups used the same corridor during the same period, it appears that commuters are more receptive to pre-trip traffic information on days when the weather is inclement.

TABLE II

Weather at the time of the unexpected congestion

Weather	**Proportion**	
	PRE-TRIP RESPONDENTS	EN ROUTE RESPONDENTS
Rainy	69.8%	52.2%
Clear	20.0%	31.7%
Cloudv	9.0%	15.0%
Foggy	0.9%	0.9%
Windy	0.3%	0.2%

The way respondents learned about the unexpected congestion is presented in Table III. A majority of pre-trip respondents used secondary information sources, particularly radio traffic reports, to acquire travel information. A large proportion of en route respondents learned about the incident from two different sources. Some of them first observed the congestion, and then tried to confirm it and find out the extent of delay by listening to radio reports. Others first learned about the congestion through radio reports and then experienced the bottleneck.

TABLE III

Sources of information about unexpected congestion

Mode of information acquisition	Proportion[1]
PRE-TRIP RESPONDENTS	
Radio reports	66.7%
Observe congestion	32.8%
Television	16.8%
Word-of-mouth	10.9%
Telephone	4.9%
Other sources	4.2%
EN ROUTE RESPONDENTS	
Observe congestion	47.9%
First observe then radio reports	23.9%
First radio reports then observe	22.7%
Only through radio reports	11.2%
Other sources	1.8%

[1]The percentages sum up to more than 100% because more than one answer are possible

Respondents were asked about the delay they expected to face when they first learned about the unexpected congestion. They also had to report how much time the congestion actually added to their trip. Results are presented in Table IV, as a function of their behavioral response. People who had more than one response (such as leave later and cancel stops) were included in each relevant category.

TABLE IV

Expected delay caused by unexpected congestion on the usual route and experienced delay, as a function of the response

	Average delay (min.)	NO change	Chng. route	Take Transit	Add stops	Cancel stops	Leave earlier	Leave later
EN ROUTE RESPONDENTS	Expected	20.3	22.8	20.0	26.7	18.8	-	-
	Experienced	24.9	24.4	28.0	42.1	26.5	-	-
PRE-TRIP RESPONDENTS	Expected	24.7	27.5	38.8	39.9	28.4	26.8	38.8
	Experienced	27.6	27.2	43.7	38.1	28.1	27.7	33.5

En route respondents, on average, experienced more delay than what they first expected, independently of their response to the unexpected congestion. On the other hand, the pre-trip respondents who took an alternate route, modified their trip chaining sequence (added or canceled stops), or changed their departure time, experienced approximately the delay they were expecting (or even less).

The table also shows that people who diverted to transit did not, on average, save time as compared with the expected delay on their usual route. Savings (or losses) range from -20 to 20 minutes for the en route respondents and from -80 to 40 minutes for the pre-trip ones. Furthermore, the time added by the switchers to their trip is on average 25 minutes longer than the difference between their auto and transit travel times on a normal day. It therefore appears, based on this limited sample (N=16), that transit travel time is also affected by the unexpected congestion.

To obtain an idea of the accuracy of delay estimation, the difference between expected and experienced delays was computed for respondents who did not change their travel plans. Both en route and pre-trip respondents on average underestimated the length of delay, as shown on Table V. The absolute value of the difference is used to measure the average magnitude of the gap between the two values of delay.

TABLE V
Accuracy of delay estimation
for respondents who did not change their travel plans.1

	EN ROUTE RESPONDENTS	PRE-TRIP RESPONDENTS
Average difference (min.) (Experienced - expected delay)	4.8	3.3
Average absolute difference (min.) (experienced - expected delay)	9.4	10.7
Percentage of respondents within ± 5 minutes of experienced delay	53.5%	47.7%

[1]Results slightly differ from Table IV because of the presence of missing values.

Whether respondents learned about the congestion on the road or while at home does not significantly affect the accuracy of their delay estimation. The wide range of differences observed in both cases between the expected and the observed delay suggests that an ATIS device giving accurate length of unexpected delays might fulfill a need.

5.1 En route switch to public transportation

About one half (1492 respondents) of the total sample reported how they responded, while on the road, to unexpected delays on their usual commute route. The proportion of respondents switching to public transportation after facing unexpected congestion on the road appears limited.

About 3.5% of the people stated that they had an opportunity to park their vehicle and complete their trip by transit after learning about the unexpected congestion[1]. This small percentage of drivers with opportunities to divert can be explained by the fact that, in spite of the reasonable level of transit service and the fair amount of park-and-ride lots, most bus lines serving the corridor are nonstop after a certain point. Also, certain constraints, such as en route stops, equipment to carry, fear about the security at park-and-ride lots, intended connections at the other end, flexibility on return or just the lack of exact change, make public transportation not a possible option for many commuters. It might finally be that drivers' awareness of available transit services in the corridor is low. In that case, the introduction of a multimodal Advanced Traveler Information System including a database about transit routes, schedules, and parking facilities, could raise the public awareness of transit options.

Among the people who had an opportunity to switch mode, one out of seven (or 0.5% of the total sample) completed their trip by public transportation. There is thus some potential to convince drivers to switch to public transportation while en route, provided that information about opportunities to divert is made available.

5.2 Pre-trip switch to public transportation

The pre-trip response to the reported incident was studied with the rest of the sample (1746 observations). Although it is still marginal, a slightly larger proportion of respondents (1.6%) reported that they took public transportation in response to the unexpected congestion*.

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*Note that the wording of the question mentioned BART or Muni as examples of public transportation. The fact that these operators are not available for most of the commuters in the corridor might have slightly biased the answers toward less opportunities to divert.

[2]Recall that this percentage applies to the 60% of pre-trip respondents who faced unexpected congestion.

Commuters who switched were found to be more frequent transit users (1.38 times/week, on average) than those who did not switch (0.43 times/week)[3] Note that the frequency of transit use can be used as a proxy for transit accessibility. The switchers also live closer to their workplace: their average commute time by car is 38.9 minutes, compared with 46.4 minutes for the rest of the sample. Larger differences were reported for the transit travel time: 57.1 minutes for the people who switched vs. 76.4 minutes for others. People who switched to transit own, on average, fewer vehicles than others (1.94 vs. 2.37 vehicles/household). Furthermore, they are part of a less stable population: the switchers have stayed for shorter lengths of time than others at both their home site (3.7 vs. 7.3 years, on average) and their workplace (4.1 vs. 6.9 years). Finally, the switchers were expecting larger delays than the others (39 vs. 28 minutes) when they first learned about the incident. This last result suggests that the expected length of delay influences the propensity to switch to public transportation.

Using the usual travel time by car, the expected length of delay, and the travel time by transit, the potential time savings from the shift to public transportation were calculated, assuming that transit travel times were not affected by the delay. The switchers could have saved an average of 23 minutes by taking transit. A wide range of values were actually observed: one switcher lost 20 minutes, while another saved one hour. Most people, however, seemed to benefit from the switch.

6. STATED PRE-TRIP RESPONSE TO UNEXPECTED CONGESTION UNDER ATIS

To explore how ATIS could influence the switch to public transportation under unexpected congestion, stated preferences were intertwined with reported behavior. Respondents were placed in an hypothetical context where they had to repeat the trip

[3] All differences reported here are statistically significant at the 5% level.

before which they became aware of the unexpected congestion. They were asked to imagine that they were not aware of any congestion until an ATIS device provides them with accurate traffic information, at home or at work, 15 minutes before their departure. They had to base their preferences on what they remember of the actual traffic conditions on the day of the incident and on the usual traffic conditions on their best alternate route. Thus, by tying in the response to a new technology with a specific situation experienced previously, the realism of the scenario was increased and contextual factors were accounted for (Khattak *et al. 1993).*

Respondents were placed in a context where a pre-trip ATIS device gave them the following message *<<Unexpected congestion on your usual route>>* and suggested that they take public transportation instead of their car. They were given the following options:

TABLE VI
Stated response to pre-trip information suggesting
to take public transportation as a response to unexpected congestion

Response	**Proportion**
No change / Can not say	***23.3%***
Take alternate route	19.7%
Leave earlier	19.4%
Use public transportation	***18.3%***
Leave later	14.0%
Cancel trip	5.1%
Take bike or walk	***0.3%***

As seen from Table VI, almost one fifth of the respondents stated that they would switch to public transportation if a pre-trip ATIS device suggests they do so. This is a significant percentage that should nevertheless be interpreted with caution. To test external validity of the stated preference response, Table VII compares it with the reported behavior about diversion to transit.

TABLE VII
Stated preference for diversion to public transportation
vs. reported behavior

		REPORTED BEHAVIOR		
		did not divert to transit	diverted to transit	
STATED PREFERENCE	would not divert to transit	834 81.7%	4 0.4%	838 82.1%
	would divert to transit	**170** 16.7%	**13** 1.3%	**183** 17.9%
		1004 98.3%	**17** 1.7%	**1021** 100%

Most respondents who diverted to transit when facing the incident stated that they would repeat the switch if it was suggested by an ATIS device. There are also 170 people who did not use transit as a response to the incident, but who stated that they would if it was suggested by an ATIS device. In light of the small percentage of reported diversion to transit, this number might actually overestimate the impact of ATIS in causing a switch to public transportation. Indeed, because the switch was directly suggested, there might be a desire to please the interviewer, or simply a tendency to overstate preferences. The percentage of potential switchers still gives an upper bound for the propensity to switch to public transportation under incident conditions. The final number of people switching will be a function of ATIS performance in providing shorter travel time options to commuters. The time savings that could result from a switch are presented later.

6.1 Profile of the potential transit switchers

To verify the consistency of the stated responses, the characteristics of the 170 people who said that they would switch to public transportation were analyzed. These people reported that they did not switch to transit when facing a real-life incident, but stated that they would do so when suggested by a pre-trip ATIS device.

6.1.1 Personal characteristics and contextual factors

The potential switchers use transit more frequently than others (a proxy for transit accessibility) and drive alone to work less often, as expected (see Table VIII). They also travel less regularly for work-related purpose and drop off or pick up children less often. People who are constrained to make stops are less likely to switch to public transportation because of the inherent advantage of the private car in this case.

TABLE VIII

Differences in normal travel patterns between potential transit switchers and others

Travel pattern	Average weekly frequency[1]	
	People who stated they would switch	**Others**
Drive alone to work	**2.75**	**3.62**
Go to work using transit	**1.21**	**0.27**
Travel for work-related purpose	1.83	**2.40**
Drop off or pick up children	**0.50**	**0.91**

[1]All differences are statistically significant at the 5% level.

Most of the people who stated that they would switch to transit live on the Bay side of Marin County (79.3% of the origins), from Sausalito to San Rafael, and work in downtown San Francisco (79.5% of the destinations), especially around the ferry terminal. As reported previously, this origin-destination pair is the one best served by ferry transit in the study area. There is thus a clear correlation between the propensity to switch to public transportation when facing unexpected delays and the level of transit services available.

Because they live closer to their workplace than the rest of the sample, the potential switchers spend on average less time traveling to work (43.8 vs. 47.4 minutes) and coming back home (47.8 vs. 51.9 minutes) than others. The difference is even larger between the transit travel times (64.1 for potential switchers vs. 80.1 minutes for others). No significant differences exist between the two groups for the expected length of delay. The switchers leave work later than the rest of the sample (5:19 PM vs. 4:53 PM, on average), maybe because of shorter travel times. They also know on average fewer alternate routes than other commuters (0.95 vs. 1.18). Furthermore, for 5 1.7% of them, the best alternate route is a major highway, while this percentage goes up to 65.4% for the people who would not switch. The presence of a second highway as an alternate route might reduce diversion to transit. Finally, potential transit switchers were more likely to be female, live in smaller households, and own fewer vehicles.

There is more diversion to public transportation when the unexpected congestion occurs on the trip home (24.0%) than on the trip to work in the morning (16.5%). This result is surprising, given that people who switch to transit at work have to forego the use of their car in the evening. However, this effect may be compensated for by the high vehicle ownership of the sample.

The cause of the unexpected congestion also influences the switch to public transportation, as shown in Table IX. Commuters are most likely to switch in response to unexpected delays caused by bad weather, while disabled vehicles or accidents have a smaller effect on modal switch. Because delays caused by bad weather or accidents have on average the same length, other explanations must be found to explain why bad weather induces more switches:

- Adverse weather reduces overall road capacity (because people drive slower), while accidents and stalled vehicles have a more localized impact;
- Accidents and disabled vehicles are more unpredictable than bad weather; and,
- Transit is safer than the private car under heavy rain, fog, or ice conditions.

TABLE IX
Percentage of stated diversion to transit
as a function of the cause of incident

Cause of incident	**Stated propensity for diversion to transit**
Disabled vehicle	8.1%
Construction/ road work	14.7%
Accident	15.9%
Other/unknown	23.7%
Bad weather	25.5%

Finally, the mode of information acquisition does not have an significant effect on the propensity to switch to public transportation, as shown on Table X. Using the chi-square test, both variables were found to be independent.

TABLE X
Percentage of stated diversion to transit
as a function of the mode of information acquisition

Mode of information acquisition	Stated propensity for diversion to transit
Television	27.6%
Other sources	25.8%
Telephone	25.7%
Observe congestion	24.8%
Word-of-mouth	20.5%
Radio reports	20.4%

Overall, these results are consistent with what was expected and tend to confirm the validity of the stated preference responses.

6.1.2 Relative importance of factors distinguishing transit switchers from other commuters

Discriminant analysis was performed to obtain the most important factors distinguishing the potential switchers from the respondents who stated they would not switch[4]. Seven variables, all significant at the 10% level, were found to be most critical in distinguishing both groups (Table XI). The table presents, for each variable, its

[4]The 13 respondents who reported they did switch were excluded from this particular analysis.

coefficient in the discriminant function and its correlation with the function. Positive signs correspond with variables for which the propensity to switch increases as they increase.

TABLE XI

Discriminant analysis of transit switchers vs. others

Variable	**F-statistic Sign.**	**Standardized discriminant function coeff.**	**Correlation with discriminant function**
Frequency of transit usage (times/week)	0.00	+0.81	**0.79**
Unexpected delay caused by accident (0 = no. 1 = yes)	0.00	-0.37	**-0.39**
Type of best alternate route (0 = highway, 1= road)	0.02	+0.23	0.27
Recurring congestion at entrance of bridge (0 = no, 1 = yes)	0.09	+0.21	0.20
Transit travel time (minutes)	0.00	-0.16	-0.4 1
Incident location (0 = going to work, 1 = going home)	0.02	+0.13	0.28
Weather (0 = good, 1 = bad (rain or fog))	0.08	+0.09	0.20
Summary statistics Canonical correlation: 0.5 1 % correctly classified: 79% Sample size: 214			

The most important criterion is whether or not the commuter is a frequent transit user. Incident cause is also a crucial variable: fewer people switch to transit when the unexpected congestion is caused by an accident (as opposed to bad weather, disabled vehicle, road construction, etc.). The type of alternate route is important; less diversion to transit being observed where no major highways are available as alternate routes. Furthermore, recurring congestion at the entrance of the bridge significantly encourages diversion. Travel time by public transportation, as expected, is also critical variable: the longer the commute, the smaller the chances of diversion. Less diversion is observed when the incident occurs on the way home, as compared with the way to work. Finally, the weather at the time of the incident is the last critical variable, bad weather significantly increasing the chances of diversion.

These results suggest that ATIS is more likely to increase the frequency of transit usage of current transit riders, who now have a reasonable level of transit accessibility. Less diversion is expected in cases where public transportation is not a competitive alternative in terms of travel time.

7. BENEFITS TO POTENTIAL SWITCHERS

This section details the calculation of the time savings and associated monetary benefits that could be obtained by switching to public transportation in unexpected delay conditions.

7.1 Time savings achieved through diversion to public transportation

The most tangible user benefits of a switch to public transportation is a reduction in travel time. The savings are simply the travel time on the usual route to or from work, plus the actual length of delay, minus the travel time when using public transportation. For simplification, transit travel times were assumed to be unaffected by the unexpected congestion. This was done because a large proportion of commuters in the corridor use either ferries or buses on HOV lanes, all of which are usually able to avoid road bottlenecks. As shown earlier, however, the few respondents who reported a pre-trip switch to transit when facing a real-life incident apparently experienced longer than usual transit travel times. The results presented in this section should consequently be interpreted with caution.

Because travel times are reported by respondents rather than directly measured, they already are “perceived” times, and are likely to include the penalty of waiting either in a queue at a road bottleneck or at a bus stop. Therefore, no weights were assigned to any of the reported travel times when performing the calculations.

Figure 1 presents the distribution of travel time savings that would accrue to people who stated they would switch to public transportation, assuming unaffected transit travel times. Twenty-nine percent of the switchers would actually lose time by taking transit, 11% would see no change in their total travel time, while 60% would save some time. The average time saving for all potential switchers is 10.8 minutes per trip.

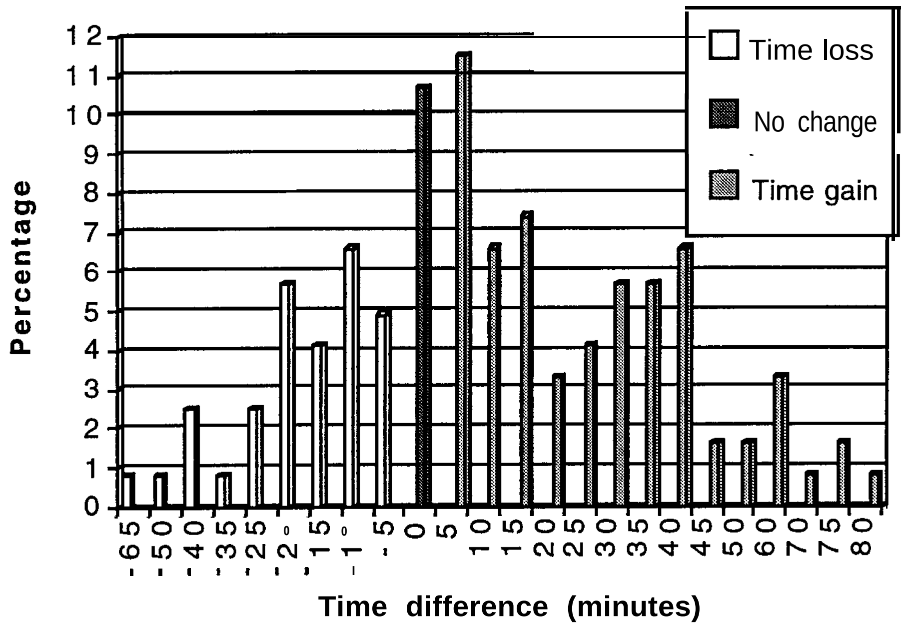

Figure 1: Distribution of travel time changes among the people who stated they would switch to transit

7.2 Monetary value of time

To attach a monetary value to time savings, an estimate of the value of time for each respondent is needed. To avoid aggregating a large number of negligible time savings into a large amount of money, the value of time was taken as increasing with time savings. Furthermore, to account for personal differences in the valuation of time, the value for each respondent was taken as a fraction of the personal hourly income (Hensher 1976). The function used is presented in Figure 2; it is adapted from a method presented by AASHTO (1978).

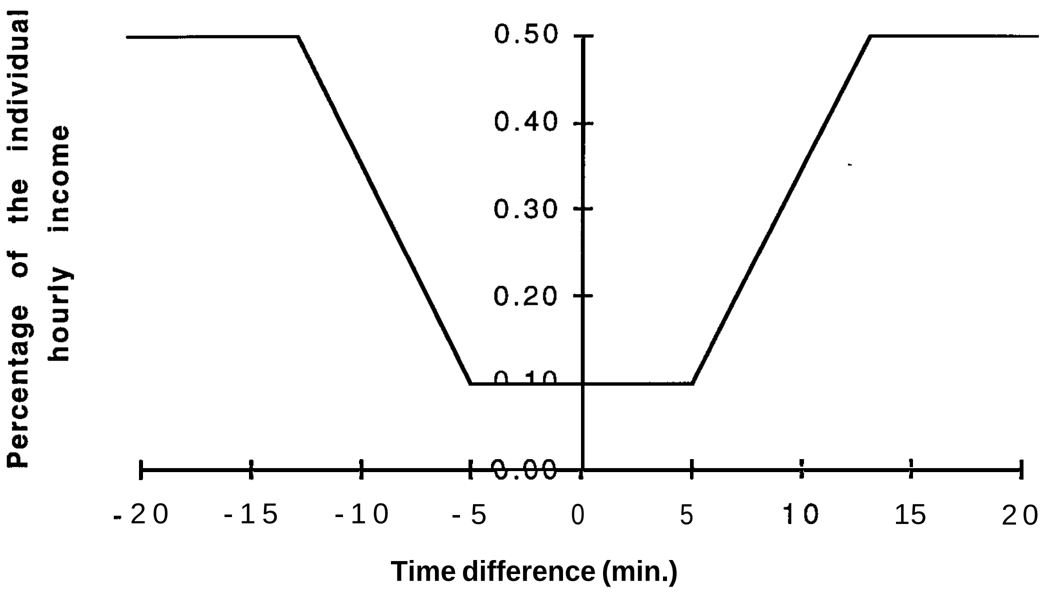

Figure 2: Function used for the monetary value of time

As can be seen from the figure, travel time variations within plus or minus five minutes are valued at 10% of the personal hourly income. Those larger than 13 minutes are evaluated using a value of 50% of the hourly income. Increases in travel time are assumed to have the same weight as corresponding savings, that is, small increases in travel time have negligible impacts.

7.3 Money benefits of diversion to public transportation

Figure 3 presents the distribution of monetary savings that would be achieved through a switch to public transportation under unexpected congestion. This was calculated by combining the time savings with the values of time for every respondent. The average saving for the sample is $3.24/trip; this value includes the 29% of people who lose time by switching to transit. When only the people who would save time by switching to transit are included in the average, the savings are $7.43/trip.

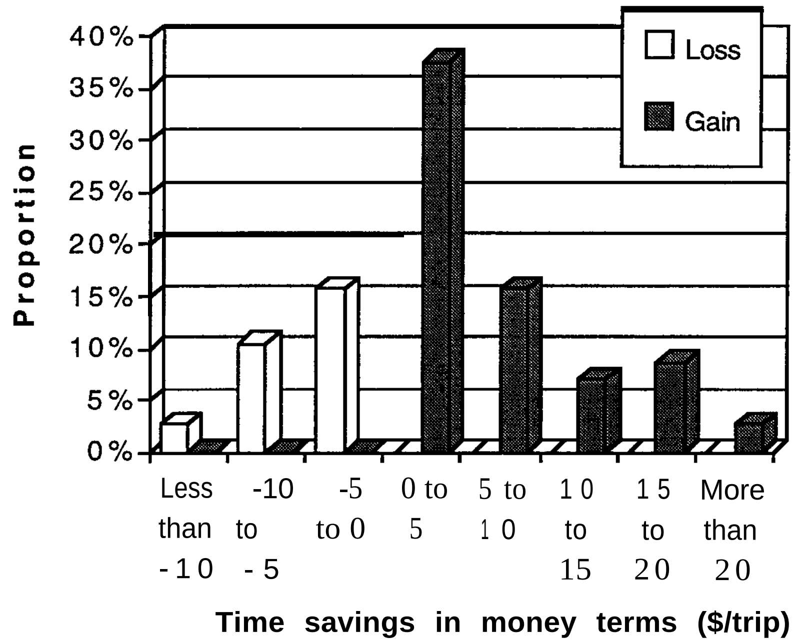

Figure 3: Distribution of monetary savings for people who stated they would switch to public transportation

7.4 Annual frequency of diversion to public transportation

The values presented in the previous section apply for a single trip with diversion to public transportation In order to evaluate the annual benefits of such diversions, it is necessary to estimate how frequently they would occur. A precise measure of switch frequency could be obtained using traffic and incident data in the corridor. For every O-D pair and time-of-day combination, it would be necessary to estimate how often an incident on the usual route would induce diversion to public transportation. However, all respondents differ in the minimum length of unexpected delay (threshold) that justifies a modification to the intended travel plans. The calculation would thus have to account for these different (and unknown) threshold values and for the fact that potential switchers are not on the road daily, since they are already frequent transit users. All these obstacles make it difficult, if not impossible, to know how often each respondent would switch to public transportation.

To overcome these difficulties, a proxy variable was used for the potential frequency of diversion to transit. When asked to report specifics of their recent unexpected congestion, respondents mentioned how long ago the incident occurred. If it is assumed that the occurrence of incidents follow a Poisson process, the time elapsed since the last incident is actually just the mathematical expectation of the time period between two incidents of at least the same size. The calculations leading to this counter-intuitive result are presented in Appendix. The number of weeks between two incidents can then be translated into an annual frequency of incidents experienced, assuming that respondents work about 48 weeks a year. Table XII presents the results and the corresponding frequencies of diversion to transit that were assumed.

TABLE XII
Potential frequency of diversion to public transportation
using the time since the most recent incident

How long ago did the most recent unexpected congestion occur?	**Corresponding frequency of incidents experienced**	**Potential annual freq. of diversion to transit**	**Proportion of potential switchers**	**Average expected delay (min.)**
Less than one week	Twice a week	96	5.4%	24
l-2 weeks	Every 1.5 week	32	10.2%	24
2+-4 weeks	Every 3 weeks	16	37.3%	28
l-2 months	Every 6 weeks	8	33.7%	30
More than 2 months	Every 12 weeks	4	13.3%	33

As seen from the table, the majority (70.0%) of respondents would divert either 8 or 16 times a year. A small proportion (5.4%) of respondents would divert as often as twice a week (out of 10 possible trips). These people might be frequent transit users with a high day-to-day variability in their modal choice, due for example to car or parking availability. They are likely to divert to transit as soon as traffic conditions deteriorate on their usual route.

The measure used for the frequency of diversion to transit, in spite of its approximate nature, has two important advantages. First, it incorporates the threshold value of all respondents since they are free to report the most recent unexpected delay they find worth mentioning. It is unlikely that smaller unexpected delays would be considered for diversion to public transportation. Furthermore, respondents who faced their incident longer ago apparently have larger threshold values, since they experienced longer delays (Table XII). They were accordingly assigned a smaller frequency of diversion. Second, people who are frequent transit users (such as the potential switchers), are less likely to be exposed to unexpected delays simply because they are less often on the roads. Indeed, it was found that potential switchers experienced their most recent incident longer ago than the rest of the sample (significant at the 5% level). The measure used for the frequency of diversion to transit takes this into account by assigning a small frequency to those people.

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[5] Recall that most of the commuters in the corridor use either ferries or buses on HOV lanes which are usually able to avoid road bottlenecks.

7.5 Annual benefits of diversion to public transportation

Combining the annual frequency of unexpected delays and the monetary savings achieved by trip, it is possible to calculate the annual benefits of-diversion to public transportation under incident conditions. Because the people who lost time by switching to transit are unlikely to repeat the switch when facing again similar conditions, they were

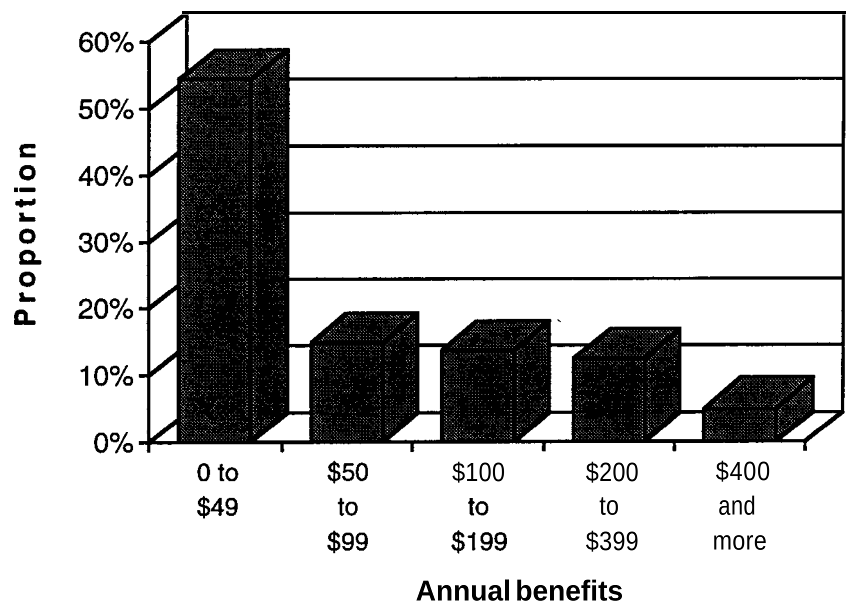

Figure 4: Annual benefits to the people who stated they would switch to transit and who would save time by doing so

assumed to have overstated their propensity to switch to transit and were not included in the calculation of annual benefits. The resulting distribution of annual monetary benefits is presented in Figure 4; values ranged from less than $1 to $5 12.

The average annual benefit of an ATIS-induced switch to public transportation is $108 per year per potential switcher. However, this value applies to only 7% of the auto commuters in the corridor (60% of respondents who saved time among the 18% of potential switchers, among the 63% of respondents who faced unexpected congestion).

8. MAXIMUM POTENTIAL BENEFITS OF DIVERSION TO PUBLIC TRANSPORTATION UNDER INCIDENT CONDITIONS

This section presents the maximum user benefits achievable by diverting commuters to public transportation under unexpected congestion. The analysis is based on the time difference between the diversion and non-diversion options and on the assumed frequency of unexpected delays. It does not take into account people's propensity to divert. It is assumed that every commuter, when facing a delay caused by unexpected congestion, would choose the option with the shortest travel time. Individuals who save time by taking transit would switch mode, while those who incur a longer travel time in transit would stay in their car. Although this appears to be a sensible assumption, it only provides an upper bound on potential benefits.

Almost half of the whole sample (47.6%) would experience a shorter travel time when taking transit to respond to an unexpected delay on their usual route to work. This was found assuming that transit travel times remained unaffected by the unexpected congestion. These people, *a priori,* would have an interest in diversion. However, only 24% of the respondents stated that they would divert to public transportation if an ATIS device suggest they do so. The people who stated they would divert are not necessarily the ones who should divert, as shown by the following contingency table:

TABLE XIII

Stated preference for diversion to public transportation vs. travel time difference between transit and car options

		TRAVEL TIME DIFFERENCE BETWEEN TRANSIT AND CAR OPTIONS		
		shorter to stay in car	shorter to divert to transit	
STATED PREFERENCE FOR DIVERSION TO TRANSIT	does not divert to transit	**196** 40.9%	**144** 30.1%	**340** 71.0%
	diverts to transit	**55** 11.5%	**84** 17.5%	**139** 29.0%
		251 52.4%	**228** 47.6%	479 100.0%

A chi-square test revealed that the variables are related, as expected. However, they are only weakly correlated: both the phi-coefficient and the Pearson's R equal 0.16. The contingency table shows that 30.1% of the total sample stated they would not divert when they could have saved time by doing so, while 11.5% of the total sample stated they would divert even though it would cost them some time.

Clearly, travel time differences alone do not have sufficient explanatory power in determining the propensity to divert to public transportation. The people who could save time by switching but did not say they would switch might have been motivated by the following:

- Their mode choice decision is based on other elements beyond travel time differences, such as time and space constraints, household structure, etc.;
- They expected transit travel time to increase as well (we assumed it would not);
- They value transit travel times (walking, waiting, riding, transferring) and time spent in vehicle bottlenecks differently.

The calculations performed here can be used, however, to obtain a theoretical upper bound to the potential travel time benefits of diversion to public transportation, since the largest benefits are obtained when everyone uses the shortest time option. Time savings were found to range from 2 to 90 minutes per trip, with an average value of 26 minutes. Using the method presented earlier to assign monetary values of time, the savings per trip ranged from $0.08 to $41.25, with an average value of $7.54. Based on the same frequency of diversion as before, the annual benefits ranged between less than $1 to $2072, with an average of $116 per person per year. Thus, given the current commuting patterns and frequency of unexpected delays, ATIS-induced diversion to public transportation can not bring time savings worth more than $120 a year per person; this value applies to 48% of the sampled population.

9. CONCLUSION

This study investigated the propensity to switch to public transportation under unexpected congestion. It analyzed the reported and stated propensity to divert to transit under a multimodal ATIS and calculated the benefits that could be expected from such a switch.

The response to unexpected congestion was explored both for people who learned about the incident on the road and before the trip. Only a limited proportion of commuters (0.5%) diverted to public transportation while en route, mostly because few opportunities to park the vehicle and switch mode were perceived as available. A larger but still limited proportion of commuters (1.6%) switched to transit as a pre-trip response to the unexpected congestion. These people were predisposed to public transportation, had greater transit accessibility, and faced a longer delay than the rest of the sample. They did not save time by switching, implying that transit travel times might be affected by unexpected congestion. However, under the assumption that it is not affected (in corridors where rail is available, for example), they would have saved about 20 minutes of travel time by changing mode.

As many as 18.3% of respondents stated that they would switch to public transportation if suggested to do so by a pre-trip ATIS device before their most recent trip where they became aware of unexpected congestion. In light of the small reported percentages of diversion, this number is interpreted as an upper bound for the proportion of switchers. Potential switchers were found to be more frequent transit users than others, have no highway to divert to as an alternate route, experience more recurrent congestion at the entrance of the Golden Gate Bridge, and have shorter transit travel times. The cause of the unexpected congestion also influenced the propensity to switch to transit, accidents inducing less people to switch than adverse weather.

Sixty percent of the potential switchers would have saved some time by switching to public transportation when they faced the incident. This is an interesting finding, given that the switch to public transportation is primarily intended to provide system benefits. The average time saving for all potential switchers amounts to 10.8 minutes, a value that can be translated to $3.24 per trip. When considering only the potential switchers who would save time by taking transit, the savings per trip amount to $7.43 and the average annual benefit of ATIS-induced diversion to transit is $108 per person (this value applies to only 7% of the commuters in the corridor). Recall that the calculation of benefit assumed that transit travel times remained unaffected by the unexpected congestion. Because this may not exactly be the case in the Golden Gate corridor, the savings might be even smaller. The calculations performed here are more applicable in corridors where rail transit is available.

It seems that prescriptive information (combined with descriptions of the cause and length of delay) has the potential to divert a certain segment of the population to mass transit under unexpected congestion. This population is pre-disposed to public transportation: it has greater transit accessibility, shorter transit travel times, lower vehicle ownership, and lives in smaller households. Further, more diversion is expected under adverse weather and in corridors where good route alternatives do not exist. Designers of multimodal ATIS should therefore focus on the segment of the population with good transit accessibility. They should also recognize that few diversions will be achieved whenever public transportation does not offer an attractive alternative to the private automobile. In addition to transit travel time, route and schedule information, ATIS devices should emphasize opportunities to switch modes and provide detailed park-and-ride information. Because information by itself will not be sufficient to achieve mass diversion of drivers to transit, the development of a multimodal ATIS should be part of a comprehensive strategy (including the development of park-and-ride lots, for example) intended to make transit a more attractive alternative to the private automobile.

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APPENDIX

This appendix details the calculation of the expectation of the time period between two incidents. Consider a time period made up of intervals between incidents. The probability of making an observation (distributing a questionnaire) during an interval of length x is:

$$\frac{x\,p(x)}{\int_0^\infty x\,p(x)} = \frac{x}{\mu}\,p(x)$$

where: p(x) is the probability that the interval length is x;
μ is the average length of intervals.

Now, given that the observation is made during an interval of length x, the expected time since the last incident is x/2. This is because observation points are uniformly distributed over the whole interval. Therefore, the expected value of time since the last incident (t) is:

$$
\begin{aligned}
E(t) &= \int_0^\infty \frac{x}{\mu}\,p(x)\,\frac{x}{2}\,dx \\
&= \frac{1}{2\mu}\int_0^\infty x^2 p(x)\,dx \\
&= \frac{1}{2\mu}(\sigma^2 + \mu^2) \qquad \text{Because } VAR(X) = E(X^2) - (E(X))^2 \\
&= \frac{\mu}{2}\left(\frac{\sigma^2}{\mu^2} + \frac{\mu^2}{\mu^2}\right) \\
&= \frac{\mu}{2}(k^2+1)
\end{aligned}
$$

where: σ^2 is the variance of the length of interval;
k is the coefficient of variation.

Now, assume that incident occurences follow a Poisson process of rate λ. It implies that interval length has an exponential distribution. Therefore,

$$E(X) = \mu = \frac{1}{\lambda}$$

$$VAR(X) = \sigma^2 = \frac{1}{\lambda}$$

And:

$$E(t) = \frac{\mu}{2}\left(\frac{1}{\lambda^2}\,\frac{\lambda^2}{1} + 1\right)$$

$$= \mu$$

$$= E(X)$$

In our case, since t_0 (the time since the last incident) is taken as an estimator of E(t), it is also an estimator of E(X). Therefore, the average time lag between two incidents can be estimated from the time since the last incident was observed.