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Assessing the Benefits and Costs of Intelligent Transportation Systems: The Value of Advanced Traveler Information Systems

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Assessing the Benefits and Costs of Intelligent Transportation Systems: The Value of Advanced Traveler Information Systems

David Levinson, David Gillen, Elva Chang

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Abstract

Recent literature has extensively discussed the social costs of highway travel. Over the next few years, driver behavior should become more informed with the advent and deployment of in-vehicle navigation systems. Information technology will provide the driver the minimum travel time between his or her current location and final destination, updated to consider real-time recurring and non-recurring congestion. This paper considers the effects of those systems, which not only reduce the driver's travel time and vehicle operating costs, but also have positive or negative external travel time effects for other commuters and environmental effects for society at large. Furthermore, over the long term, such systems may reduce the need to construct additional highway infrastructure, or may induce additional demand.

The effects of social and technical change such as in-vehicle navigation on the environment are quite complex. Whether the technology of in-vehicle navigation systems move transportation towards or away from environmental sustainability cannot easily be foretold. The effect of traveler information is to shift both the supply and demand curves for travel. By making the transportation system operate more efficiently and by reducing stopped delay and vehicle minutes of travel for a particular trip, there should be some positive environmental outcomes. However, the same cost reduction will increase travel demand.

The traveler's full cost per trip is comprised of a bundle of costs, which include the expected travel time, monetary cost, quality of the trip, and reliability (e.g. the probability of being late). Individuals will be willing to endure a higher expected travel time on trips with lower variance or higher reliability. Two effects will cause the total number of trips to rise. First, there is movement along the demand curve as the expected travel time (price of travel) is reduced. Second, as the quality of trips increase due to improved reliability, there is a greater willingness to make a trip at a given cost (travel time), implying a shift of the demand curve. After reviewing the literature on information and travel behavior and on the value of time, this paper explores complex topics from a theoretical economic perspective and then simulates stylized cases.

Keywords: Transportation Information Systems, In-Vehicle Navigation, Full Cost of Transportation, Social Costs of Transportation, Advanced Traveler Information Systems

Introduction

Recent literature has extensively discussed the social costs of highway travel (Keeler et al. 1974, Fuller et al. 1983, Quinet 1990, Mackenzie et al. 1992, INRETS 1993, Miller and Moffet 1993, IWW/INFRAS 1995, IBI 1995, Delucchi 1996, Levinson et al. 1998). Over the next few years, driver behavior should become more informed with the advent and deployment of real-time in-vehicle navigation systems. These will provide the driver the shortest path between his or her current location and final destination, updated to consider real-time recurring and non-recurring congestion. In the absence of choice, information is of relatively little value. However, many drivers have the opportunity to select dynamically between alternative routes, modes, schedules and activity locations. This paper considers the full economic value of those systems. We posit that they not only reduce the driver's travel time and vehicle operating costs, but affect (either positively or negatively) the travel time of other commuters. Moreover, there are environmental effects for society at large. Furthermore, over the long term, such systems may reduce the need to construct additional highway infrastructure, or they may induce additional demand. It is natural to expect that there will be environmental consequences, either positive or negative, but it is too early to say whether, and by how much, the reduction in stop-and-go traffic is offset by additional demand.

With an Advanced Traveler Information System each traveler individually, and the road network as a whole, could be made more productive if travelers were informed in real-time about the best available route between their current location and their destination. Current travelers would save time by being informed, while dynamic (and stochastic) variations in the utilization of transportation capacity could be smoothed out, thereby resulting in a higher traffic throughput.

This paper begins by conducting a literature review of the studies that have examined, mostly hypothetically, but also from some field operational tests. We then develop an ATIS typology of traveler information technologies. The next section asks whether traveler information is a public or private good, and thus who should provide it. We consider some possible sources of information, in particular vehicle probes, to see how accuracy of the system varies with the number of probes. Then we qualitatively discuss some problems with traveler information systems. Our model is developed and applied to some stylized cases. We conclude with a discussion of the effects of traveler information and some consequences for public policy. The appendix includes annotated bibliographies on the field of ATIS and on induced demand.

Literature Review

Our literature review summarized in Table 1 focuses on studies about the benefits from ATIS systems. Emmerink et al. (1995a) examine the effects on traveler behavior of various kinds of information using simulation. In one paper they examine the effects of information in the case of route switching with recurring congestion. They employ bounded rational user equilibrium (satisficing), so that with the provision of en route information, route switching is carried out only if the improvement in the expected remaining travel time of alternative route compared to the expected remaining travel time of the route currently chosen exceeds a certain threshold. Thus, the number of routes used decreases as the bound (indifference band) increases. They suggest a steady state travel time reduction of 7 percent compared to the base case (no switching). Examining the network with stochastic perception of travel times (Emmerink et al. 1995b), the authors conclude that information is beneficial to both informed and uninformed drivers, and as the level of market penetration goes higher, the gap of expected travel costs between informed and uninformed travelers shrinks. When the percentage of informed drivers is relatively low, informed travelers can switch to the least cost route. However, as the percentage of informed travelers increases and the equilibrium principle of informed drivers ensures that the travel costs on all routes in the network are identical. Extending the model from one to two origin-destination pairs, Emmerink et al. (1995c) find that while information still increases overall welfare (for both the informed and uninformed together), it may have negative effects for the uninformed.

Al-Deek and Kanafani (1989) try to estimate the benefits, in terms of total travel time saved, from vehicle route guidance in urban network with the aim of moving route selection from user equilibrium to system optimal. Total timesavings are typically on the order of 3-4%, but are sensitive to network parameters, particularly city street speed. There is a little gain from route guidance if there is a severe shortage of freeway capacity or if there is ample freeway capacity – it is most effective at the edge between congested and uncongested conditions. Al-Deek and Kanafani (1993) investigate the application of ATIS for incident management using a deterministic queuing model. Over the period of the incident, equipped travelers are always better off than unequipped travelers. However, once the alternate route starts to have a queue, the system benefits decrease.

Vaughn et al. (1993) investigate drivers' learning and pre-trip route choice behavior over time under the presence of ATIS by an interactive route choice simulation experiment. All subjects choose one of two possible routes throughout 32 simulation days, each day with a random amount of delay on each route. Three separate groups of subject drivers were run through simulation at three levels of accuracy of information, 60 percent, 75 percent, and 90 percent. At the end of 32 simulation days, subjected drivers were asked to rate their potential for purchasing a traffic information device, their perceived accuracy of the device, and their own ability at selecting routes when compared to the information device. Males are more willing to accept advice than females, and make their decisions faster. Experienced drivers are not as willing to accept advice as less experienced drivers. Travelers are more willing to accept advice to divert to a freeway rather than local route. Males and less experienced drivers are less willing to purchase an information system.

A survey on the Golden Gate Bridge was conducted by Khattak (1993) to understand how people deal with congestion and how they might respond to a multi-modal ATIS. He found that currently available real-time traffic information broadcast through the electronic media provides a basis for making travel decisions, but that 45% of people didn't change their route in spite of having advance information. When faced with the hypothetical situation of having an ATIS device provide them with information, respondents were inclined not to change routes unless the device specifically advised this action or gave specific information about delay times on the usual route. When monetary incentives were offered to ATIS equipped travelers for following system optimal advice, particularly when the advice conflicts with their usual route and departure time selection, potential participants showed a willingness to change route and departure time. When offered \$25, \$50, \$75, and \$100, about 20%, 29%, 42%, and 76%, respectively, would definitely leave 30 minutes earlier than normal once a week.

Khattak et al. (1998) develop a simulation comparing user choices when different market segments are given different sources of information (ATIS with full compliance, radio reports, and observation). With the full compliance ATIS model, the average delay for all travelers under both under-saturated and over-saturated conditions decreases with an increase in market penetration of equipped travelers. However, no significant reduction in delay is observed when penetration level is around 50%. They find that the benefits of an ATIS under incident conditions are marginal; however, there are cases where active guidance can produce significant system benefits.

Wunderlich (1996) estimates the time-savings from 10% use of dynamic route guidance for three scenarios: rainstorm (25% overall), construction (50% localized), and incidents (localized with a 20 minute time lag). 10% market penetration is assumed for each service. He finds that 72% of an equipped user's delay could be reduced in the construction scenario, 45% in rain, and 49% with an incident. Overall system delay was reduced respectively by 18%, 12%, and 6%.

Sengupta and Hongola (1998) examine the potential benefits of using Changeable Message Signs (CMS) for the management of non-recurring congestion during the AM peak in the I-10 Smart Corridor using a simulation model. The impact on four different control strategies and different levels of market penetration are modeled, assuming that incident duration is 20 min. Strategies that continue to divert traffic after the incident clearance yield more saved time. The more the traffic is diverted, the more the travel time savings. The time saved at 15% diverted traffic ranges from 6% to 16%, and from 11% to 20% in case of 20% and 40% reduction in capacity, respectively. When incident duration is reduced from 20 min to 10 min, 5.7% of time would be saved even with no diversion.

Adler et al. (1999) investigate in-vehicle route guidance with a network simulation model which incorporates the idea of complexity (indexed by the number of turns or changes in roads). Under freeflow conditions, the greatest reduction in travel time for equipped vehicles occurs at market penetration rate 10%. As is generally the case, travel time benefits decrease as market penetration increases. At 100% penetration, the improvement over the base case for informed drivers is smaller.

Several Field Operational Tests (FOT) have been conducted in the U.S. as well as elsewhere. The INFORM program in New York as well as the Sirius Project in Paris used variable message signs and other ITS technologies, finding significant savings in the case of incidents. The SmarTraveler program in Boston used the telephone, a less than ideal user interface, to provide real time information, and found that users changed their travel patterns. Pathfinder, in the Los Angeles region is a real-time in-vehicle navigation system FOT conducted on the I-10 Smart Corridor. Surveys from users indicate that 64% of regular commuters believed the system helped them to save time, while 75% of those driving to an unfamiliar destination believed so. The STORM project in Stuttgart is similar, 87% of participants felt that the individual route guidance system is helpful, while 40% of participants reportedly changed routes for regular trips according to system recommendations. Over two thirds of the interviewees felt that the system helped to save travel time. According to simulation results, vehicles fitted out with route guidance equipment use 20% less time, while non-equipped vehicles also take slightly less time to complete the trip. The TravTek system in Orlando was studied with surveys of respondents and simulation studies, serving primarily tourists using rental cars, thus suggesting what happens for unfamiliar trips. Two-thirds of those surveyed would be willing to pay about \$1,000 for a device similar to TravTek. According to simulation, total trip time decreases by about 11% when market penetration reaches 50%. Fuel consumption decreases but at a slower rate. Equipped vehicles have a “one-minute” average trip time “advantage” over non non-equipped vehicles. Schofer et al (1997) and Saricks et al (1997) describe the ADVANCE system. ADVANCE (Advanced Driver and Vehicle Advisory

Table 1: Summary of Time Saved with ATIS by Study

Author	Congestion Level/Type	Time Saved:	Market Share
Adler, Blue & Wu (1999)	Free Flow (800vph)	2.7%	100%
	Congestion (1500vph)	3.1% (highest)	80%
Al-Deek and Kanafani. (1989)	Difference in SO and UE.	3-4%	
Emmerink (1996)	Recurrent Congestion	1%-4%	100%
Emmerink Axhausen, Rietveld. (1995)	Recurrent Congestion	7%	
STORM, Stuttgart, Germany, (1996)	Field Operational Test Simulation	20%	
TravTek, Orlando, FL (1998)	Field Operational Test Simulation	5%	10%
		8%	30%
		11%	50%
Wunderlich (1995a)	Congestion but not reaching saturation	8-20%	5%
	Saturation	7%-12%	5%
Wunderlich (1995b)	Capacity-reducing incident	15%	
Wunderlich (1996)	Rain (25% drop in overall capacity)	12%	10%
	Construction (50% drop in capacity locally)	18%	10%
	Incident (50% drop in capacity locally)	6%	10%

Note: Time Saved **Overall** or *Equipped Vehicles Only*

Navigation Concept) is an in-vehicle advanced traveler information system (ATIS) that operated in the northwest suburbs of Chicago, Illinois. It provides OD shortest-time route guidance to a vehicle. The path is based on an on-board static (fixed) data base of average network link travel times by time of day,

combined as appropriate, with available dynamic information on traffic conditions provided by radio frequency communications to and from a traffic information center.

Typology of Traveler Information Technologies

To better understand the differences in technologies, we define a hierarchy (see Table 2) of travel information based on the information attribute, they affect. This shows the gamut of travel information for which value may be determined. Our study focuses on the economics of real-time en route vehicle guidance.

Table 2: Hierarchy of Traveler Information

Type	Points	Temporal Specificity	Spatial Specificity	Information Content	User Specificity
1. Permanent Signs and Markings	5	None	High	Low	None
2. Traffic Information Reports (Metro Traffic, Shadow Traffic)	5	Delayed	Low	Medium	None
3. Traffic Radio (AM 560, AM 1610)	7	High	Medium	Medium	None
4. Signals	7	High	High	Low	None
5. Variable Message Signs	8	High	High	Medium	None
6. Pre-Trip Route Specific Information Reports (construction, incidents; transit schedules) (TRAVINFO)	9	Low	High	Medium	High
7. Pre-Trip Route Planning (No Travel Time Info) – Available Now on Web	9	Low	High	Medium	High
8. Pre-Trip Route Planning (With Travel Time Info)	10	Delayed	High	Medium	High
9. Dynamic (in-vehicle, real-time) Route Guidance/ Navigation	12	High	High	High	High
10. Dynamic Route Guidance with driver/ vehicle feedback	13	High	High	Very High	High

Note: Points: Very High = 4, High = 3, Medium/Delayed=2, Low = 1, None=0

The quantity of information provided by different types of traveler information varies. The most basic types (1, 2) do not help with route or departure time selection, but the more fundamental issues of vehicle control - these signs, markings, and signals are a form of information for travelers, but not what is generally

referred to by traveler information systems. At the low-end (3), we presently have radio updates of traffic on major facilities every 10 minutes, while information is available on all incidents in the region. There are also electronic messaging signs (5), particularly useful around construction sites. Mid-level services, pre-trip route planning and reports (6-7) are available but not widely used as they are not easily accessible in the vehicle or do not provide sufficient value-added for most trips. However at the high end (8-10), dynamic (real-time) personalized routing information is technically feasible and, with the advent of lower cost geographic positioning systems (GPS), could become widespread in the near future. This is often called Electronic Route Guidance.

It is not obvious who (public or private sectors) should provide high end travel information services. A single electronic messaging sign, or vague generalized (non-personalized) traveler information, is of extremely limited value. In the absence of high end services it may be better to have low end services than nothing, witness radio stations employing firms such as Metro Traffic and Shadow Traffic to compete on traffic broadcasts. However, these low-end services are unlikely to generate direct revenue from individual travelers, either to purchase special equipment or to subscribe, and will remain advertiser supported. Our research focuses on real-time Electronic Route Guidance, which incorporates Pre-Trip ERG.

The question also arises as to the emergence of standards for a given technology, so that equipment, particularly in-vehicle equipment is interchangeable between regions and among providers. The value of the system as a whole depends on its interchangeability. The willingness of consumers to pay money for a system depends on its utility and thus interchangeability. We assume that there will be an open, rather than closed, architecture for the system. However, there is a National Architecture for the US and this standard will effect the conformity of the emerging technologies.

Who Provides Advanced Traveler Information Systems

Who provides the traveler information service is inextricably linked with what objective is used to decide how information is distributed. The appropriateness of the provider further depends on whether traveler information is a public or private good.

Two criteria can help classify a good as public or private: excludability and rivalry. Excludability implies that the good's provider can prevent a user from obtaining it without charge. National defense for instance is non-excludable, America's nuclear weapons protect anyone in the country, whether or not they want it. On the other hand, the sale of anything in a store is excludable – the owner can prevent a customer from obtaining a good unless the customer pays (assuming enforceable property rights etc.).

Rivalry implies that one person's consumption of a particular good prevents another individual from consuming it. National defense again is non-rivalrous – one person's protection does not prevent another's protection. Shoes are rivalrous, only one person can wear a pair at a time. Public goods are non-excludable and non-rivalrous, private goods are both excludable and rivalrous. Club goods (for instance a country club membership) are excludable, but non-rivalrous (in the absence of crowding). Finally, there are goods that are rivalrous but not excludable, for instance a crowded street. While an individual cannot be excluded from a city street that person's presence may cost you extra time and the occupation of space does prevent you from occupying the same space at a given time. We call these "congesting" goods. (Note that limited access highways are potentially excludable, unlike city streets.)

These ideas are illustrated in Table 3. The definitions of the goods are based on two attributes, excludability and rivalry. Excludability means that property rights must be well defined and assignable so people can be prevented from using a good or service. Rivalry means my consumption prevents someone else from consuming the good or service. So for example our highways are non-excludable and are rivalrous. This is what gives rise to too much use. When we are considering how to represent information and how and whether it has value, these two attributes form a useful framework within which to organize our thinking.

So what properties does information possess. Is it excludable or rivalrous?

“For your eyes only.” Information is potentially excludable. Its viewing can be limited to a fixed number of eyes. Information is excludable assuming some sort of encrypted or scrambled communication system between information provider and information consumer.

Table 3: Defining Public, Private, Club and “Congesting” Goods

		Excludability	
		Yes	No
Rivalry	Yes	Private	“Congesting”
	No	Club	Public

“Information wants to be free.” Information is non-rivalrous, my possession of information does not prevent you from having it. However, your possession may diminish the value of my information. Scarce or unique information can be more valuable to its possessor than common knowledge. While the information itself is non-rivalrous, the production of information is less so, there are limited computer resources, generating the information has some costs, for instance developing the route for consumer A may delay the computation for consumer B.

Nevertheless, collecting, processing, and transmitting information all have a relatively high fixed cost, and a low (and not necessarily rising) variable cost. An infrastructure to collect, process, and distribute information must be constructed, but once constructed, adding an additional user is relatively inexpensive. This is what makes it non-rivalrous. Furthermore, this economic structure of high fixed and low variable costs suggest that marginal cost pricing won’t work. The second best solution is average cost pricing. Average cost pricing will exhibit declining costs with the number of users, the larger the network (the number of users), the lower the cost. Ramsey Pricing may also be a reasonable alternative.¹

Figure 1 illustrates the demand and supply of information. We can represent the demand for information as, D, a regular type of downward sloping demand curve that indicates as information becomes less expensive people would want more of it. The value people place on information is reflected in the demand curve – a steep curve reflects high valuation and few substitutes and a flat demand curve reflects many substitutes. As more people have information, something we consider in detail below, the value people place on information will change.²

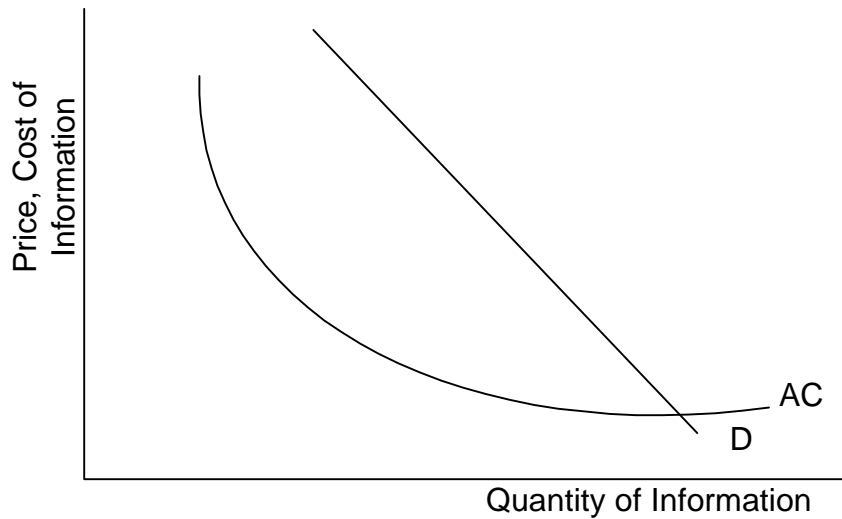
The cost of supplying information is reflected in the unit or average cost curve (AC). Notice the added cost of more information is less and less as more information is supplied. This would generally be the case. The reasoning is that the fixed costs of collecting and organizing information are quite high but the cost of providing it to additional people is quite low. Hence as more information is distributed the unit cost function will tend to fall and follow the path depicted in Figure 1.

Traveler information’s excludability and non-rivalry most closely resembles a club good. Club goods can be provided successfully by the private or the intermediate (non-profit) sectors. They do not require government provision, though many club goods are publicly provided (for instance recreational facilities).

¹ Ramsey pricing involves setting prices in relation to the inverse of the elasticity of demand. It is considered an economically efficient form of pricing since prices are first set equal to identifiable marginal costs for each market segment. These prices are increased above marginal cost in inverse proportion to the elasticity of demand in order to cover all common or joint costs. This process continues until total costs are equal to total revenues.

² Specifically it will shift the demand curve. See Figure 2 below together with the explanation.

Figure 1: The Demand and Supply of Information



If government is providing information, should it provide a user optimal (UO) or socially optimal (SO) route? If the jurisdiction is welfare maximizing, it should attempt to route people for the benefit of all - this implies convincing people to engage in a socially optimal route. Of course, if that socially optimal route is noticeably inefficient for individual users, it will be ignored.

Government provision of socially optimal information raises the further question of how to encourage information recipients to accept that information. Some incentive must be in place to overcome the extra user time involved in engaging in a non-user optimal solution. So how should government structure those incentives? We can speculate on some possible incentives:

Free or Discounted Information. The government might provide only SO routes, and provide them for free or at a low cost. Further there could be a cash kickback of a sort to those who chose the SO route, this however lends itself to gaming and abuse. Furthermore, unless a large number of individuals choose the socially optimal paths, they are unlikely to be effective (self-interested travelers will switch routes to take advantage of the changed path of the “SO” driver).

Subsidized Travel. In the ideal case with electronic road pricing, travel on the SO route might cost less to users than travel on the shortest time path route. However this is really using pricing to determine the minimum generalized cost (time + money) path rather than information as we generally perceive it (of course a price contains information).

Private provision is much more straightforward. A private firm will provide users with user optimal routing information without question, or they will soon go out of business. One can imagine their advertising campaigns touting the time saved compared with non-users or consumer’s of other firms services.

We may see multiple information providers, the government providing free System Optimal information while private firms charge for User Optimal information. We might then ask if the government information is at all useful. If only a fraction of users switch from UO to SO routes, others will change their UO routes.

Therefore, overall no gain may take place. There is a fundamental question of how many people need to switch to SO for mixed public/private information provision to work.³

Sources of Travel Information

As of this writing, it is 1999. Why isn't a system to tell commuters the fastest route to their destination in real time widely deployed? The technology to provide this information has been tested for over a decade. Transportation analysts can find the shortest route between two points given the times on each link with modern computers. Communications systems can transmit the request for information and the result between a mobile phone and a base station. Devices can display that information in the vehicle.

The problem is the lack of data, transportation agencies still cannot tell users the travel speed on each segment of the freeway network, much less the arterial system. While many technologies (loop detectors, video cameras, laser, radar guns) can measure link speed, none are sufficiently cheap and reliable and none have been installed ubiquitously.

An institutional economist might argue that the information is not available because the incentive structure is wrong. What incentive does a public highway agency have for reducing travelers' time or increasing the number of users? There is no reward for efficiency.⁴ In fact, efficiency probably would lead to less new construction, fewer staff, and less budget. That suggests considering alternative sources and institutional arrangements.

Information is a two-way street

How does the information provider get its information? How does it develop "value-added" against its competition. The conventional answer is permanent monitoring stations on the freeway (cameras, loop detectors, etc.) There are alternatives.

Each consumer of information can become a probe vehicle to update times for the information provider and thus provide information that is more accurate for the next consumer. More members implies more value for the club. This integration of consumption and production of information is a very interesting and relatively unexplored topic. The information provided can remain within a network (club), so that the larger the club, the more valuable it is. Though there may be multiple sustainable clubs (and diminishing marginal returns to club size), small clubs are less valuable than large ones. The American Automobile Association (AAA) for instance would seem an ideal organizational structure. We could imagine that service is provided as part of dues, where each user installs GPS and user-end communications, while AAA warehouses and serves the information.

An information network becomes more valuable the more users it has providing real-time data. This is referred to as a network externality. The demand for this information (say from a real-time Electronic Route Guidance system) slopes downward (low demand at high prices, higher demand at lower prices) but shifts upward as the number of consumers rises. Complementarity between network components leads to network externalities (Economides 1996). While drivers provide a negative externality to other drivers at the same time due to congestion, drivers a little ahead of you can tell you of traffic conditions. This information might encourage you to change your anticipated route and provide a positive externality if you share an information network. The more links that are covered by drivers in your information network, the greater the quantity, freshness, and accuracy of the information.

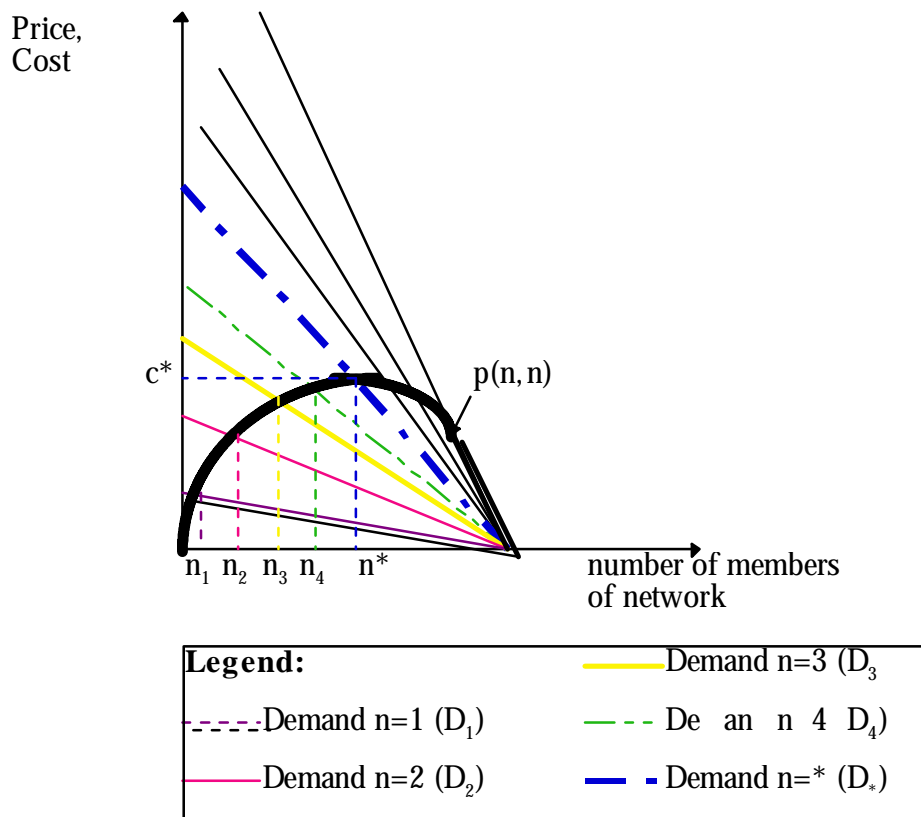
³ As always, the difference between UO and SO routing is due to market failure. UO route choice is based on private cost perception while SO is based on social costs. Any one choice effects the costs of others so unless all users have complete real time information there will be a divergence between UO and SO routing.

⁴ One can refer to personal satisfaction and minimizing political costs but these are idiosyncratic and are not part of an incentive scheme or which could be integrated into a contract.

Figure 2 constructs the revealed demand curves for positive network externalities. Let $P(n; n_e)$ be the willingness to pay for the n th unit of the good when n_e units are expected to be sold (assume each consumer purchases only one unit of the good). The network is more valuable the more units are sold. With only one consumer, ($n=1$), the network is not particularly valuable, so the implicit demand at $n=1$ (D_1) is low, lower than at D_2 , which is lower than D_3 , etc. Drawing a line between the number of consumers (n) and the implicit demand curve at that number (D_n) traces out an approximately parabolic shape, $P(n, n)$. $P(n, n)$ is the equilibrium price where the demand curve for a network of size n (D_e) intersects the vertical projection of the network size when the number of consumers (network size) is n^* . $P(n, n)$ is thus the fulfilled expectations (or revealed demand) curve, the set of prices that the n th consumer would actually pay to join the network which would sustain n -consumers. The fulfilled expectations demand is increasing for small n if any one of three conditions hold:

- (1) “The utility of every consumer in a network of zero size is zero, or
- (2) there are immediate and large external benefits to network expansion for small networks, or
- (3) There is a significant density of high-willingness-to-pay consumers who are just indifferent on joining a network of approximately zero size.” Economides (1996)

Figure 2: Construction of Revealed Demand (Fulfilled Expectations) Curve with Positive Network Externalities



ref. Economides (1996)

While aggregate demand rises with the number of members, thereby exhibiting positive network externalities under perfect competition, there are diminishing returns; each additional individual adds successively less to the value of the network. If there is non-satiation, a unique equilibrium exists but if satiation is reached there may be multiple equilibria (the largest of which is stable). Under perfect competition, the amount of network may be undersupplied because the positive externalities cannot be internalized to the producing firms.

Probes: A model of network coverage on roads

This section estimates how many vehicles must be providing information to ensure a certain amount of network coverage. This is important for several reasons. First, it is essential to understand the costs of traveler information. If many probes are required, both collection and communication costs will be higher. Second, it suggests the feasibility of the “club” model of information provision outlined in the previous section. Third, if it is infeasible, alternative collection methods, such as in-roadway surveillance by a department of transportation, may be required.

To begin, we assume a uniform (or “flat”) network with no hierarchy, so that each link is equally likely to be used. We also assume no spatial auto-correlation, so that links are used randomly. We apply the binomial theorem to estimate the likelihood that a road segment will be covered. We use the same information to estimate the expected number of vehicles that cover the link. For the purposes of this section, we will assume that a link is defined spatially and temporally. That is, it has a location, but that a given link is only valid for a particular time slice. A vehicle traveling on a link three hours ago provides almost zero information about present conditions, for the purposes of this discussion, the link at time $t-3$ is a different link than the one at time t .

We compute the probability that a link is covered given n vehicles (or trials) and a probability p that a vehicle which is traveling is using a given a particular link (the probability of success). This probability can be interpreted as an information quality or level of service measure, which we denote as S :

$$S = P(Y > 0) = 1 - P(Y = 0) = 1 - (1-p)^n.$$

The variable n , the number of vehicles required to meet a level of service standard, can be found by setting $n = \ln(S)/\ln(1-p)$.

The expected value of the number of vehicles on a given link is simply the total number of vehicles on the network multiplied by the probability that any one of them is on that given link: $n \cdot p$.⁵

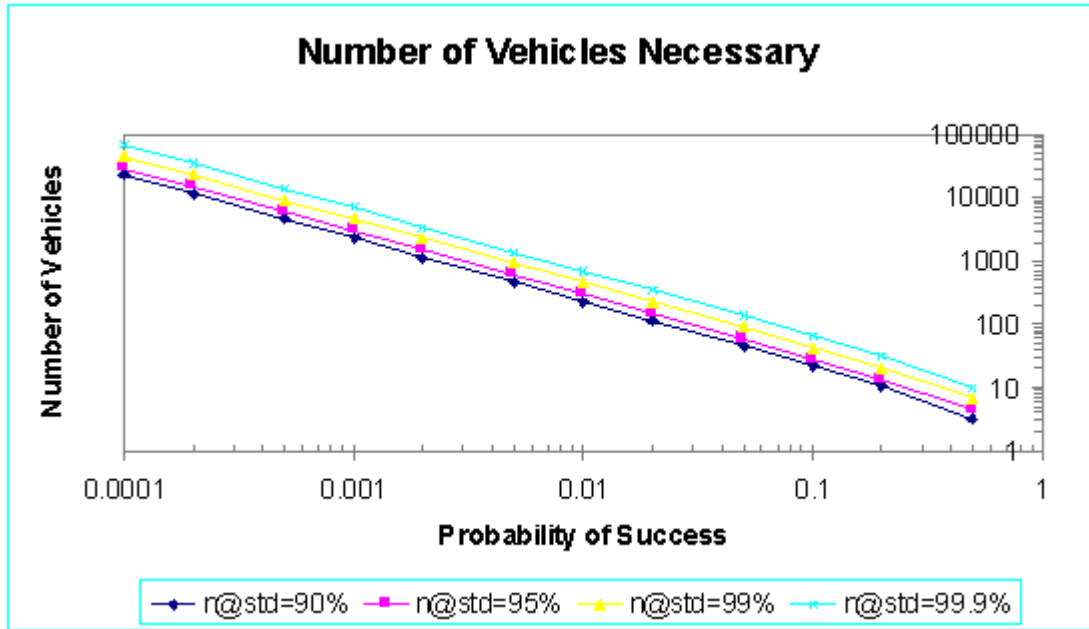
The actual value of p depends on the size of the metropolitan area, the number of links traversed by a given vehicle at some time divided by the total number of links. For instance, a driver may use 50 road segments on the trip to work between 8:00 and 8:30, in a metropolitan area of 100,000 road segments, in that case, $p = 50/100000 = 0.0005$. Of course, if we discard the assumption of equal use, we may have some very busy road segments used by a much higher segment of the population and some less used residential streets used by a much smaller segment. This is important, as it implies more coverage for the more important road segments and suggests that this simplistic approach overestimates the number of probe vehicles (n) necessary to provide information to achieve a particular coverage standard.

The figures below illustrate the use of these equations to find the necessary number of probe vehicles to achieve a particular standard. Later sections will consider how much coverage is needed to achieve a given accuracy level. The accuracy can be used to find the time saved. The time saved can be evaluated to estimate the willingness to pay for information.

Figure 3 shows the number of probe vehicles needed to achieve a given service level (90% confidence that a link is covered to 99.9% confidence that a link is covered). The number of vehicles on the road in a given time slice to achieve this varies from 4600 to almost 14000 assuming a probability p of 0.0005. This number must be higher to cover more time slices, but lower if the level of service is only desired on particular important segments (for instance freeways). At for instance 4600 vehicles, and $p=0.0005$, each segment on average has 2.3 observations, at 14,000 vehicles, each link averages 7 observations. The more observations the more reliable the information.

⁵ This assumes that the likelihood of being on a link is the same for all users given that all links are homogeneous, but this can be relaxed. Changing this assumption would not alter the conclusions.

Figure 3: Number of Vehicles Necessary to Meet Standard as Probability of Success Varies



Note: Probability of Success $p = (\text{Links Traveled})/(\text{Total Links})$

Figure 4 alters the analysis to give the expected probability that a link is covered given the number of probe vehicles and the probability that any given vehicle will use a particular link. The more probe vehicles, the more likely a link will be covered, the more so the higher the probability that a particular vehicle uses a given link.

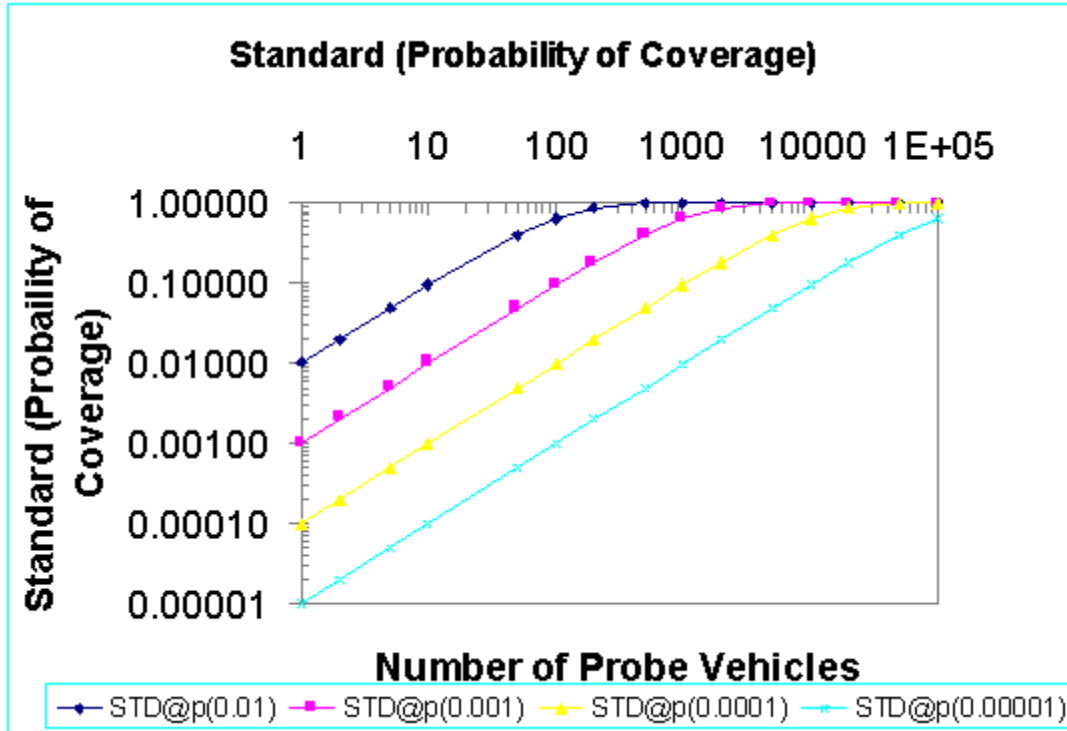
The Number of Sustainable Clubs

The number of sustainable clubs is an interesting question, it depends on the quality of the service provided. Above a certain size, a club ceases to increase very much in value with membership (how much more valuable is 99.9% and 99.99% probability of coverage), there may be room for a second (or n^{th} club).⁶ For instance, if sufficient quality is achieved with 20,000 members, and there are 60,000 people willing to join, then three clubs are potentially sustainable. While this analysis restricts itself to the value of traveler information, such a club has a number of operations in addition to collecting information, it must also collate and distribute it. It is not clear, where the economies and diseconomies are in those operations.

The optimal number of clubs can be determined by trading off the additional benefits (including the increased coverage and economies of scale) associated with larger club size against the additional costs (including such things as loss of economic efficiency, increased span of control and information

The value of a club will continue to rise as long as there is no congestion or desired service levels by members do not deviate from actual service levels.

Figure 4: Probability of Meeting Standard as Number of Probes Varies and Likelihood of Coverage Changes



Problems with Traveler Information

Does the value of information diminish if everyone has that information? We might expect that private value freeway and arterial. In the absence of a traffic incident, all long distance traffic takes the faster freeway.

driver is informed, his travel time on arterial will still be essentially “freeflow” arterial speed (not as good freeflow” freeway speed, but faster than zero). However, as everyone switches over, he must travel ever more slowly as congestion on the arterial rises. Therefore, the user’s value of information declines with market saturation. (Though if probe clubs are used, the quality of the information is increasing with market saturation). So we have diminishing but still positive marginal returns to information. On the other

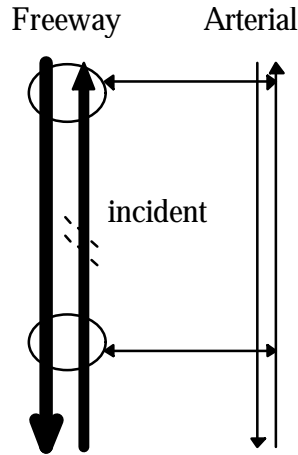
progressively worse off as more freeway traffic diverts. Presumably, the gains to freeway users (from an infinite or very large time to a large finite time) will outweigh the losses to arterial users (from a low to

This issue of freeways and arterials resembles the issue of information define information **haves**

have-nots as those without the haves increases or decreases time for have-nots. It turns out that the results are somewhat different in cases without incidents, as information helps

This will depend upon the amount of time saved and the number of users, assuming the valuation of time

Figure 5: Thought Experiment Geometry



This can be represented as:

Time on	Without Incident	With Incident
Freeway	T_{fn}	T_{fi}
Arterial	T_{an}	T_{ai}

Where: $T_{an} \leq T_{ai} \leq T_{fi}$

The provision of information is overall welfare improving if:

$$F (T_{fi} - T_{ai}) > A (T_{an} - T_{ai})$$

Where: F = number of freeway users
A = number of arterial users

Misinformation

In the previous section, it was assumed that the private value of information was always positive. In theory, if you don't like the information provided (for instance, a suggested alternative route) you don't have to use it. You are no worse off except for the time and money costs to acquire the information. However, there is the problem of misinformation.

In general, we assume that the information provided is:

- (1) accurate
- (2) fresh
- (3) helpful - privately
- (4) socially beneficial

If information is supposed to be user optimal, it is intended to reduce the stochastic and inefficient nature of individual routing. We expect diminishing marginal returns. But this theory that a third party, particularly a monopoly provider like the government, knows more about your route than you do would seem a classic case of what Hayek called the "fatal conceit". Errors will crop up undetected in the central analysis of information that a familiar individual driver will avoid from experience. Thus, information provision is probably best for what an individual won't know from routine behavior - dynamic incidents and unfamiliar territory.

If too many people are given the same information, and act identically, this may be self-defeating - this is the problem of over-reaction. Seemingly, good information can turn into misinformation if there is over-

reaction (or similarly it may be ineffective if there is under-reaction, especially in the case of an attempted

Freshness

Several lags associated with this process affect the quality of the data. The first lag is between the about a segment until the vehicle has passed the segment, which makes it old. Transmission of the information is not instantaneous, but rather requires making a connection and sending a burst of data on the requested. A driver will need information for links between his present location and destination. He might not use many of those links for several minutes or even hours (on long trips), by which time the not have been the best path to take in retrospect if perfect information were available.

This problem may be solved in part by developing rankings of best routes based on 'expected' link-route destination, a probable path can be selected and recommended. This will be contingent on other users in the system, hence a ranking of best paths depending on the choice of others. Of course, another method of solution since non-purchasers still have spillovers effects on information users.

Benefits and Costs of Traveler Information Systems

society at large through externalities. The costs, borne mainly by the information provider are likely to fall over time as surveillance technologies, electronics, and communications fall in price. It is too early to ascertain environmental externalities for more than the most general level. Specific effects clearly depend speeds and distances, and levels of demand.

Time: Expected and Variance

increases the reliability of the travel system by lowering the cost of travel between two points. In the absence of information, a driver may always choose route A, with a typical time of T_f minutes but an T_u minutes. But with information, the driver can confidently select route B on those slower speed days and bear a lower expected time. If the driver does not shift his demand curve, then we anticipate that the travel time goes down. However, if the driver does shift his demand curve, his total travel time may rise or fall, depending on the magnitude of the shift relative to its intercept with the new supply curve.

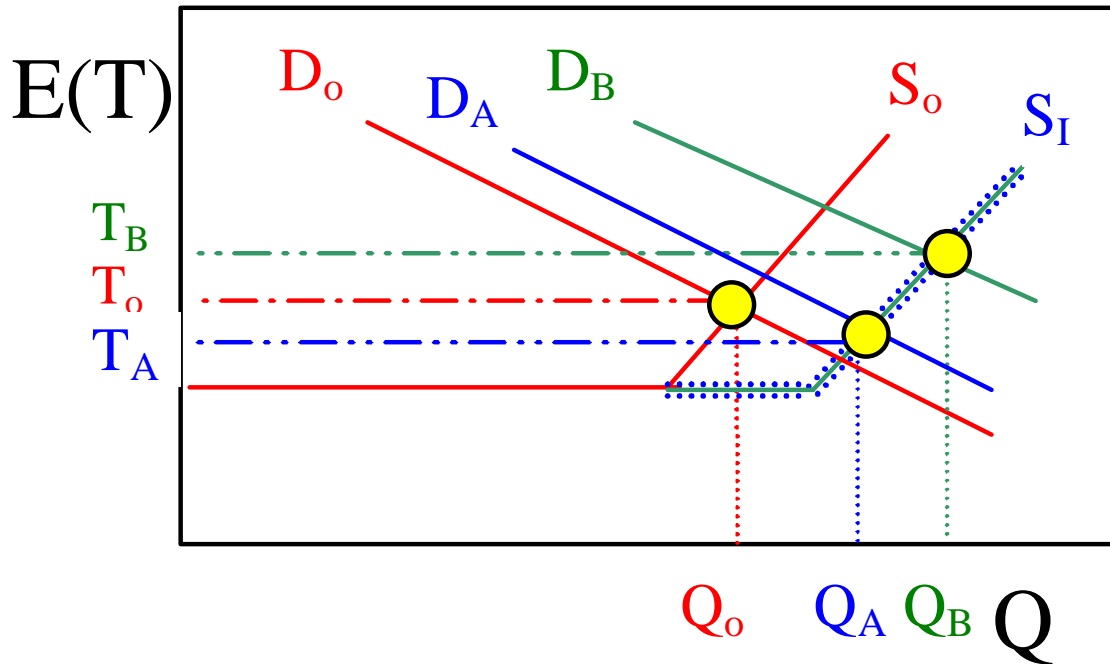
First, we can represent lowering the expected travel time by moving the supply curve. Because the supply curve moves downward from S_0 to S_1 , demand increases along the original (uninformed travelers') demand curve (D_0), the magnitude of the increase being constrained by the timesavings.

Second, we view the cost of trip as being comprised of a bundle of costs, which include factors such as expected travel time ($E(T)$), the cost of information ($C(I)$), and the quality and reliability of the trip ($V(T)$). So with information, individuals will be willing to endure a higher expected travel time if the reliability is increased (variance is lowered). We show this by shifting the demand curve upward (from D_0 to D_A or D_B), reflecting a higher quality of service. In other words a change in the value of $E(T)$ or $V(T)$ will shift the demand function while a change in the value of $C(I)$ will move us along the demand function (due to a shift of the cost function).

$$D = f(E(T), V(T), C(I)).$$

The demand curve for informed travelers can shift a relatively small amount (represented by D_A on the graph) or a relatively large amount (D_B). If it shifts a small amount, there will be a small increase in demand (to Q_A) and a decrease in the average travel time (from T_o to T_A). If the demand curve shifts a large amount (D_B), there will be a larger increase in demand (to Q_B) and an increase in the average travel time (from T_o to T_B).

Figure 6: Shifting Supply and Demand for Travel with Traveler Information



The amount individuals will pay for information will depend upon their gains from lowering either the expected time or the variance in time or both. This would be measured by the increase in consumers' surplus. Therefore, we must know value of time and value of variance (time above and below the expected time) as well as the magnitude of the reduction in $E(T)$ and $V(T)$ resulting from the presence of information.

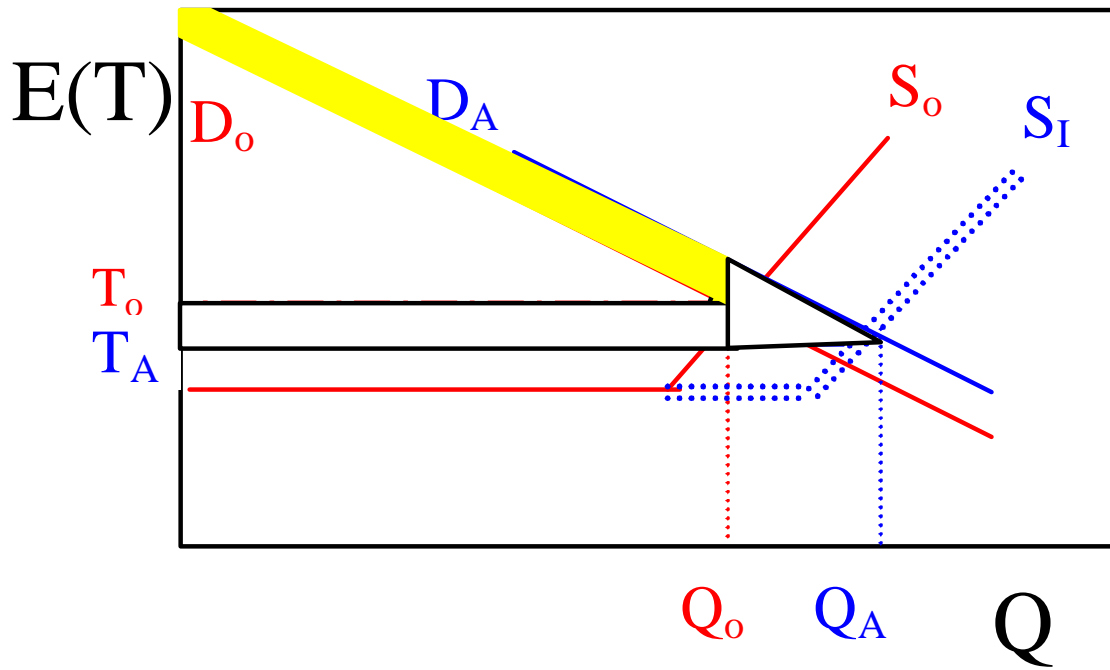
The benefits can be broken into two groups:

- benefits accruing to "old" trips (Q_o) made with or without information, and
- benefits accruing to "new" trips ($Q_A - Q_o$) or ($Q_B - Q_o$) only made because of the presence of information.

The new trips can be viewed as increasing the productivity of the system.

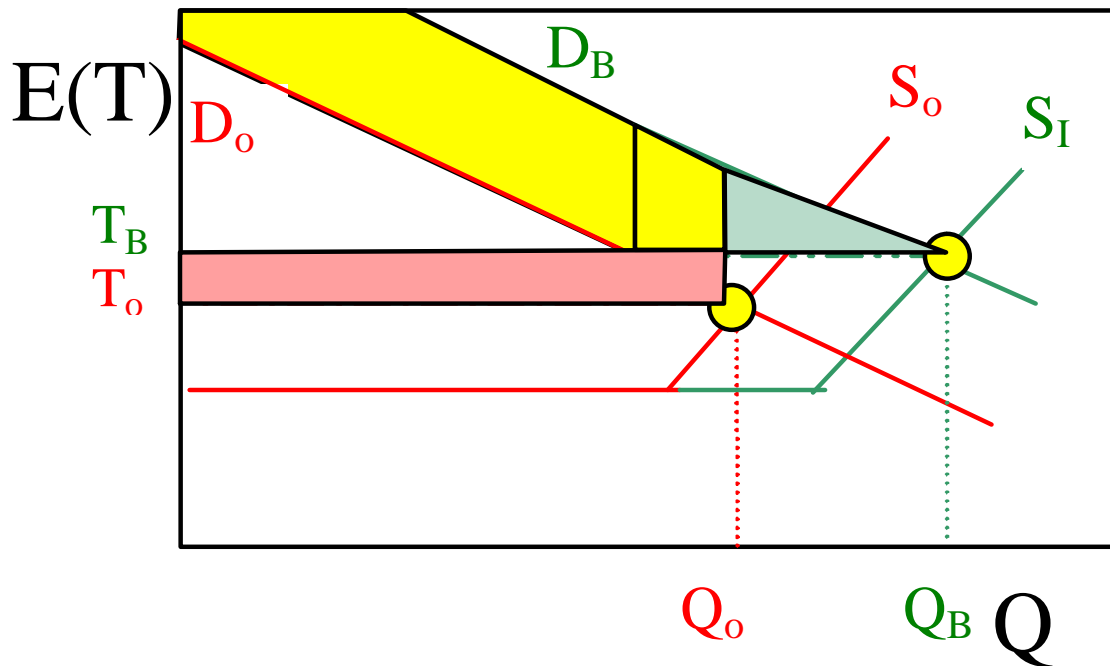
The benefits accruing to traveler information in the case where there is a small shift in the demand curve can be represented, in a stylized fashion, using Figure 6a. There are three parts to the benefits. First, benefits to old users resulting from a reduction in travel time (the hatched area between the old and new travel times). Second, benefits to old users resulting from an increased willingness to pay for the same trip due to the improved quality of the trip (the solid area between the demand curves). These benefits are hard to measure, as the demand curve isn't generally well specified far away from equilibrium. Third is the benefits to new users, who make trips they couldn't justify in the absence of traveler information (the bricked triangle).

Figure 6a: Benefits Associated with Small Shift of the Demand Curve



The benefits due to information in the case of a large shift of the demand curve are somewhat more costs, shown by the right-hatched rectangle between T_0 and T_B

Figure 6b: Benefits and Costs Associated with a Large Shift in the Demand Curve



because trips are more reliable, shown by the solid shaded area between the original and new demand curves. There are also gains to new users, shown by the brick-hatched triangle between Q_o and Q_B . In general, the gains outweigh the losses.

Which of the two cases is more realistic, A or B, cannot be known with certainty. Travel behavior studies tend to be more concerned with time than reliability, probably because it is easier to measure. However if the changes in travel time associated with information are significantly more than the changes in variance, than we can probably assume we are operating in a situation much more akin to Figure 6a than 6b.

Even if we know what we mean by information, the question remains on how to value it. As before, we have the question of an individual's private value vs. social value. There are two components to the value of information, the price per unit of information and the quantity of information consumed. The price per unit depends on the quality of the information, it declines with the number of users because of the information cost function (high fixed but low variable cost). However the usefulness of the information declines with the number of users (the market saturation problem) (the private value of information decreases as its ubiquity increases).⁸ In contrast, if information comes from probes, other users may increase the value of information by increasing coverage (in terms of time and space) which increase the accuracy and freshness of the information - and therefore increases the time saved.

The value of the information can relate to the travel time saved. We must distinguish among user equilibrium times between a deterministic user equilibrium (DUE) which is the actual shortest time path for a traveler, and a stochastic user equilibrium (SUE), which reflects the randomness or noise in the system both in arrival rates and in capacity. Therefore to evaluate the value of information, we must quantify the time difference between DUE and SUE. The difference between system optimal and deterministic user equilibrium of course varies with the difference between average and marginal costs of travel and is case specific. One of the important differences is the question of whether to travel rather than which route to use. For instance it may be optimal for some trips to be deferred, which a negative information forecast may induce. This would need to be quantified as well.

Familiar Trips: Information is important for familiar trips in the presence of both *recurring* and *non-recurring* congestion. The benefits are higher with non-recurring congestion, as travelers are unlikely to have found equilibrium between alternative routes, so advance warning and suggested alternatives will be viewed favorably. There may still be benefits associated with recurring congestion however. Even if there is in general an equilibrium between alternative routes, there is still enough randomness in the system, which a real-time guidance system under ideal conditions can help smooth.

Unfamiliar Trips: Information can also be quite useful for drivers on an unfamiliar landscape, not simply to avoid congestion, but also for the straightforward task of finding the shortest path or recovering from a wrong turn. In order to value time, we need to know the amount of time wasted by inefficient individual routing today. Jeffery (1988) says inefficiency on unfamiliar roads is about 25% and in another paper (1986) suggests excess travel distance of 6%. This landscape has both spatial and temporal dimensions. While the spatial are obvious, shortest time paths on familiar terrain may vary by time of day.

Vehicle Operating Costs

To the extent that information reduces excess driving, it may reduce wear and tear on the vehicle as well as the need for gasoline and other maintenance items that are primarily a function of distance traveled.

Qualitative Factors

Stress Reduction is said to be one of the benefits of traveler information. Having more certainty about how long a delay will be can be of great merit. With cell-phones, it permits postponing of meetings or rescheduling appointments. However measuring the amount of stress-reduced is difficult. It may require

⁸ As the private value of information decreases the public value may still rise. The differences are between marginal and total values. As more people receive information, the marginal value to each additional individual will decrease. However, the aggregate value, the public value will increase.

experiments such as wiring subjects with a galvanometer as they travel in vehicles with and without information. Then the value of that stress would need to be estimated. An alternative way of assessing it would be by comparing the willingness-to-pay for information, determining the economic value of the time saved, and subtracting the difference as an estimate of the other qualitative factors such as stress reduction that are associated with traveler information.

Measurement of User Values

There are two basic methods for surveying the value of something: what people actually do (Revealed Preference) or what people say they would do (Stated Preference). In general, if the data are available, revealed preference is preferred to stated preference, but for new technologies data are not always available.

Even if we can measure quantitatively (e.g. in minutes) the reduction in travel time and the reduction in travel time variance, we still need to measure the value (e.g. in \$/minute) of reducing the expected travel time and the variability of a trip’s duration. Reducing variability allows a traveler to leave for a destination later than he might if he knew the trip were more variable in length. There are further benefits (particularly in reducing anxiety), harder to measure, of knowing how long something will take. The value of a trip as a whole needs to be measured as well, as sometimes information will cause a trip to be deferred or canceled, other times the information may induce travel to new destinations.

Induced Demand

The issue of demand elasticity or induced demand is a controversial topic in research. Researchers are trying to identify the extent to which trips are induced, shifted, and lengthened due to capacity expansion. Because ATIS systems have similar effects to capacity expansion, the literature on demand elasticity is pertinent. The most recent results are suggesting overall demand elasticities between -0.5 and -1.0 . (These results are detailed in the annotated bibliography.) Indicating that a 1% increase in capacity or reduction in travel time will increase demand by between 0.5% and 1.0%. Clearly, this is still a broad range, and results vary with assumptions, methodologies, locations, and other background information, but it is important to note that these results are significantly different from 0%, so some elasticity should be considered in analysis.

Modeling Approach

By its very nature, the value of information lends itself to analysis using a simulation approach, because deterministic demand (traffic flow) coupled with invariant supply (network times) does not require real-time information, only experience. Varying either demand or supply suggests gains from information, varying both will result in more gains. Whether demand and supply are deterministic or stochastic depends in part on perspective. The farther away one is (the larger the time slice, the bigger the network component

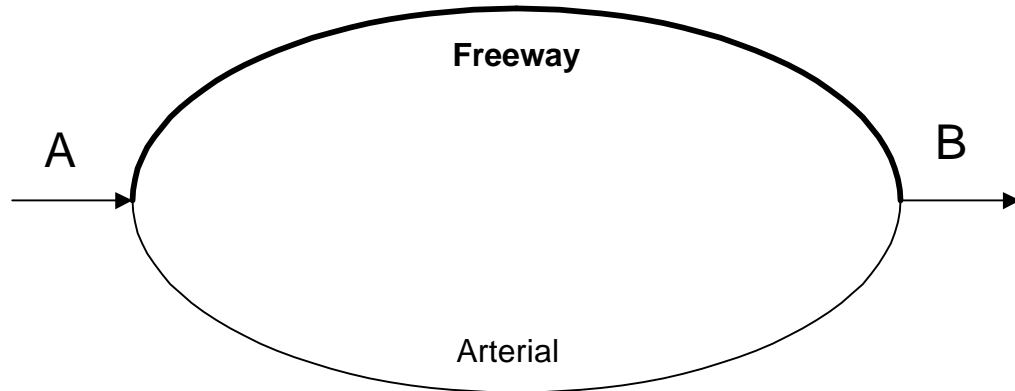
information requires a detailed approach. Consideration of the transportation system at the level of the individual vehicle is necessary to fully treat this problem.

Arrival	Information		Stochastic
	Informed		
	Uninformed		
Stochastic			X
	Uninformed		

Network

The analysis presented here assumes link is labeled “freeway” while the other is dubbed “arterial”, though this is not meant to imply anything about their capacities or free-flow travel speeds. Informed drivers receive their information at point A.

Figure 7: Network



The modeling methodology is illustrated in Figure 8. The starting point for the driver is the current context in which they arrive (size of the queue) and the historical context (historical data for the driver). The driver can choose to be informed or not. If they have ‘some faith’ or believes in the information they have collected historically they may rely on this for making a route decision. Alternatively, they may choose to be informed about the queue length of each road. Their route selection will be either stochastic if they rely on historical data or deterministic if they are advised as to what route to select based on current information regarding the queue. The route is selected and the driver exits the server.

Route Choice

In traditional traffic assignments, fully informed travelers behave according to the principal of user equilibrium, that no time can be saved by switching routes. It is clear however that if we are attempting to value information, we cannot assume away the information problem. Drivers are not perfect in their assessment of travel costs (time is not necessarily the only cost considered) and future travel costs cannot be known with certainty because of the variation of other drivers’ behavior and the possibility of incidents.

Queueing Model

The simulated arrival headway (H_v) in seconds between vehicle v and $v-1$ is given by the following expression:

$$H_v = -\text{LN}(\text{RAND}(\theta)) / \lambda$$

Where: $\text{RAND}(\theta)$ = indicates a random real number between 0 and 1
 λ = average arrival rate in vehicles per second

While the average headway is simply $1/\lambda$, each vehicle’s headway differs. In the presence of information, the expected travel time is simply the length of the queue at the time of arrival at the fork in the road (the decision point) multiplied by the average service rate (flow through the bottleneck).

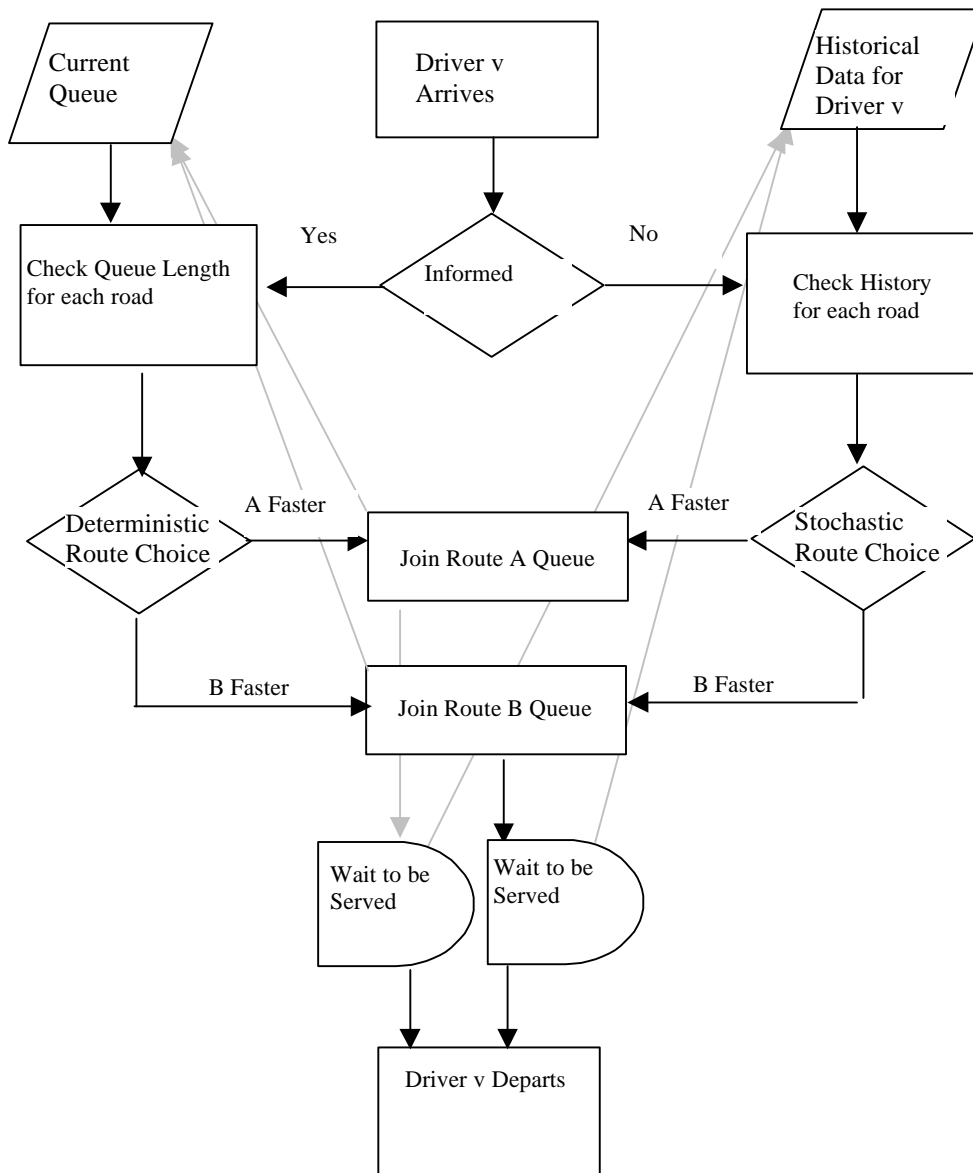
The simulated service time (τ) in seconds per vehicle is given by the equation below⁹:

$$\tau_v = \tau + 0.5 * \text{RAND}(\phi) * \sigma$$

⁹ This Random number is distinct from that in the previous equation

Where: τ_v = service time for vehicle v
 τ = average service time in seconds
 σ = dispersion parameter, measured as the maximum variance in service time.¹⁰

Figure 8: Flowchart of Modeling Methodology

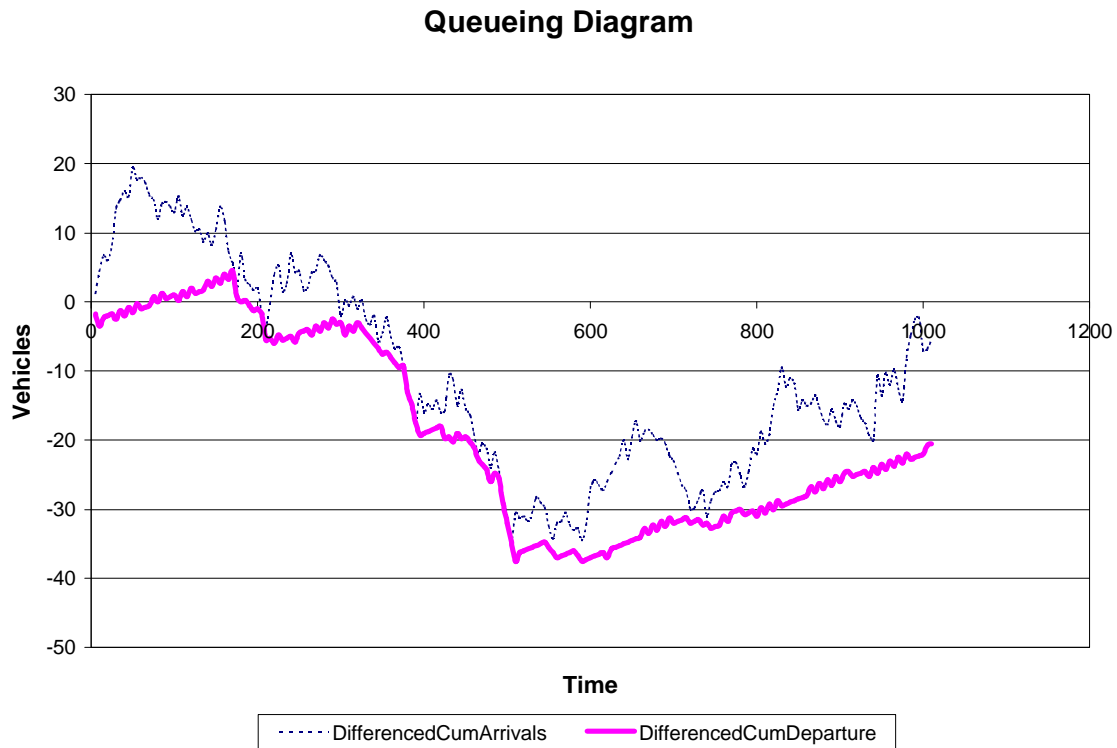


¹⁰ The values will depend upon the nature of the distribution selected.

The average service time is adjusted in the case of incidents. As the mean increases, it may well mean an increase in the variance as well. The queue on each link operates as first in first out, and there are assumed to be no spillovers between links.

Figure 9 shows a queuing diagram for a typical case, where the arrival and departure curves both have the average flow rate subtracted from them.

Figure 9: Typical Queuing Diagram



Behavior with and without Information

In our model, there are two classes of drivers: informed and uninformed. A driver who has an information system in his vehicle is called *informed*, one who doesn't is considered *uninformed*. However because of queuing externalities, even uninformed drivers are affected by information.

Uninformed drivers learn from experience what to expect, and based on that expectation, choose routes. These choices are going to produce better results in the case of recurring than non-recurring congestion. The process is illustrated in Figure 8.

Incident Frequency, Duration, Lanes Affected

Incidents vary in their severity and duration. Some incidents simply involve a car that the driver pulls to the side of the road. Others involve a vehicle temporarily stalled in its lane that ultimately clears itself. Only a small percentage of incidents block lanes for an extended period or require assistance. In order to calculate the value of information, we need to understand the probability of incidents. This research

employs data collected on I-880 as part of a project to understand the effects of a Freeway Service Patrol program (Skabardonis et al 1995, Petty 1995).

Figure 10 shows the distribution of incidents by duration together with a model estimated from that data. That model is given in Table 4 and has a very good statistical fit. The model was estimate using cumulative probability of the number of incidents less than certain duration. For instance, if 50% of incidents were less than 20 minutes, the dependent variable would be the $\ln(20)=3$ and the Cumulative Probability would be 0.5. Solving the equation in Table 4 would give $0.941+4.149*0.5=3.01 \rightarrow 20.4$ minutes. The model also suggests that 60% of incidents are less than 30.88 minutes.

The dependant variable is the incident duration in minutes and this is modeled as a function of the cumulative probability. The estimates contained in Table 4 are both significant and show that the delay in minutes rises significantly with the cumulative probability. At the same time the faster the incident is removed the reduction in delay decreases dramatically. Given no incidents the delay is very small – as indicated by the value of the constant term in the regression.

Table 4: Incident Duration Model: $\ln(\text{Minutes})=a + b \text{ Cumulative Probability}$

	Coefficients	t Stat
Intercept	0.941	12.9
Cumulative Probability	4.149	46.2
Adjusted R ²	0.985	
Standard Error	0.104	
Observations	33	

Trying to model lane blockage is somewhat more difficult, as there were very few multiple lane blockage incidents in the database. A simple model is given in Table 5, while the data are shown in Figure 11.

Table 5: Lane Blockage Model: $\ln(\text{Lanes Blocked} + 1) = a + b \text{ Probability}$

	Coefficients	T Stat
Intercept	1.086	5.66
Probability	-1.165	-2.87
Adjusted R ²	0.707	
Standard Error	0.325	
Observations	4	

Table 6: Number of Lanes Blocked by Frequency

Lanes	N	Share
0	2104	0.964253
1	62	0.028414
2	11	0.005041
3	5	0.002291

Figure 10: Incident Duration by Frequency

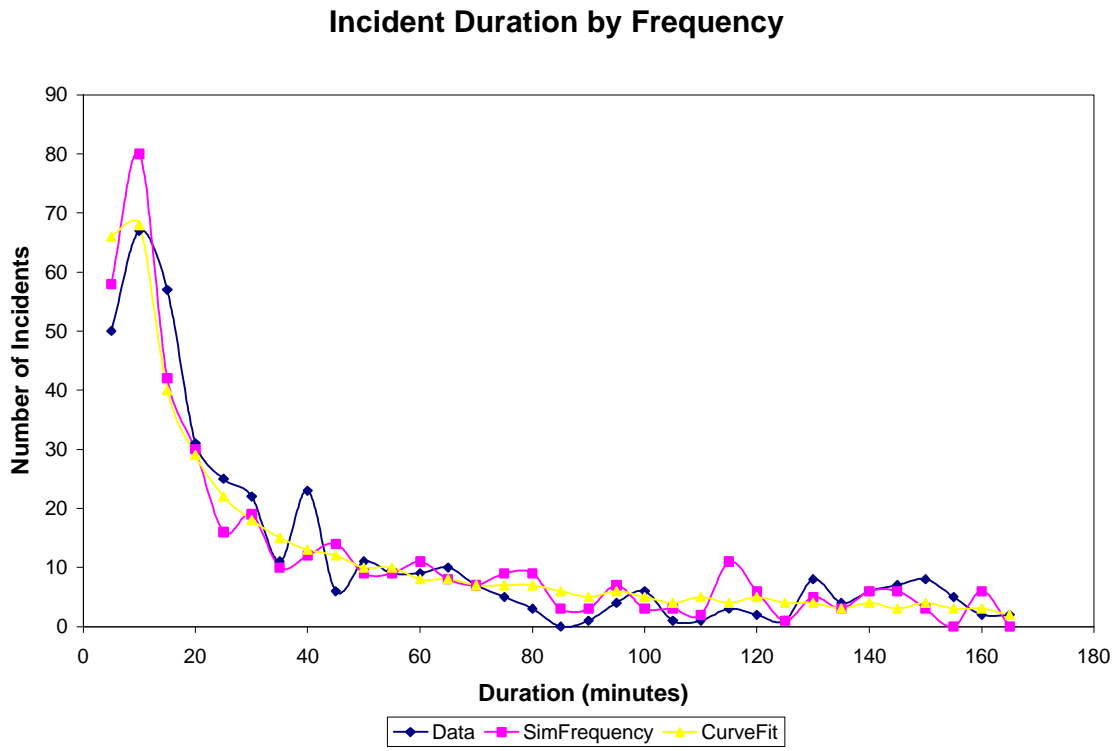
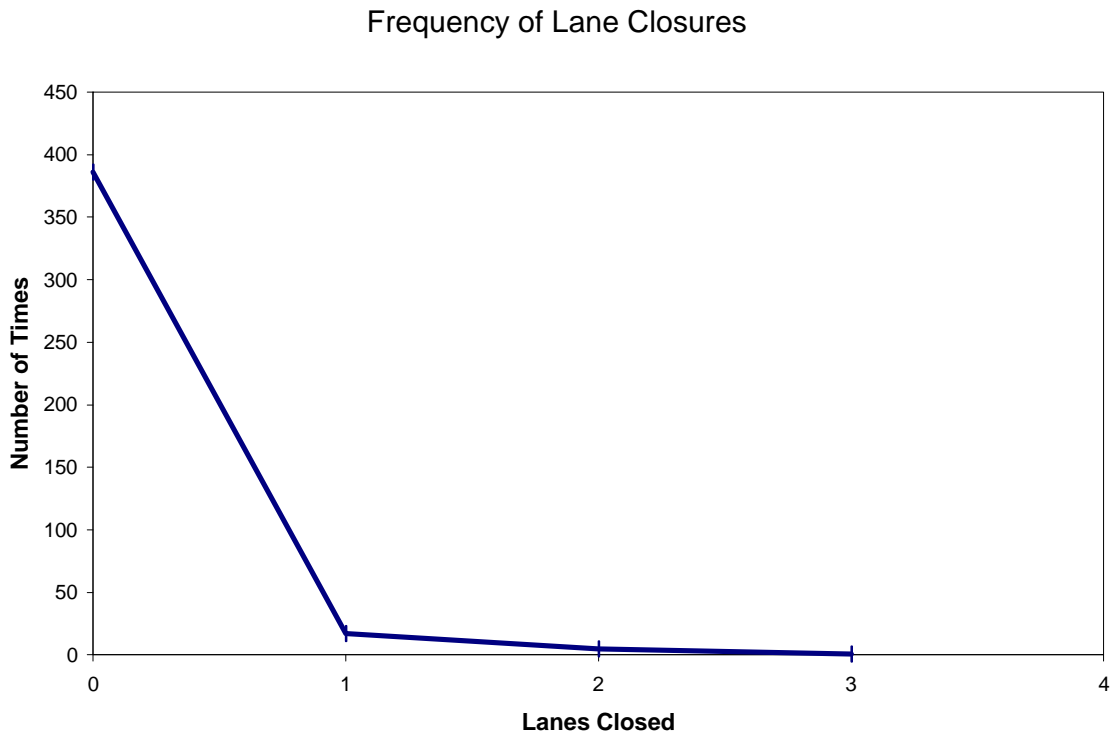


Figure 11: Frequency of Lane Closures



Modeling Results

Several different modeling sets were run, beginning with the simplest, perfect information and no incidents. For each, we varied the share of informed drivers and the congestion level.

Perfect Information, No Incidents

In our model demand arrives at an average rate of λ for 1000 vehicles, with zero arrivals before or after those 1000 vehicles. Each simulation (point on the graph) was the average of 150 distinct simulation runs. Still, the results are highly variable, particularly in unstable regions where flow is at or in excess of capacity. The historical information, important for the uninformed travelers, was assumed to be that both routes have equal expected times and equal variances.

Figures 12 through 19 show the results from modeling the simplest cases. Figure 12 shows the average travel time (in seconds) of informed drivers as the percent of informed drivers increases from 17% to 100% and the arrival to service rate (λ/μ) varies from 0.5 to 1.05. This suggests that increasing the share of population with information will do little to reduce travel times, and may slightly increase them for informed drivers. Of course, travel times are higher as capacity utilization increases. Figure 13 shows the results for uninformed drivers, which suggest that information has a positive externality, reducing times for the uninformed. Scaling and overlaying the two graphs does show that informed drivers have consistently lower times than uninformed drivers, so there is some advantage to information. However, when a driver is already informed, having others be informed does not have a positive effect. Rather, it reduces the opportunities that he can exploit. Still, as more drivers are informed, the average travel time generally drops, as shown on Figure 14.

Figure 12:

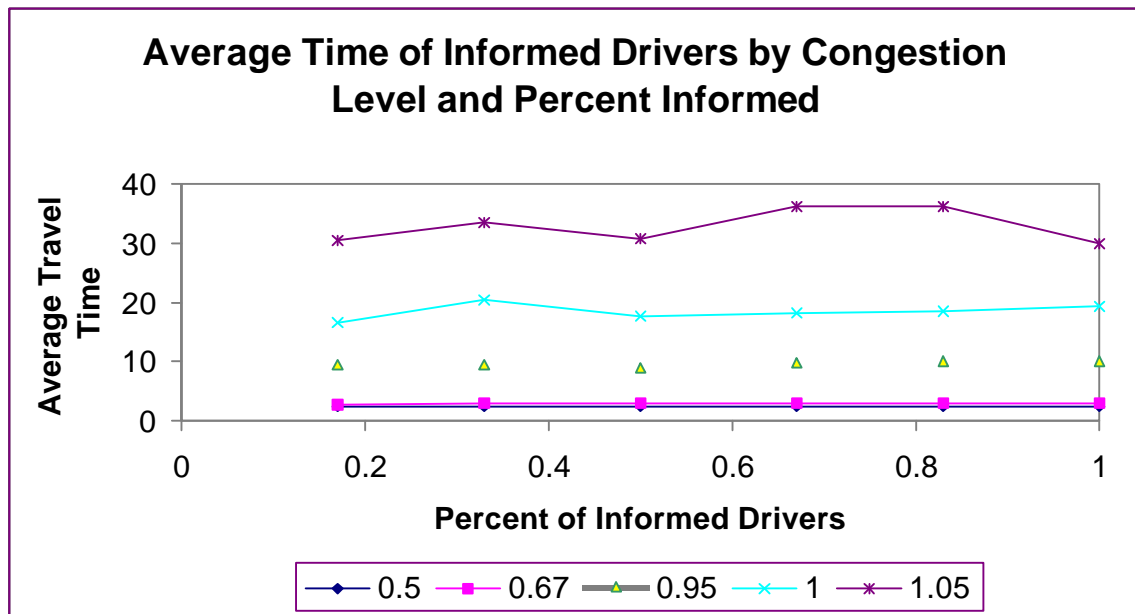


Figure 13:

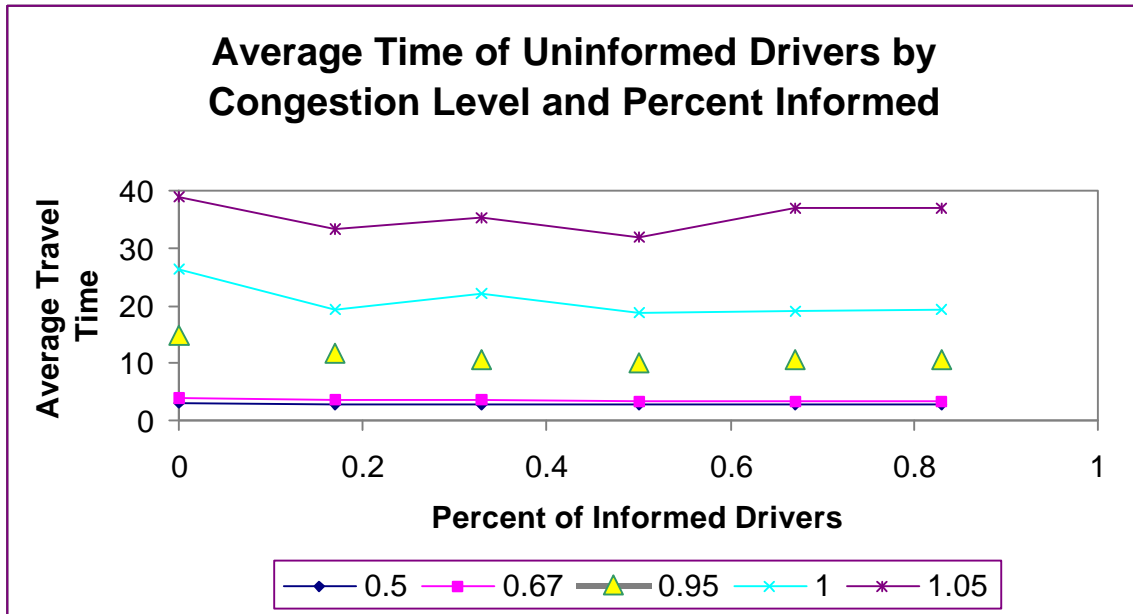


Figure 14:

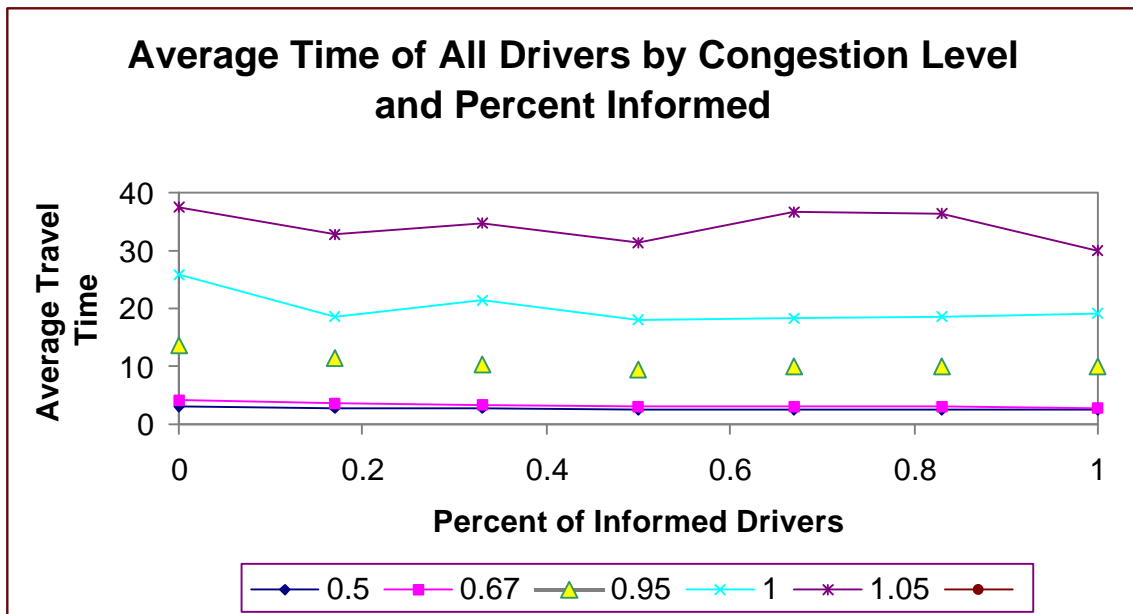


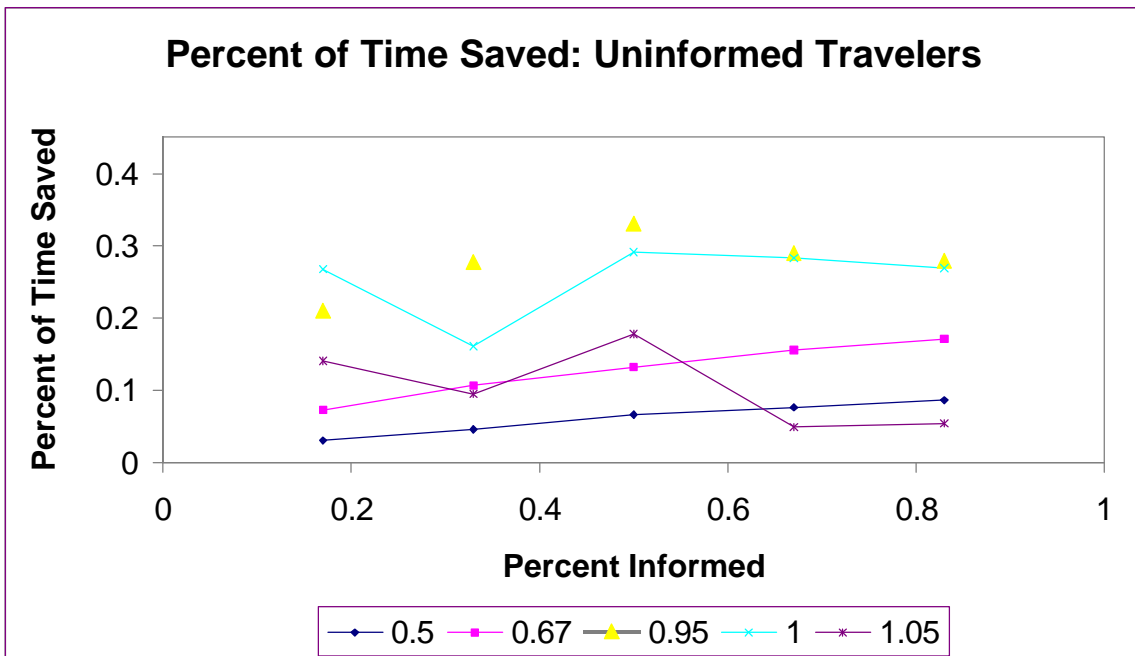
Figure 15 displays, in percentage terms, the amount of time saved with information is greatest when traffic flows average 95% of capacity. This level has significant opportunities to switch routes dynamically and avoid a queue altogether. As traffic flows increase on average to 100% and 105% of capacity, the percentage of time saved drops precipitously. At under capacity levels (50% and 67% for instance), there is little value to information because the travel time is unlikely to be significantly affected by other cars. However, as the percent informed increases, the percent of time saved tends to drop. In contrast, for the uninformed (Figure 16), as the percent of informed drivers increases, the percent of time saved increases.

Again, the most time is saved at flows around 95% of capacity. The greatest volatility is found at flows at and above capacity.

Figure 15:



Figure 16:



In terms of variance, standard deviation is highest for the most congested flows and declines as congestion does. For informed drivers, variance remains constant with the percentage of informed drivers, as seen in Figure 17. For uninformed drivers, however, standard deviation tends to fall slightly as the environment becomes more ordered, shown in Figure 18. In general, as the environment becomes more informed, the effect of any given individual becoming informed shrinks. Figure 19 illustrates that the difference in the standard deviation tends to approach 0 as the percent informed approaches 100%.

Figure 17:

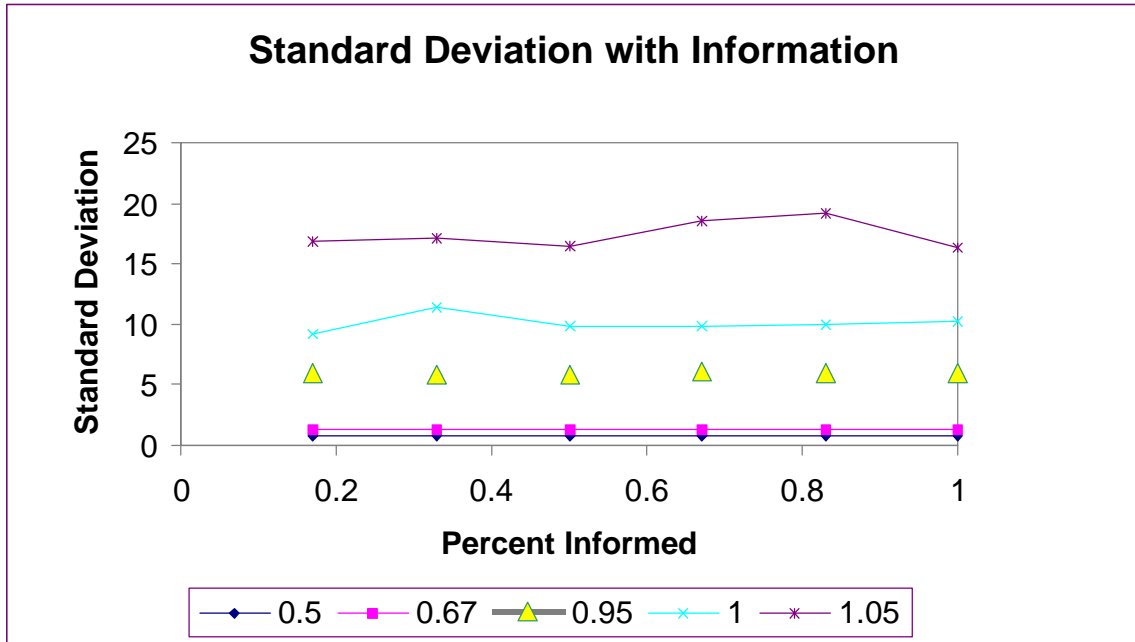


Figure 18:

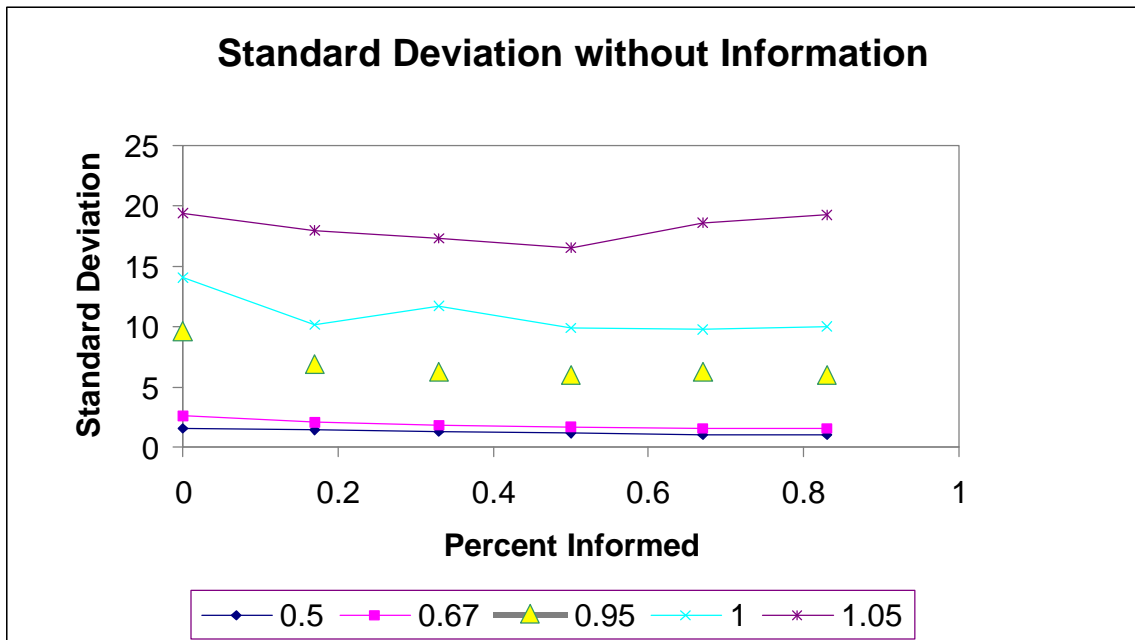
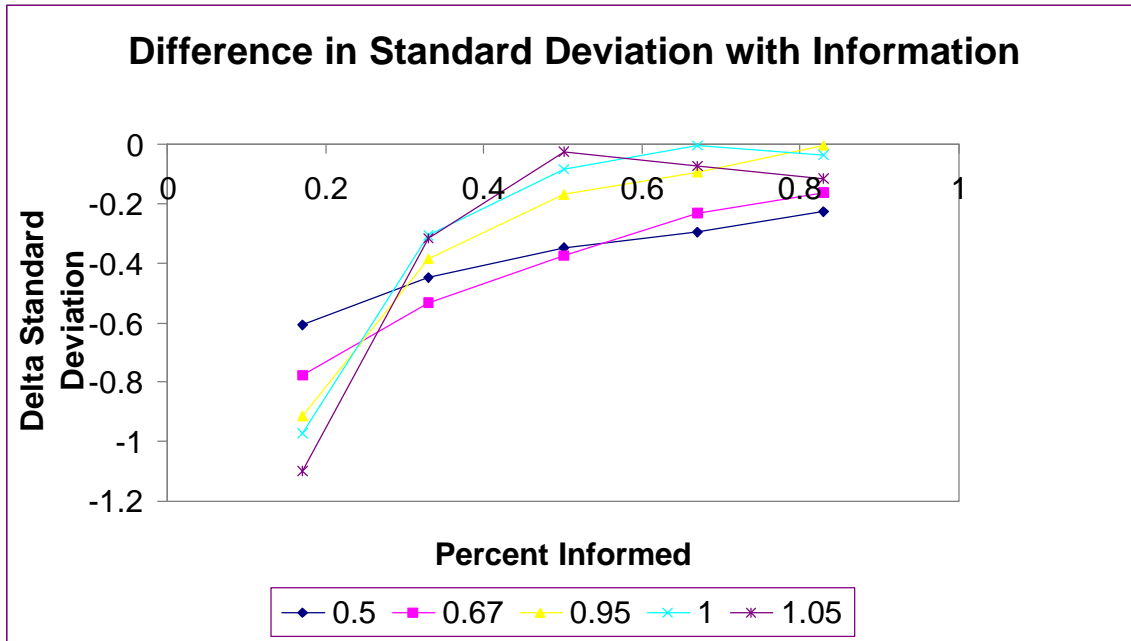


Figure 19:



Perfect Information, Incidents

While there may only be limited benefits to ATIS associated with recurring congestion, peaking when traffic is on the precipice of over-saturation, non-recurring congestion is a different story. Incidents, accidents, and crashes lower highway capacity on one facility below what was expected. While uninformed drivers will take their normal route and sit in traffic, informed drivers can shift to avoid the new and temporary bottleneck. This section analyzes the case of unexpectedly reducing capacity on one link in the network of two parallel links. We assume that there is an approach flow averaging 0.67 vehicles per second (arriving randomly assuming a Poisson distribution). Because each link has a normal service rate of 2 seconds per vehicle, combined they service one vehicle per second. Thus, traffic flows freely under normal circumstances. In the absence of any capacity reduction, traffic splits evenly between the pair of links. With a capacity reduction, uninformed traffic still splits evenly, but informed traffic takes the route with the shortest anticipated travel time (which is more often, but not always, the unaffected link). Our results are again based on thirty simulation runs per data point, where each simulation run loads one thousand vehicles.

Figure 20 considers the average travel time for informed travelers as the freeway service rate on the affected link is worsened from 2 seconds per vehicle. Clearly, the average time worsens for all travelers as capacity shrinks. However, the fewer informed drivers there are, the better it is for each one who is informed. For instance, at only 17% informed drivers and a service rate of 6 seconds per vehicle (reducing from 3 to 1 lanes open), those informed drivers could switch to the parallel route and take only 10 seconds. However, when more drivers are informed, more switch, so the parallel route gets more congested. Figure 21 shows the affects on uninformed drivers. The more drivers who are informed, the better it is for all uninformed drivers. In fact, it is beneficial for the uninformed drivers on the affected link but detrimental to those on the unaffected link, who must share the road with many more informed drivers who switched. Overall, Figure 22 shows that information is a net good, the more informed drivers are, the lower the average travel time.

In percentage terms, the greatest gains come from the most severe incidents. Figure 23 shows that the worse the freeway service rate, the greatest percentage time can be saved from information, though again,

for each individual informed driver, it is best if only he has that information. For uninformed drivers, Figure 24 shows a somewhat more interesting pattern. The percentage of time saved peaks for incidents that reduce capacity by 33% - 50%. Uninformed drivers are still best served if others are informed.

The standard deviation is interesting, illustrated in figures 25 and 26. An informed driver has the lowest standard deviation the fewer the number of other informed drivers he has to share the roadspace with. Uninformed drivers on the other hand clearly benefit from widespread distribution of information, as it lowers the standard deviation, and therefore make travel more reliable.

Figure 20:

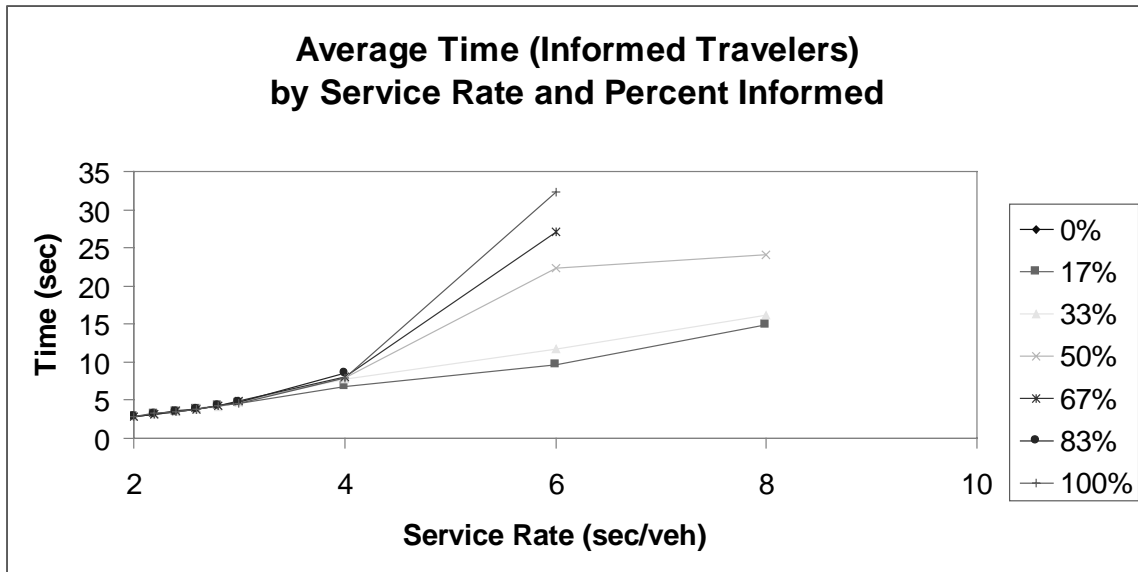


Figure 21:

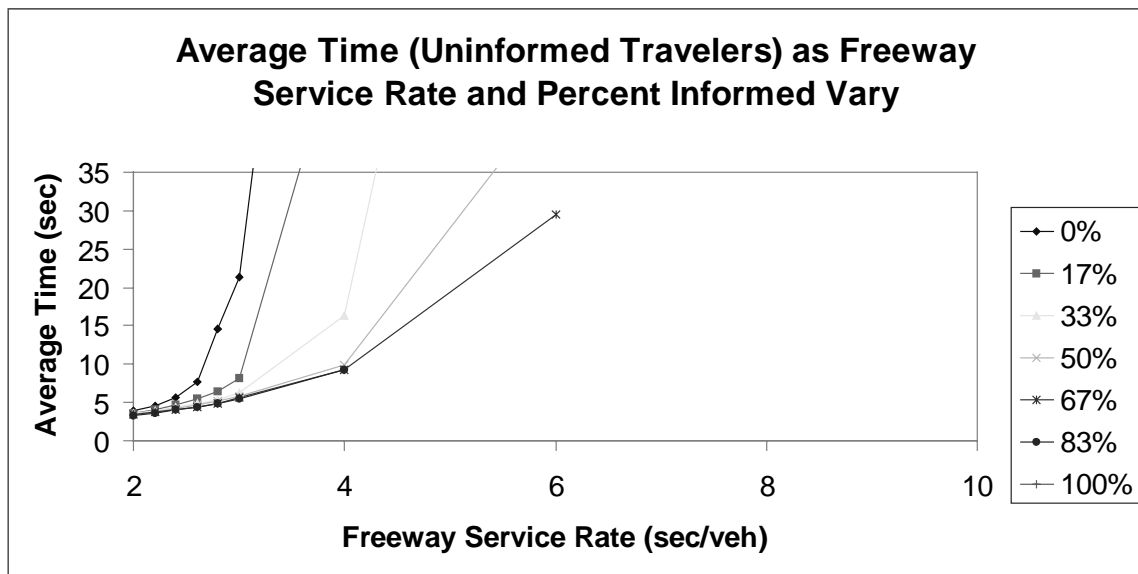


Figure 22:

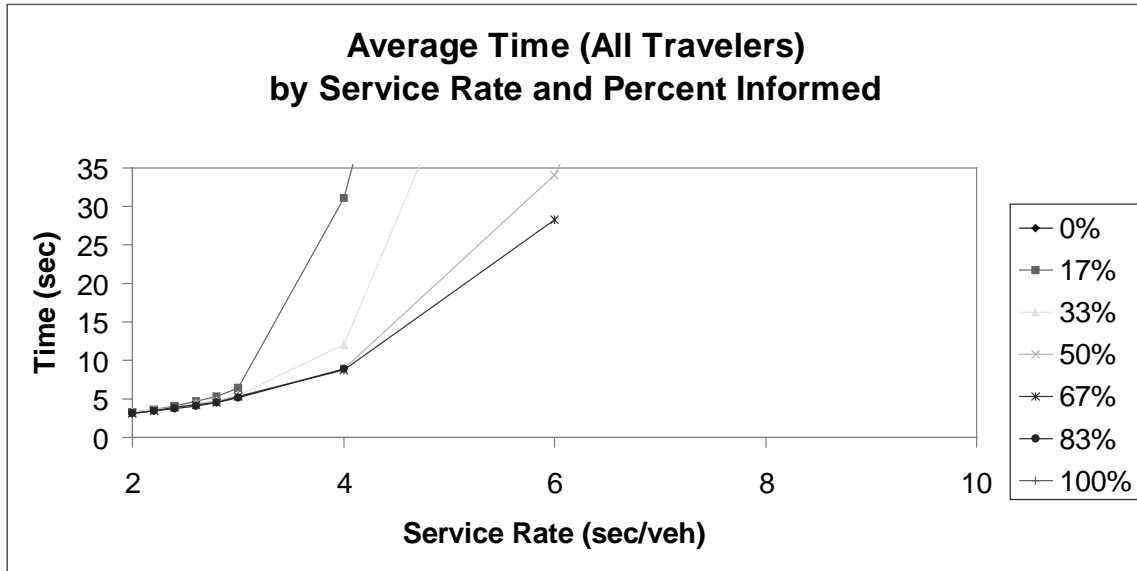


Figure 23:

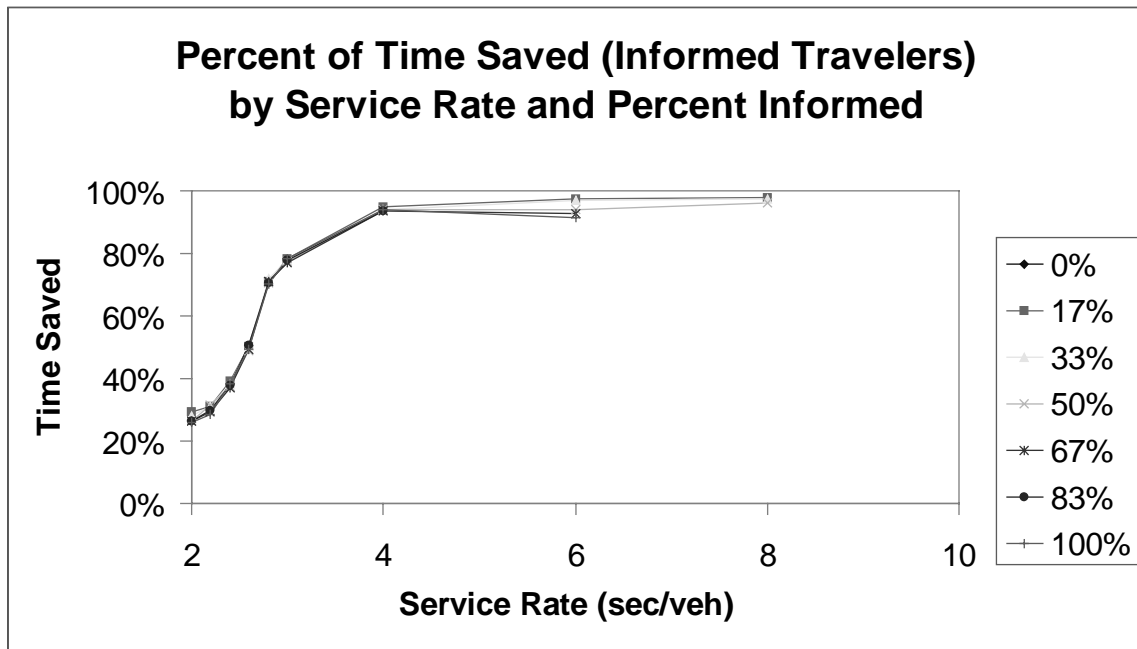


Figure 24:

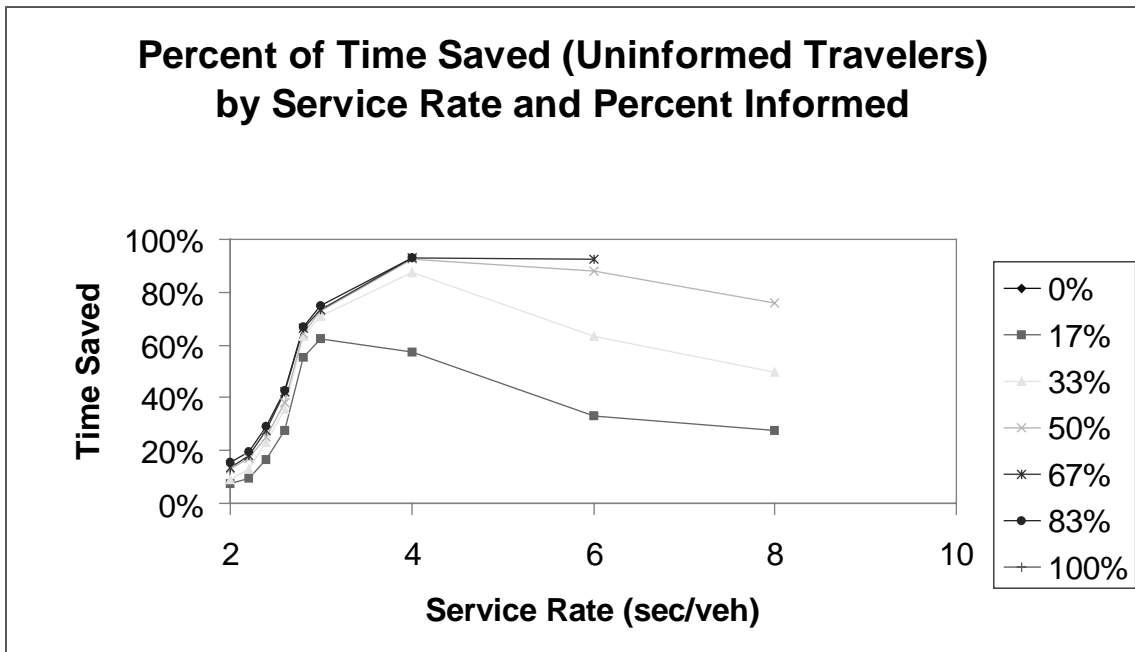


Figure 25:

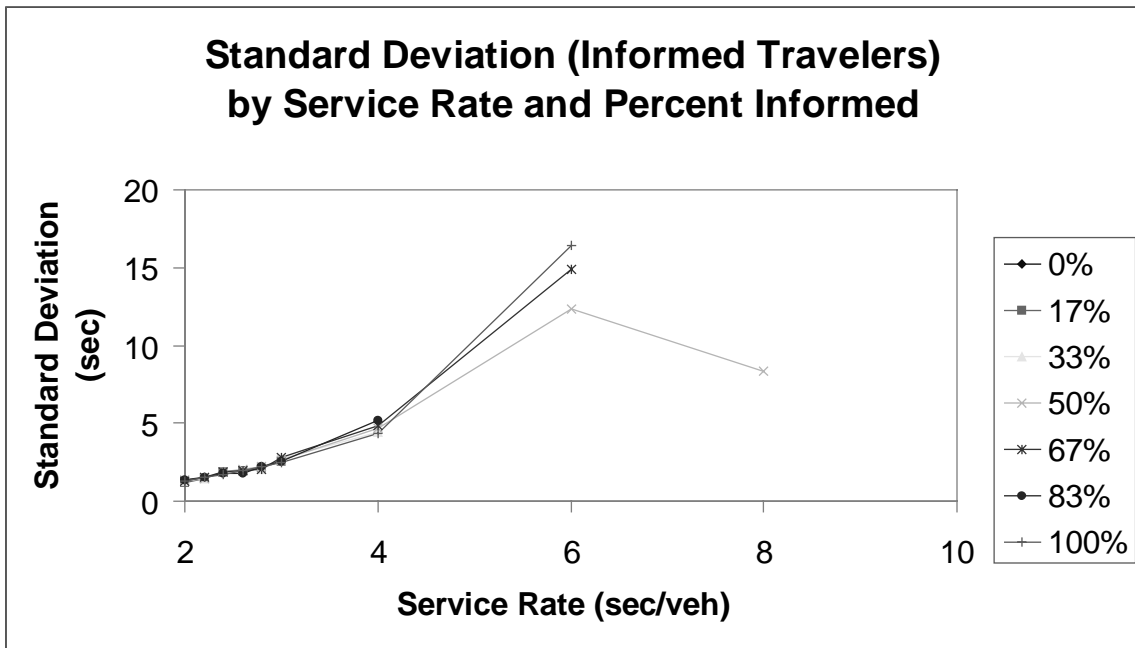
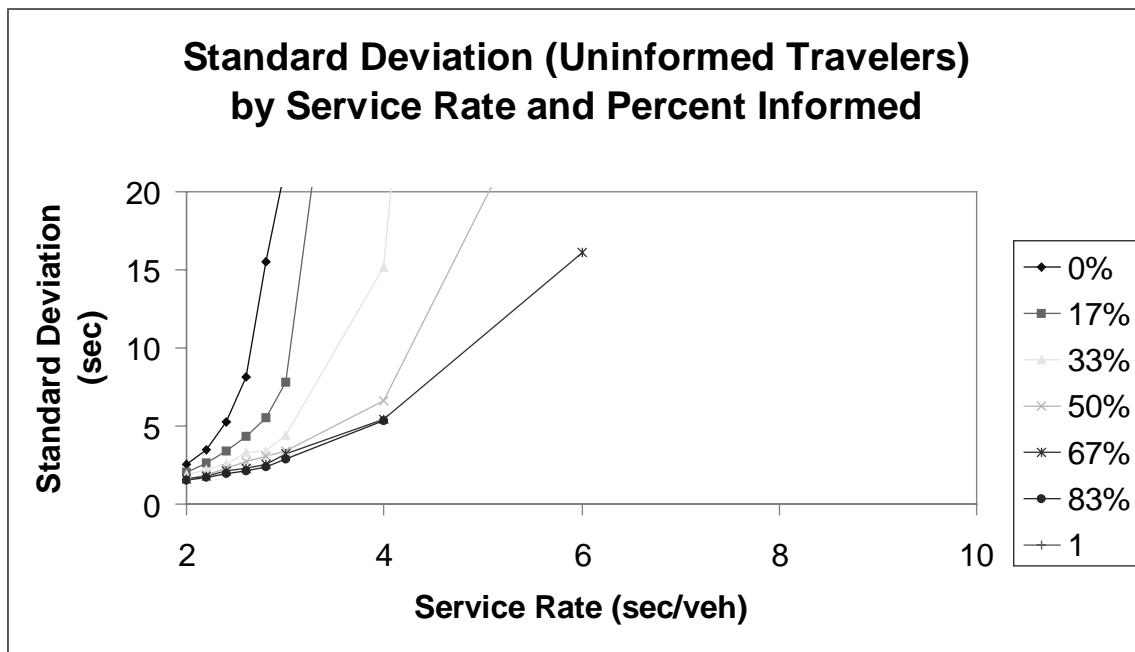


Figure 26:



Probe Information, Recurring Congestion

The previous results sections assumed perfect information. Wiring the road network to have such complete information may be expensive. An alternative that has been proposed is to rely on what are called probe vehicles. Probes are otherwise normal vehicles used by commuters which send back to a transportation center their travel time, speed, and location. This section examines how congestion levels vary with how many drivers use ATIS and what percent of the fleet is comprised of probes. The percent of probes is important, because if only a few vehicles are probes, information will no longer be fresh. That is particularly pertinent when trying to save time from a stochastic process, like recurring congestion, because every second counts. It is likely to be less severe in the case of non-recurring congestion, which takes longer to clear. It is important to be able to identify what percent of the fleet needs to be probes to achieve time savings, as this will affect the cost. Another advantage of probes is that they can be implemented without government involvement because they do not rely on installing devices on the public right-of-way. However, if probes are the only source of information, problems can arise when information is no longer recent, misinformation can be worse than no information. This suggests that probes require a large critical mass to be successful, or that they are best used in combination with other sources. This section though assumes that only probes provide information, in order to determine where that critical mass arises.

Figure 27 shows the average travel time for informed drivers as the congestion level, and the percentage of probes on the network, increases from 0 to 100%. Figure 28 shows that result for the uninformed travelers, and Figure 29 for all travelers overall. In these cases, the percent informed averages 50%, though samples are drawn equally from 30 runs each at 0%, 17%, 33%, 50%, 67%, 83%, and 100%. As noted before, informed drivers are best off if the information is not widely distributed, but uninformed drivers do benefit from wide distribution of information to others. Overall, information is a good thing for congestion. The more interesting point concerning probes is that the benefits of probes are steadily increasing. If there are few probes, the average travel time is high compared with many probes (listening to old information is counter-productive). It is also important to note that probe-like information (that is, information with lags)

is most useful at or near congestion for cases of recurring congestion (non-recurring congestion will be examined below).

This shows up more clearly by examining the percent time saved or lost as the percent of probes and the congestion level varies (Figures 30 and 31). For informed drivers and low congestion levels (0.5 or 0.67 volume to capacity ratios), probe information is simply too old to be of any value. Ignoring old probe reports will be better than listening to them. However as traffic approaches and exceeds capacity, a critical mass of probes can be useful. As the share of probe vehicles on the network exceeds 30%, the percent of time saved for informed drivers becomes positive, up to 30% timesavings are possible, though typical values are lower. Uninformed drivers also have benefits in congested conditions when probes comprise 30% or more of the fleet, and even modest benefits for relatively uncongested conditions at much higher share of probe vehicles (80% or more).

Figures 32 and 33 examine the standard deviation for informed and uninformed drivers respectively as the percent probe and congestion level vary (at an average percent informed of 50%). The more probes on the network, the lower the standard deviation. The standard deviation does increase with congestion. Informed and uninformed drivers have similar standard deviations, varying only at low percent probes, where misinformation leads to informed drivers having a higher variance.

Figure 27:

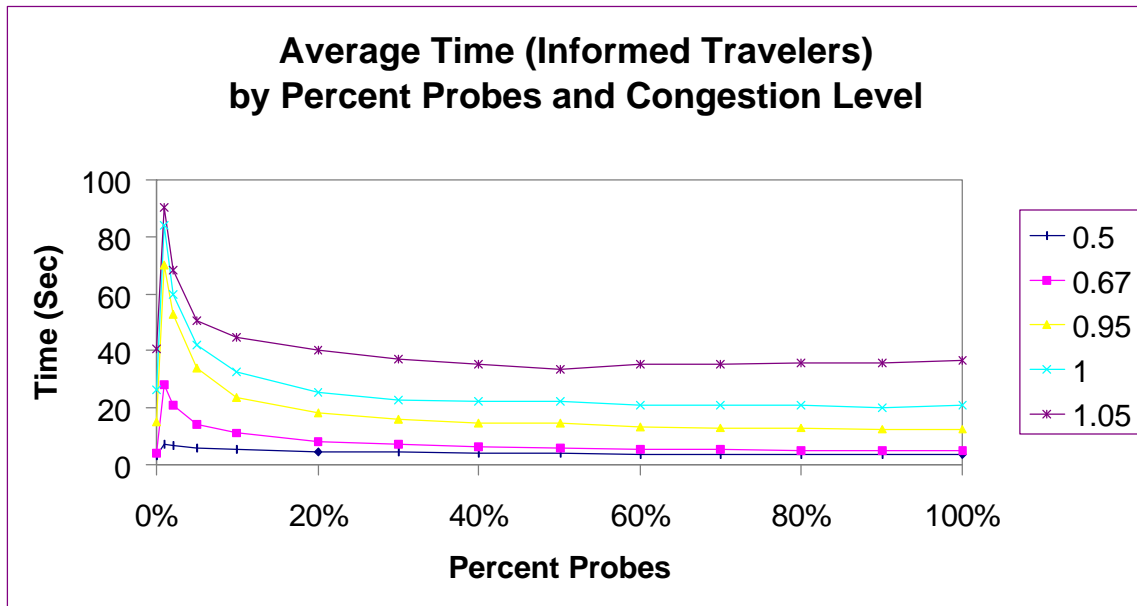


Figure 28:

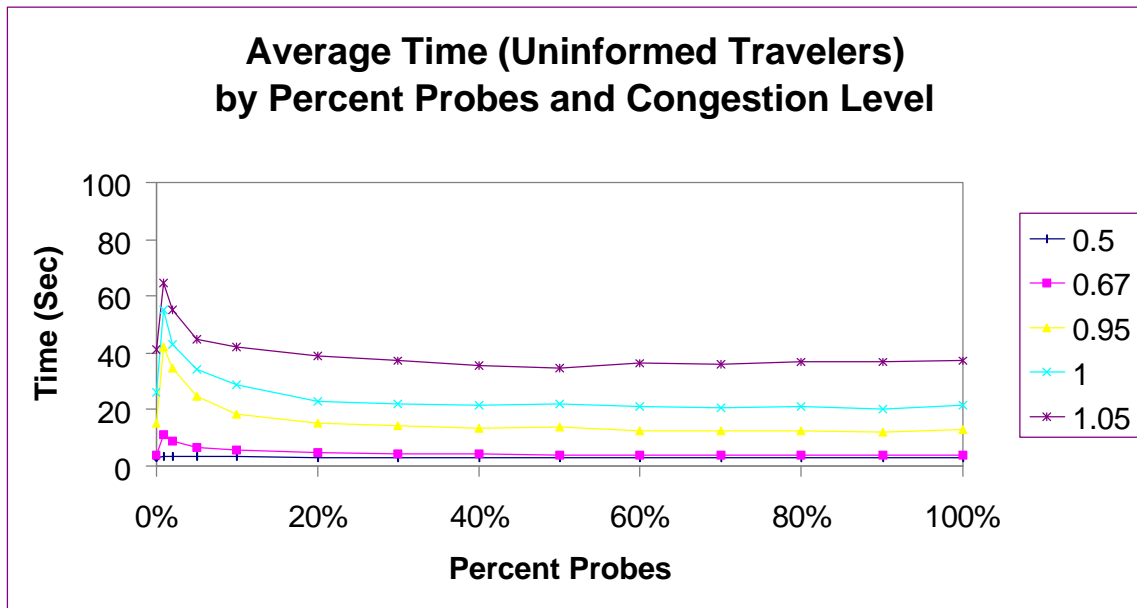


Figure 29:

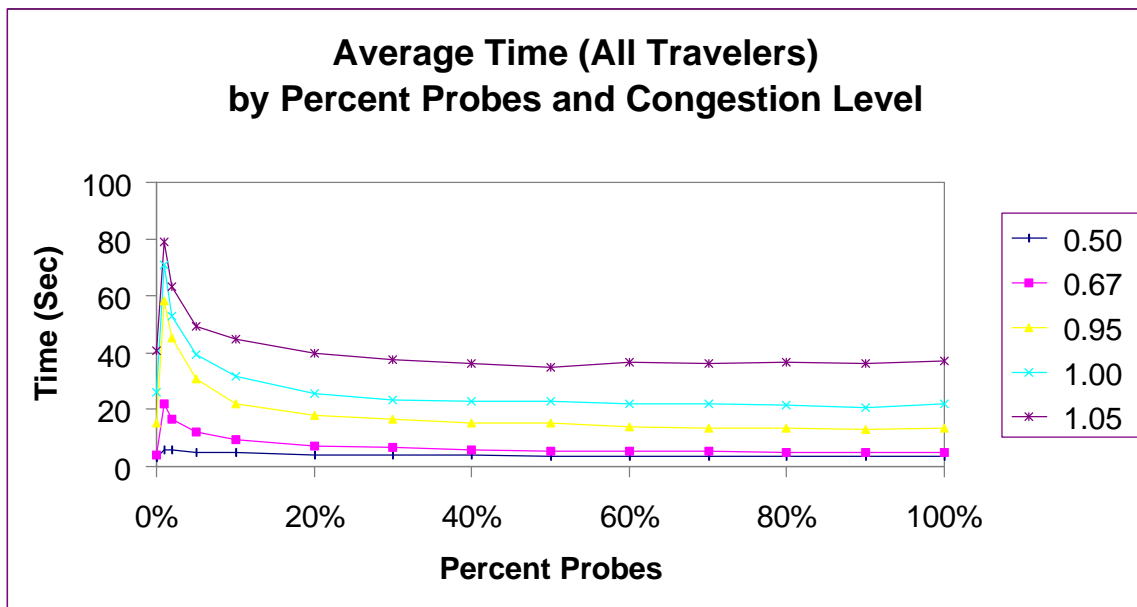


Figure 30:

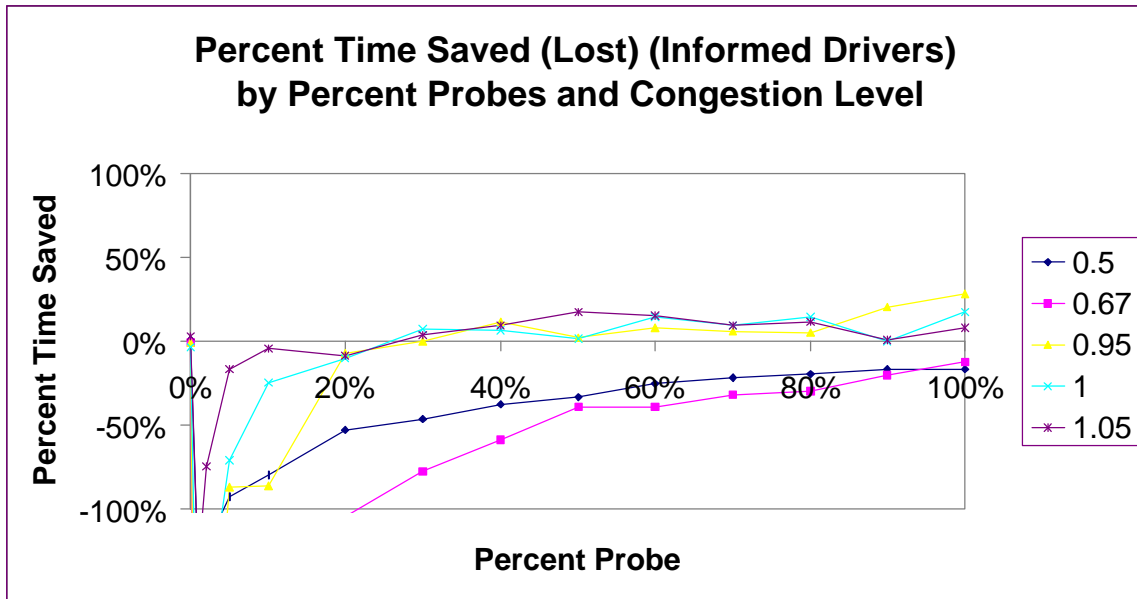


Figure 31:

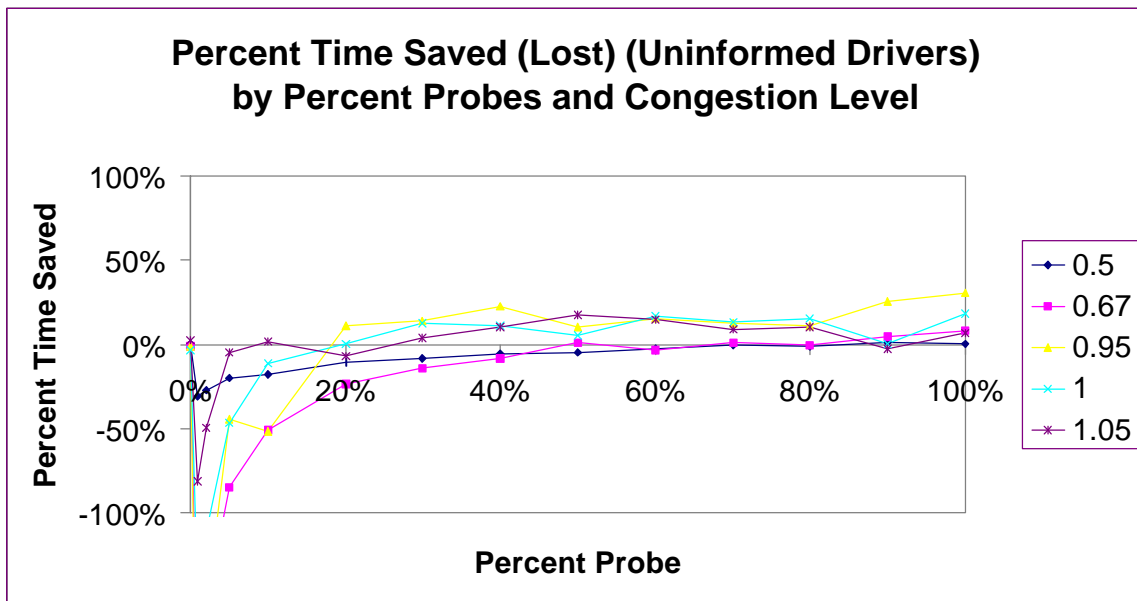


Figure 32:

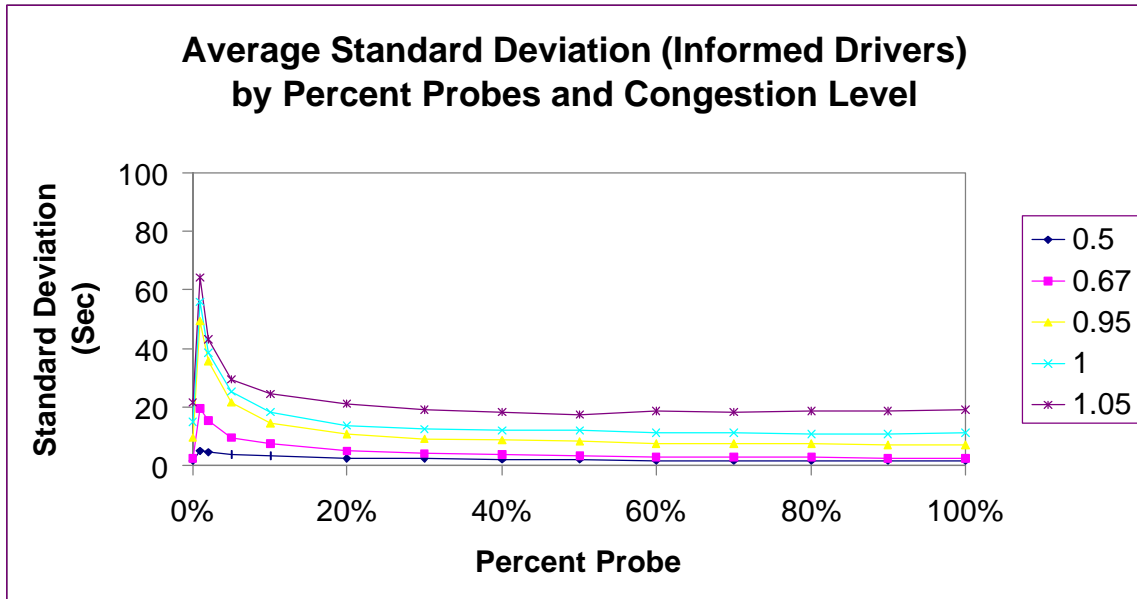
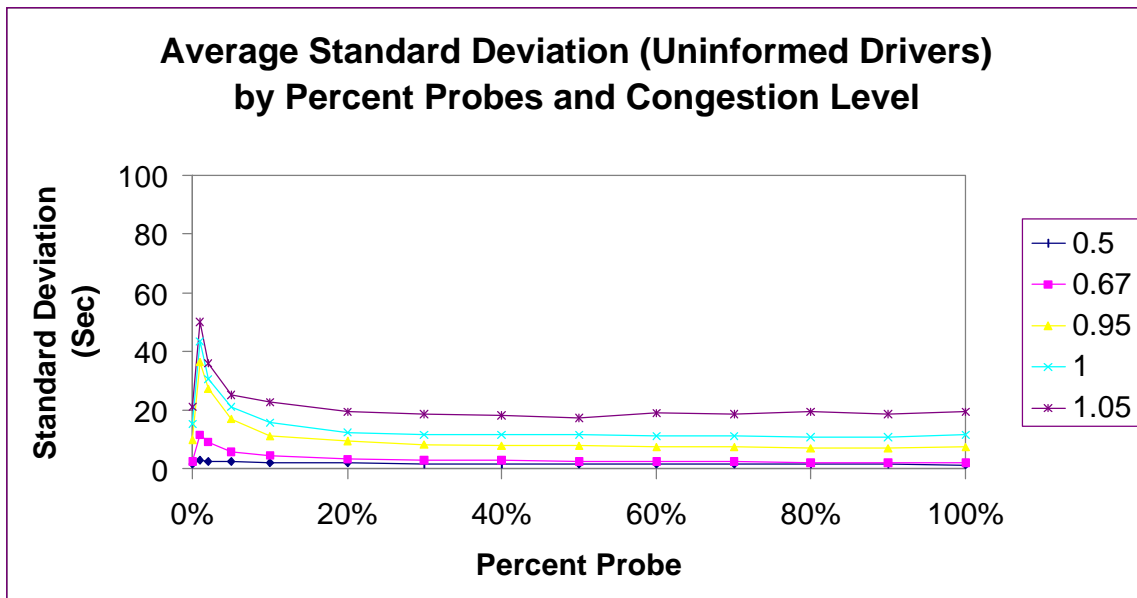


Figure 33:



Probe Information, Incidents

While probes have some serious drawbacks in assisting travelers during recurring congestion, the same is not true of non-recurring incidents. This section, like the earlier section on incidents with perfect information, considers the effects of information as the service rate increases on one link, while a parallel link retains its capacity characteristics (2 seconds per vehicle). It is assumed that the capacity reduction is for the entire period (the time required to serve 1000 vehicles arriving at 0.67 vehicles per second).

Figures 34-36 show how the travel time varies with the service rate and percent probes for informed, uninformed, all drivers respectively. As the time to serve each vehicle increases, the average time increases. But as the number of probes on the network increases, the average time tends to decrease. Even a few probes are sufficient to shift almost all informed travelers to the shortest route, though the more probes on the network, the faster an incident will be detected, and the faster an over-reaction can be arrested.

The next figures (37 and 38) show estimates of the percent of travel time saved with probes. Informed travelers can save nearly 100%, as they completely avoid the incident (though the link without the incident may still have some congestion). Furthermore, uninformed drivers save time too (about the same as the percent of informed drivers when the incident is severe, here 50%). This is because the informed drivers don't exacerbate the queues on the affected link (the queue is half as long without the informed drivers) when they switch to the link without the incident. Before the incident, 50% of travelers used each link and 50% were informed. After the incident, 75% will use the unaffected link (of whom 67% are informed) and 25% will use the affected link (of whom 0% are informed). While 75% on one link will lead to delay, this is much less delay than associated with the affected link. In all cases, more probes are better for the reasons noted above, though most gains can be achieved with a relatively low probe percentage (20% or less may be sufficient).

The standard deviation increases with the decrease in capacity, but tends to decrease as the number of probes increases, as seen in Figures 39 and 40. Still, only a relatively small probe percentage is necessary to achieve most of the gains in reliability associated with information.

Figure 34:

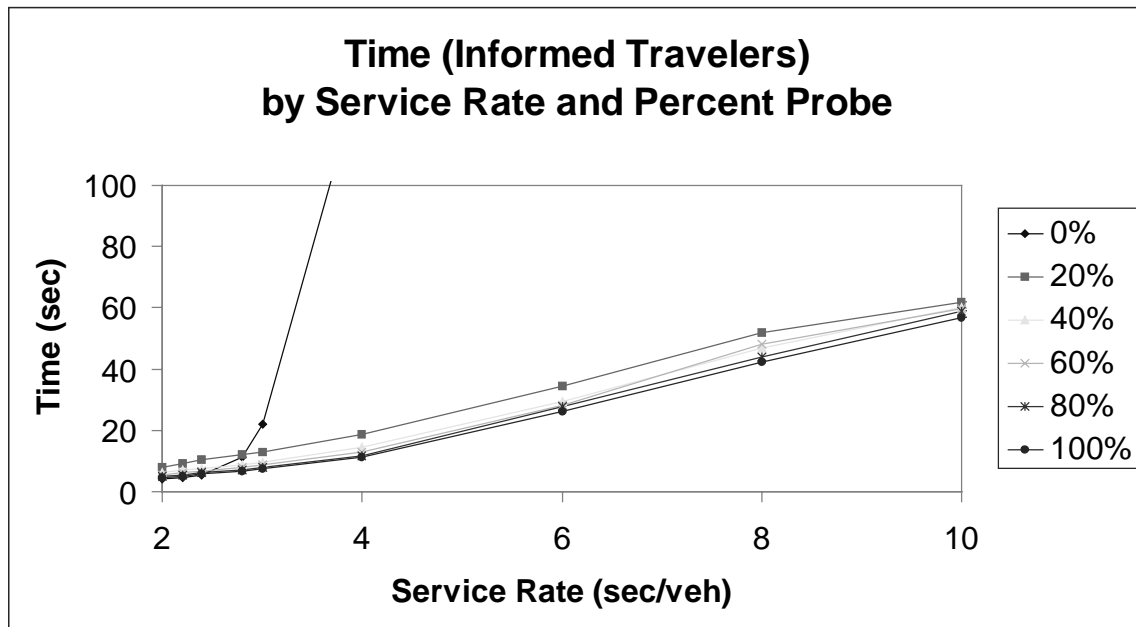


Figure 35:

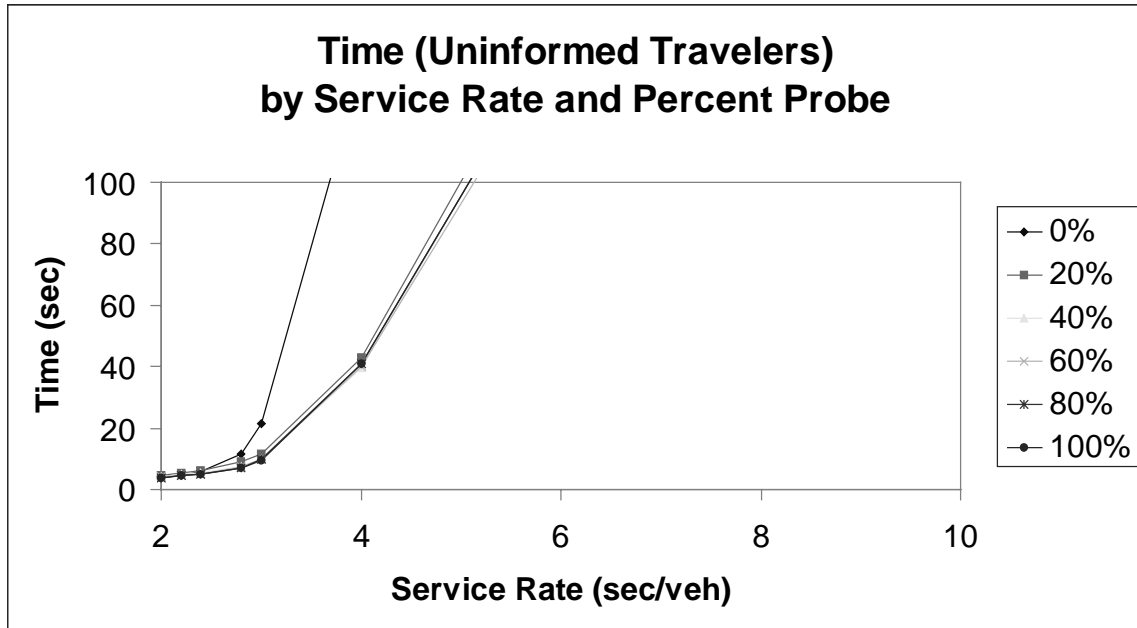


Figure 36:

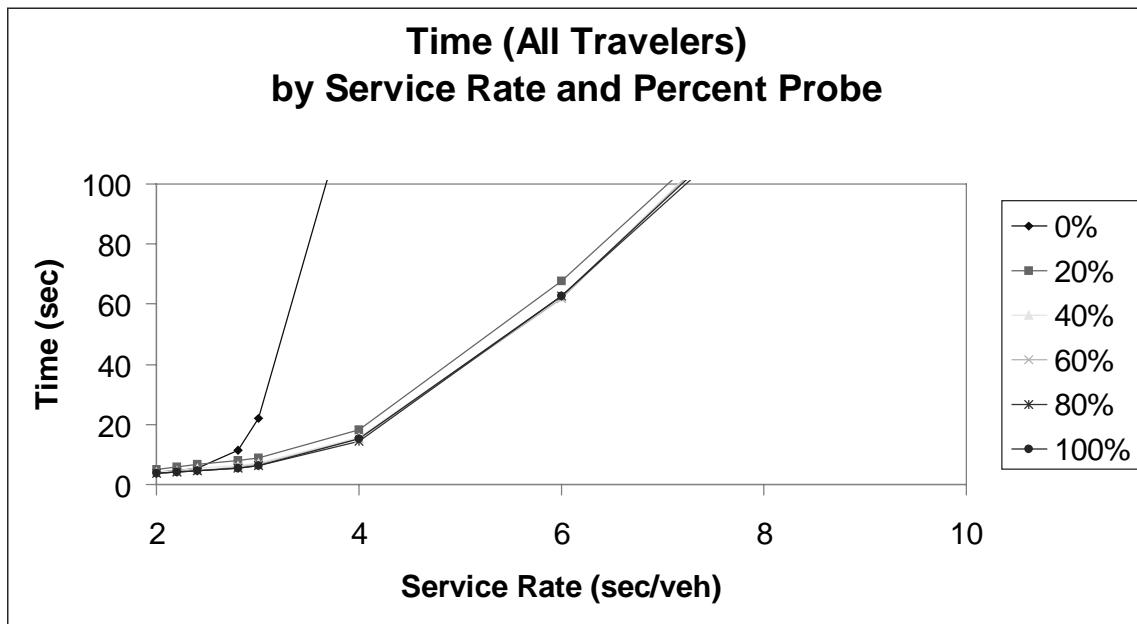


Figure 37:

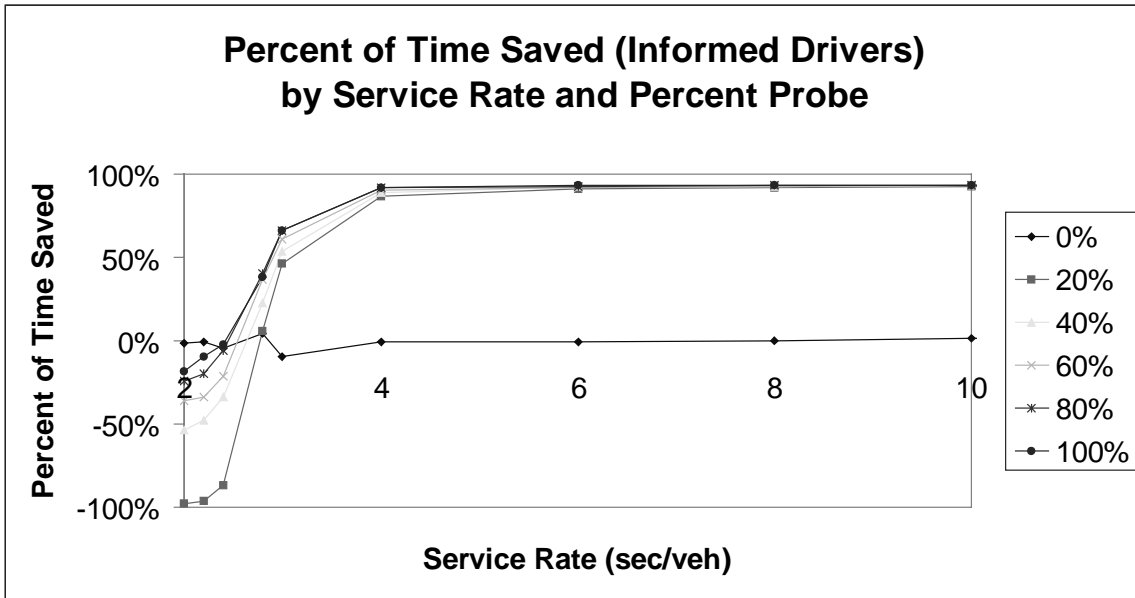


Figure 38:

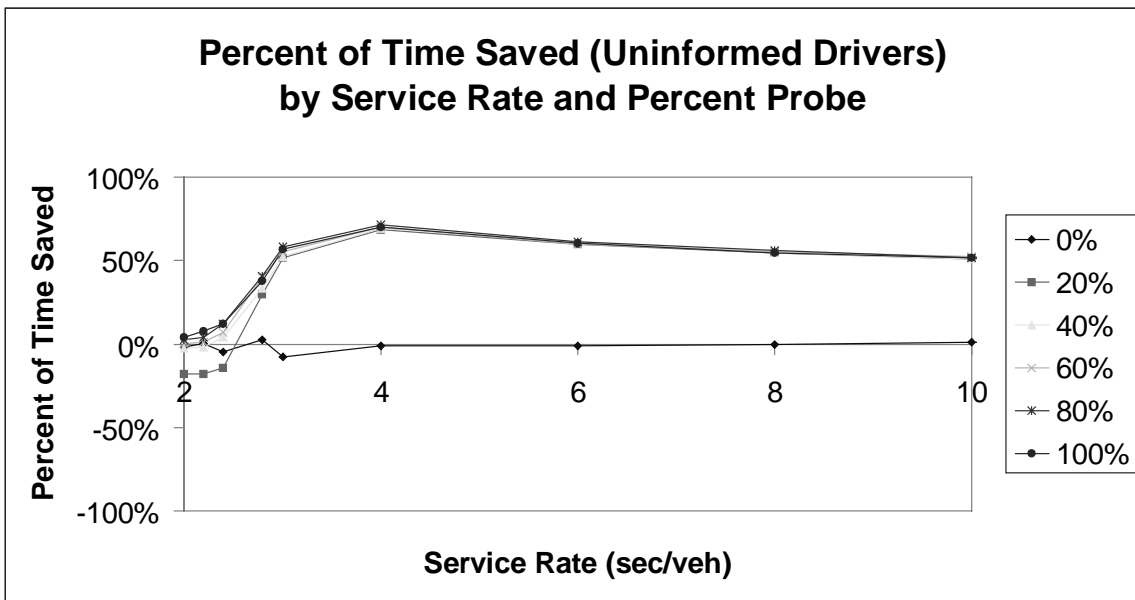


Figure 39:

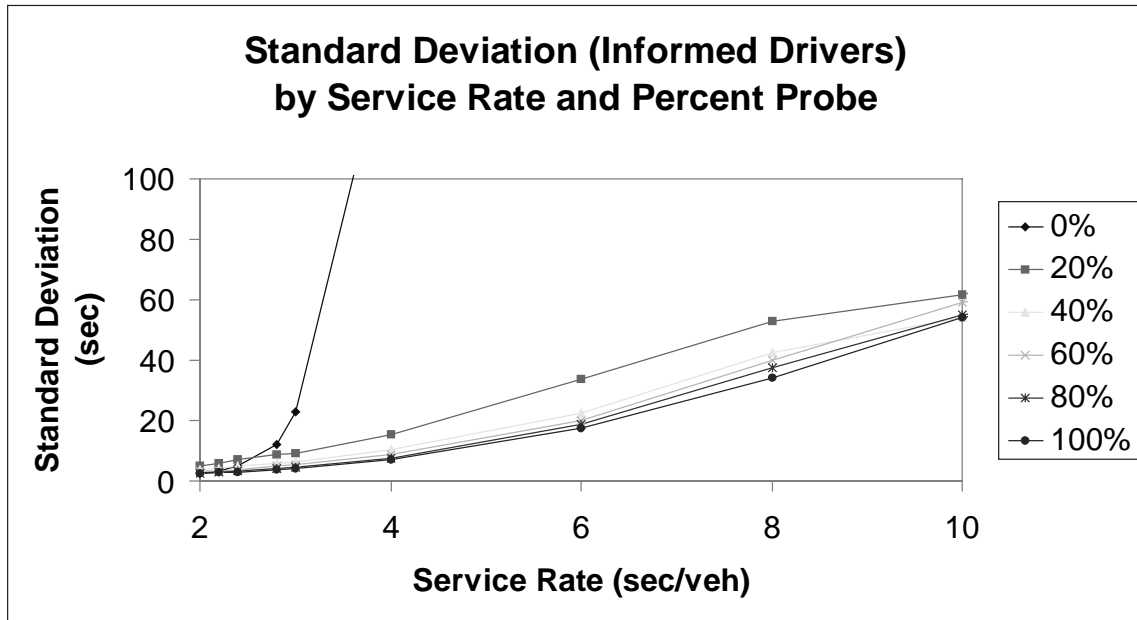
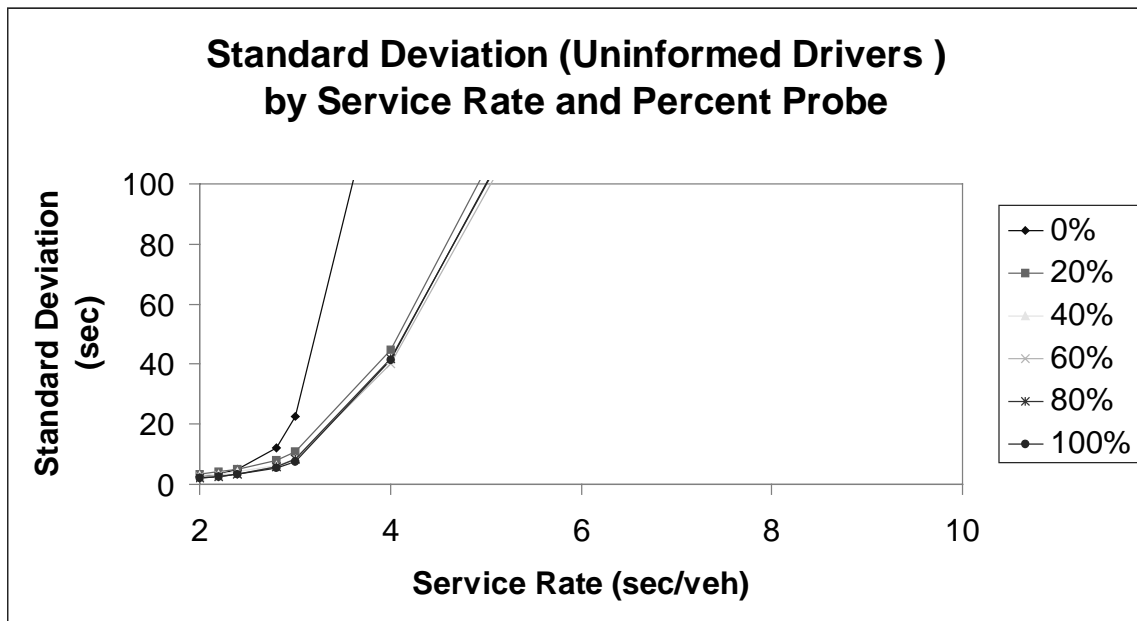


Figure 40:



Summary and Conclusions

A review of the literature and our own simulations show that ATIS provides travel time benefits to users and society overall, although it may increase the time for select non-users. The value of ATIS presupposes viable alternative routes, which are admittedly not available everywhere, but are common on arterial networks. It also presupposes driver's willingness to switch routes, at the cost of more effort and stress. The amount of time saved under recurring congestion is greatest when traffic is near capacity, when small changes in traffic flow can make large differences in travel times. When traffic is much lower than capacity, dynamic route guidance has few opportunities to save time, while for super-saturated conditions, uncongested alternatives may not be available either. Fortunately for ATIS, even as congestion and over-saturated roadways become more common, there will always be a point near, but not over capacity, the shoulder of the peak. The greatest value for ATIS is with non-recurring congestion, incidents that cannot be easily anticipated. Furthermore, ATIS reduces the variance in the travel time, making private vehicle transportation more reliable. The natural consequence is some additional induced demand, the amount proportional to the amount of time saved. The net effect for vehicle emissions is thus ambiguous; there will likely be more total trips and thus greater total travel distance, but that travel will be more efficient and less likely to be stop-and-go or idling.

Widespread adoption of in-vehicle navigation systems providing real-time en-route guidance is probably inevitable as the costs of electronics and communications decline while congestion fails to abate. That adoption requires that quality of the information used by those systems improve through some combination of public and private resources. However, because of positive externalities and network economies, private resources at first may produce an inefficiently small level of resources for information collection. Whether the main source for measuring roadway speeds and detecting incidents is vehicle probes (using cellular phones, toll tag readers, cameras with license plate matching or special purpose devices), or roadway based sensors (magnetic loop detectors, cameras, lasers, or other technologies), or both is still unclear. But the method of detection will have something to say about the level of public involvement in collection. Public resources to collect and disseminate real-time traffic data to travelers may help overcome the chicken-and-egg problem of ATIS not being valuable until there are many users and high quality information. However, public involvement may not be needed forever. Plausibly, the public sector will become an information customer (for use in traffic control and emergency response) rather than producer when the ATIS market matures. Many new technologies do not require directly accessing the public right-of-way in the same way that older technologies such as loop detectors do.

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Annotated Bibliography: ATIS

Simulations

Emmerink, R. H. M., K. W. Axhausen, & P. Rietveld. (1995) “**Effects of Information in road transport networks with recurrent congestion**”, *Transportation* 22, pp.21-53.

Questions:

Implications of information provision to drivers on the performance of road transport networks with recurrent congestion only. Given different types of information provided, the relationship of overall day-to-day performance of networks and market penetration was investigated.

The models assumed fixed departure-time, and open route choice and that the provided information is as reliable as drivers’ own experience. This assumption is shown on the equal weight given to both while updating information.

Methodology

Simulation.

Types of information provided

Own experience. Information on different routes is acquired solely through own experience. After a trip has been made, the expected travel time of the chosen route is updated.

After-trip. This type of information provides drivers with information on the unchosen routes after their trips have been completed. Such as radio or TV reports that describe in detail the day’s situation on the roads or in-home traffic information systems.

Real-time pre-trip. This information is based upon the actual situation in the network just before the start of a trip, enabling drivers to change route before the trip according to the current situation in the network. No attempt is made to provide predictive information.

Real-time en route. This is real-time en route information on the current situation in the network, enabling drivers to switch routes during the trip based upon the most recent information available.

Behavioral Model

Updating information. Drivers’ travel time expectations are updated after new information is available and depend on the information provided. Updating mechanisms are based upon the following linear equation, known as an exponentially weighted moving average Here, ET_r denotes the expected travel time for route r , subscript n denotes time period n , and new information on route r is embedded in *NewInformation_r*.

Parameter a lies in the closed interval $[0,1]$, and reflects the weight given to the last travel experience.

Some research applied this mechanism recently and found that large discrepancies among different individuals, ranging from 0.3 to 0.7. The other research found that $a = 0.2$ led to the largest log-likelihood.

$$ET_r^{n+1} = a * New\ Information_r + (1-a) * ET_r^n$$

Decision-Making. Bounded Rational User Equilibrium (BRUE) theory is used rather than Wardrop’s User Equilibrium (UE) principle. According to BRUE, individuals are trying to achieve a satisfactory outcome, rather than maximizing utility. With the provision of en route information, route switching is carried out only if the improvement in expected remaining travel time compared to the expected remaining travel time of the route currently chosen exceeds a certain threshold.

Simulation

Assumptions and settings:

Traffic is simulated using a linear speed-density relationship.

Fixed departure time

Assign $\alpha = 0.4$ to all individual drivers.

Only one O-D pair

There are 300 drivers, and they behave according to a simple decision-making model describe above.

The simulation runs until either the system has reached a steady state for at least ten subsequent periods, or the number of simulated periods exceeds 400. Overall network performance is measured in terms of travel time averaged over all drivers.

Results

The number of routes used decreases as the bound (indifference band) increases. The models with bound generally outperform the base case (bound = 0). A steady state travel time reduction of 7 percent compared to base case is suggested. The drivers use the different route alternatives more efficiently in a model with bound. However, if the bound gets too large, the overall network performance deteriorates due to too many missed good route opportunities.

Emmerink, R. H. M., P. Nijkamp, & P. Rietveld. (1995) **Perception and Uncertainty in Stochastic Network Equilibrium Models: An Alternative Approach**. TI 95-159, Tinbergen Institute, Amsterdam-Rotterdam, the Netherlands.

Objective

To develop an alternative model on travel behavior to help better understanding the expected impacts of new information technologies on transport networks and apply this concept to develop new user equilibrium under elastic demand.

Methodology

Here, the user equilibrium model of route choice was discussed. The basic assumption is that users maximize their utility by choosing the route with minimal travel costs, which is decided exclusively by travel time.

The authors argue that the discrepancy of traditional deterministic user equilibrium and stochastic user equilibrium can be eliminated by the provision of perfect information. Stochastic user equilibrium concept distinguishes itself from its deterministic counterpart by allowing for limited (incomplete) information from the traveler's point of view.

Unlike the traditional user equilibrium model, which treats the nature of networks as deterministic, the authors take into account stochastic nature of networks. The authors treat travel costs (dependent on travel time only) as random variables, and information provides travelers with realization of these random variables. Thus, informed users make their decision based on actual travel costs, while uninformed travelers make their choice based upon expected travel costs.

$$E(\text{Travel Costs}) = a * E(\text{Travel Time}) + b * \text{Var}(\text{Travel Time})$$

For C_r^o informed users, information provides the realizations of drawings from the stochastic C_r^o route travel cost variables, while subscript r denotes a set of route, including alternative mode and superscript o denote

objective perception. An informed user will choose the alternative that minimizes his/her costs:

The expected costs without information are given by

$$\min_{r \in \{0, \dots, R\}} C_r^o$$

$$\min_{r \in \{0, \dots, R\}} E(C_r^o)$$

With perfect information on the realizations of the stochastic route travel costs is available, expected costs of road users are given by $E(C_{\min}^o)$

While denotes the stochastic variable that is defined as the minimum of the sequence of stochastic route travel costs (including the alternative model “O”)

$$C_0^o, C_1^o, C_2^o, \dots, C_R^o : C_{\min}^o = \min(C_0^o, C_1^o, C_2^o, \dots, C_R^o)$$

$$E(C_{\min}^o) \leq \min_{r \in \{0, \dots, R\}} E(C_r^o)$$

$$E(\text{Travel Costs}) = a * E(\text{Travel Time}) + b * \text{Var}(\text{Travel Time})$$

The difference between these two values, then, can be a measure for the expected gain in costs from perfect information for the uninformed road user with objective perceptions. The expected value of perfect information (EVPI) can be defined as:

$$EVPI = \min_{r \in \{0, \dots, R\}} E(C_r^o) - E(C_{\min}^o)$$

EVPI denotes the maximum amount of monetary units that an individual is willing to pay for obtaining perfect information.

Throughout the analysis, the authors assume that subjective stochastic travel costs are equal to the stochastic subjective travel costs. If this is not the case, so-called perception errors take place. Due to traveler-specific characteristics, the traveler under consideration is not perfectly aware of the prevailing objective stochastic travel costs.

To extend and elaborate this basic model, the authors incorporate the variability of travel time into travel costs. This additional term allows the authors to take into account the critical role of schedule delay in route choice. The parameter α now is interpreted as the value-of-time, while the parameter β measures the monetary costs of uncertainty.

As for informed travelers, the within-day travel time variance disappears; the traveler is certain when he/she will arrive. Hence the expected value of perfect information (EVPI) can be derived:

$$EVPI = \min_{r \in \{0, \dots, R\}} (a * E(C_r^o) + b * \text{Var}(C_r^o)) - a * E(C_{\min}^o)$$

As traditional network equilibrium theory, route travel costs depend on the number of vehicles using a route. By underlying route choice mechanism described above, the authors derived expected travel costs given different level of market penetration at equilibrium. However, details of analysis are not available in this paper.

Primary Conclusions

Information is beneficial to both informed and uninformed drivers.

As the level market penetration goes higher, the gap of expected travel costs between informed travelers and uninformed travels shrinks.

When the percentage of informed drivers is relatively low, informed drivers will benefit from so-called route-split effects. That is, informed travelers can switch to least cost route. However, as the percentage of informed travelers increases to certain extent, the equilibrium principle of informed drivers ensures that the travel costs on all routes in the network are identical. The benefits of the latter category to informed travelers are owing to “mode-split” effect: informed travelers are never regretting a decision to use the transport network.

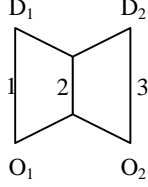
Emmerink, R. H. M., E. T. Verhoef, P. Nijkamp, & P. Rietveld. (1995) **Information in Road Networks with Multiple Origin-Destination Pairs**, TI 5-95-1198, Tinbergen Institute, Amsterdam-Rotterdam, the Netherlands.

Objective

To investigate the impact of information to travelers in a stochastic network equilibrium model with two O-D pairs. Some research has shown that the provision of information is beneficial to both informed and uninformed drivers in the network of a single O-D pair. The authors question whether this conclusion holds for general multiple O-D pairs by examining the network with two O-D pairs and hope to gain some insight into more realistic condition.

Methodology

A simple network with two O-D pairs is constructed to analyze in this paper.



As depicted above, drivers traveling from O_1 to D_1 can choose between link 1 and 2, and drivers from O_2 to D_2 can take either link 2 or link 3.

Assume that an incident occurs on link 1 with a fixed probability p , thereby reducing its capacity. Informed drivers know whether the incident takes place or not and thus make decision based on actual travel costs. On the other hand, uninformed drivers make their decision based on expected travel costs. In addition, demand is elastic, drivers have an option of not using the network at all.

Three models are constructed to compare the impact of information:

N: no information is available.

P^X : information is available for all drivers willing to travel from O_1 to D_1 .

P^{X+Y} : information is available for all drivers willing to travel from O_1 to D_1 as well as from O_2 to D_2 .

The inverse demand functions for drivers from O_1 to D_1 and O_2 to D_2 are given by $D^X(N^X)$ and $D^Y(N^Y)$, respectively, where N^X and N^Y denote the number of travelers from O_1 to D_1 and O_2 to D_2 . The link travel cost functions for route 2 and 3 are given by $C_r(N_r)$, where N_r denotes the number of drivers using route r .

On route 1, link travel costs function of low capacity, due to an incident, is given by $C_1^1(N_1)$, where $C_1^0(N_1)$ denotes high capacity link cost function of link 1.

Assume link travel cost functions and the inverse demand functions are linear over the relevant ranges of road usage.

In case one, only route 1 and 2 are available.

$$D^g(N^g) = d^g - a^g N^g \quad (g = x, y)$$

$$C_1^0(N_1) = k_1^0 + b_1^0 N_1$$

$$C_1^1(N_1) = k_1^1 + b_1^1 N_1$$

$$C_2(N_2) = k_2 + b_2 N_2$$

According to previous research by the same authors, the values of parameters are following:

$$d^X = d^Y = 50, a^X = a^Y = 0.02, p = 0.25, k_1^0 = k_1^1 = k_2 = k_3 = 20, b_1^0 = 0.015, b_1^1 = 0.04, b_2 = b_3 = 0.015$$

In case two, route 3 is also available. Then, the values of parameters are following:

$$d^X = d^Y = 50, a^X = 0.02, a^Y = 0.03, p = 0.25, k_1^0 = k_1^1 = k_2 = 20, b_1^0 = 0.015, b_1^1 = 0.04, b_2 = 0.015$$

In both cases, the impact of information under different capacity level of route 2 and 3, respectively, were tested by varying the value of b_2 and b_3 . The decrease in b_2 and b_3 represents the increase in capacity in route 2 and route 3, respectively.

Primary Conclusions

The comparison between model N and P^X shows the welfare gains from providing information to drivers who travel from O_1 to D_1 , while comparison between P^X and P^{X+Y} tells the welfare gains from providing information to drivers from O_2 to D_2 in addition to drivers from O_1 to D_1 .

In this context, welfare is measured by the amount of total willingness-to-pay minus total expected costs. In case of only route 1 and route 2 are available, following conclusions are drawn from the presented model:

Providing information increases system welfare.

Information is beneficial to both informed and uninformed drivers when capacity of joint alternative (route 2) is high ($b_2 \approx 0.2$).

Uninformed users from O_2 to D_2 are “negatively affected” by the information provided to drivers from O_1 to D_1 when the capacity of route 2 is low and the size of the “stochastic capacity change” (the difference in capacity between normal condition and incident circumstance) of route within certain range.

When route 1, 2 and 3 are available, following conclusions are drawn from the model:

Providing information to drivers increases system welfare.

Uninformed users from O_2 to D_2 are “negatively affected” by the information provided to drivers from O_1 to D_1 when the capacity of route 2 is low. The welfare losses faced by drivers from O_2 to D_2 are even worse when information is provided to drivers from O_2 to D_2 . In this case, drivers from O_2 to D_2 may favor remaining uninformed.

Note: Figures in section 4 tell the story very clearly.

Al-Deek, H. M. and A. Kanafani. (1989) **Some Theoretical Aspects of Benefits of En-Route Vehicle Guidance**, PATH Research Report UCB-ITS-PRR-89-2.

Objective

To estimate the benefits, in terms of total travel time, from vehicle route guidance in urban network. Some characteristics of the network were examined, such as speed on the surface streets, and different configuration of networks, were examined to draw more general results. En-Route Vehicle Guidance (ERVG) is reckoned as a tool to achieve system optimal assignment. Thus, the benefits in this context were measured by saving in total travel time at equilibrium in a given demand under System Optimal (SO) assignment and User Equilibrium (UE).

Methodology

In this report, traffic volume on each link in the network were determined according to either UE, achieved by each individual driver seeking for the minimum travel time path, or SO assignment.

Two types of idealized corridors are constructed. One is a freeway corridor, which is long in relation to the trip length, and the other one is a corridor leading to a single destination such as a CBD. A simple network with two O-D pairs is constructed to analyze in this paper.

In the first case, since trip length (L) is short compared to the length of freeway, the flow on the freeway is constant and depends on the width of the freeway. Suppose that all trip trajectories remain on one side of the way. Drivers can either use surface streets only, or drive down to the freeway and use it for distance L and then return back to the destination point via a short local street. In the second case, flow on freeway is no longer constant; instead, it accumulates as a destination area is approached. That is, flow on the freeway increases with distance up to a point at which no additional motorists would enter the freeway.

Sensitivity Analyses were conducted by varying the capacity of freeway, length of trip, trip density, speed on the city streets, and the presence of parallel freeways.

Primary Conclusions

Total time saving is typically of the order of 3-4%, but is sensitive to network parameters, city street speed, in particular.

In the first case, the maximum route guidance savings from 3% to 9% can be achieved when average speed on the street network is 10 mph. Notice that the variance of time saving also depends upon trip density.

The saving drops to 1.5% to 3% with a speed of 25 mph and virtually disappears at a speed of 40 mph.

Also in case one, there is a little gain from route guidance if there is a severe shortage of freeway capacity. On the other hand, if there is ample freeway capacity then, depending on trip density, freeway congestion may not arise and there may be little need for route guidance.

In the second case, no numerical results but figures were drawn to indicate the benefits. According to the analysis, system optimal assignment will always divert some traffic away from the freeway.

Comment

It is interesting to notice that the way that the change of traveler's behavior in response to the provision of information in this report is quite different from the rest. Here, information is a tool for planner to achieve better overall consequence. While in the rest of papers, information provides advice from the viewpoint of individual driver. In those papers, drivers choose the route with shortest travel time (or generalized travel costs), and then, a new User Equilibrium is achieved.

Al-Deek, H. M. and A. Kanafani. (1991) **Incident Management with Advanced Traveller Information Systems**, PATH Research Report UCB-ITS-PWP-91-5.

Objective

To investigate one of important applications of ATIS: incident management. This paper uses an idealized traffic corridor and deterministic queueing methods to identify the usefulness of the route guidance information under different situations and estimate the benefits gained from saving in travel time.

Methodology

A simple corridor consisting of 2 routes connecting two points is constructed. Assume that the first route is a freeway with higher capacity and lower free flow travel time, and travel times are independent of flow except under queueing conditions. Hence, in absence of queues, the first route is always preferred. Furthermore, the location of the incident is assumed such that queue does not back up into junction of two route. Once a traveler passes this junction point, ATIS information is irrelevant since he would already be committed to one of the two routes.

The time saving is analyzed by drawing a queueing diagram (with arrival and departure curves). This approach is applied to the case of off-peak incident scenario. The benefits of presence of ATIS are measured by comparing the travel time with the absence of ATIS. Several numerical examples are employed to illustrate the approach.

Several conditions are examined with a sensitivity analysis:

Different level of diverted equipped vehicles: p

Incident parameters: duration, severity, and location

Travel demand in the corridor

Difference between free flow travel times on the two routes

Primary Conclusions

Equipped travelers are always better off than unequipped travelers during diversion period. The maximum benefits are not necessarily gained by equipped travelers who are diverted to the alternate route; instead, the maximum benefits are gained by travelers arriving after diversion ends.

Equipped traffic gains maximum benefits as long as the fraction of diverted traffic does not exceed a critical value $p_c = \text{capacity of alternative route } (\mu_2) / \text{total arrival rate } (Q)$. The time during which equipped

travelers are better off than unequipped travelers decreases drastically once a queue forms on the alternate route. System benefits are maximized when p is equal to p_c .

There are no benefits when the incident duration is short.

The further the incident location from the junction, the smaller the benefits are.

The value of ATIS information declines as the freeway capacity is improved. On the other hand, improving the capacity of the alternate route enhances the role of ATIS in incident.

System benefits are expected to increase as the difference in free flow travel times between two routes decreases and are maximized when the two routes are identical.

System benefits are expected to reduce during the peak conditions because of disadvantage caused to travelers originally using the alternative routes where guided traffic is diverted. To conclude, there is a need to spread traffic over time rather than space. In this case, pre-trip traffic information that encourages potential travelers to switch departure times, can be more beneficial.

Also see:

Al-Deek, H. M. and A. Kanafani. (1993) **Modeling the Benefits of Advanced Traveller Information Systems in Corridors with Incidents**, *Transportation Research*, C1, no.4, pp.303-324, 1993.

Vaughn, K. M. M.A. Abdel-Aty, R. Kitamura, R., P. P. Jovanis & H Yang. (1993) **Experimental Analysis and Modeling of Sequential Route Choice Under ATIS in a Simple Traffic Network**, University of California, Davis, Path Research Report, UCB-ITS-PRR-93-12.

Objective

To investigate drivers' learning and pre-trip route choice behavior over time under the presence of ATIS by an interactive route choice simulation experiment.

Methodology:

An interactive route choice simulation program is developed. All subjected drivers have to choose one of two possible routes throughout 32 simulation days. For each day, the amount of delay is randomly assigned to each of the two routes. Three separate groups subjected drivers were run through simulation at three levels of accuracy of information, 60 percent, 75 percent, and 90 percent. At the end of 32 simulation days, subjected drivers were asked to rate their potential for purchasing a traffic information device, their perceived accuracy of the device, and their own ability at selecting routes when compared to the information device.

An ANOVA model is used to find out the factors that influence significantly route choice behavior and learning based on 2464 individual choices made by the 77 subjects.

As for route choice behavior, a conventional binary logic model is used and travelers update their utility function to reflect their learning processes. A set of 1376 individual choices made by 43 subjects are used.

The perceived utility for a specific alternative is based on the perceived outcome of previous experiences. The updating mechanism used in this paper is as follows:

$$X_{ij}(k) = \tau X_{ij}(k-1) + (1-\tau) * u_{ij}(k-1)$$

where, $X_{ij}(k)$ is the perceived value of attribute X by individual I, for alternative j, for trial k and likewise, $X_{ij}(k-1)$ is the perceived value for the previous trial k-1. The variable $u_{ij}(k-1)$ is the actual value of the attribute as experienced by individual I on the previous trial k-1. The coefficient τ is an experience importance factor whose value gives an indication of the relative importance of an individual's previous experiences in updating his/her perception or expectation on the current trial.

The random utility function of individual i for a specific alternative j takes a form of a linear combination of following five attributes: the perceived delay on alternative j, the perceived accuracy level of the information, and three dummy variables, which take a value of one for advised route, males, and an inexperienced driver for the advised route.

Primary findings

As for travelers' willingness to follow route advice, their decision time, and their potential usage of an information system:

Accuracy of information.

Males are more willing to accept advice than females, and make their decisions faster.

Experienced drivers are not as willing to accept advice as less experienced drivers.

Travelers are more willing to accept advice to divert to a freeway rather than local route.

Males and less experienced drivers are less willing to purchase an information system.

As for route choice model, the model with the greatest log-likelihood value is the model for which τ was set equal to 0.8. However, only coefficient for gender and experienced drivers passed t-stat test. This leads to a conclusion that it is indifferent to exclude some perceived attributes. The model prediction rate is 79.2 percent.

Khattak, A. J., H. Al-Deek, & P. Thananjeyan (1994) A Combined Traveler Behavior and System Performance Model with ATIS, Path Research Report, UCB-ITS-PRR-94-06.

Objective

To develop a framework to assess the benefit of ATIS under unsaturated conditions as well as recurring congestion (over-saturated condition).

Methodology

A simple network with one O-D pair and two routes is analyzed. A full compliance model is applied to underlie the behavior in the presence of ATIS. A probabilistic reported behavior model is assumed as a traveler receives traffic information from radio or so. Simulation is used as a means to describe system performance under different models.

In the full compliance model, drivers are assumed to follow the diversion instructions to the alternative route fully. In contrast, travelers characterized by the reported behavior model are assigned probability to divert. The probabilistic reported behavior model tries to capture realistic response based on a survey of travelers in Chicago in 1991. Longer delay (with a threshold of 20 min) and longer travel times increase the probability of diversion. Travelers are more likely to take alternate routes if they receive delay information through traffic reports as opposed to observing congestion.

Numerical examples were input to run simulation.

Primary findings

In full compliance model, the average delay for all travelers under both under-saturated and over-saturated conditions decreases with an increase in market penetration of equipped travelers. However, no significant reduction in delay is observed when penetration level is around 50%.

In the Reported Behavior Model, no significant relationship between reduction in average delay and market penetration is observed. Furthermore, the maximum reduction in average delay with increased market penetration of information for the behavioral model is much less than the full compliance model.

In the Reported Behavior Model, equilibrium of travel times between the two routes was not achieved, and travel time via route two is longer than via route one. It may be explained by over-diversion of travelers in order to avoid queueing delay, even though they may not save travel time.

In case of higher values of incident duration, flow rate, route 2 travel time, and capacity difference between route 1 and route 2 the full compliance model results in lower average delay in 42.2% of the cases. In the rest of the cases, the reported behavior demonstrates larger benefits than the ATIS full compliance model.

Both models agreed that the benefits of an ATIS under incident conditions are marginal; however, there are cases where active guidance can produce significant system benefits.

Also see similar results in:

Khattak, A. J., H. Al-Deek, & P. Thananjeyan (1998) "A Combined Traveler Behavior and System Performance Model with Advanced Traveler Information Systems", *Transportation Research*, 32A, no.7, pp.479-493, 1998.

Khattak, A., A. Kanafani, & E. Le Colletter. (1994) **Stated and Reported Diversion Behavior: Implication on the Benefits of ATIS**, PATH Research Report UCB-ITS-PRR-94-13.

MITRE Corporation. (1996) **Intelligent Transportation Infrastructure Benefits: Expected and Experienced**, FWHA-JPO-96-008, HVH-I/I-96(10M)E, Washington, DC, January, 1996.

Summary: Results and benefits of several ITS program up to date are presented. Some benefits have been recorded in early ITS projects and related deployments such as accident reduction, time savings, transit customer service, roadway capacity, emission reduction, fuel consumption, and vehicle stops. Evaluations from field operational tests, as well as from simulation and user surveys are collected. The scope of this report includes the following systems:

- Freeway Management Systems
- Traffic Signal Control Systems
- Incident Management Programs
- Multi-modal Traveler Information Systems
- Transit Management Systems
- Electronic Toll Collection Systems (ETC)
- Electronic Fare Payment

Available on the web: <http://www.its.fhwa.dot.gov/>

Wunderlich, K. E. (1996) "An Assessment of Pre-Trip and en route ATIS Benefits in a Simulated Regional Urban Network", in the 3rd world Congress on Intelligent Transport Systems, *Intelligent Transportation: Realizing the Future*, Orlando, Florida, 1996.

Objective

To estimate time-saving for a regional traffic network as well as for an average individual as a result of introducing pre-trip and en route ATIS. Three types of real-time ATIS user services are considered in this paper: pre-trip mode shifting, pre-trip route selection, and en route guidance. Benefits of these three services, which serve identically-sized mutually exclusive sub-populations, are evaluated both individually and concurrently by using simulation techniques, called Smart-Shift and INTEGRATION. Three scenarios are set as various capacity reductions in a network: rainstorm, construction, and incidents.

Methodology

The benefits, exclusively travel time savings, are assessed by employing a framework of a traveler pre-trip choice module (Smart-Shift) and a traffic simulation module (INTEGRATION) in a network based on the Detroit, Michigan metropolitan area. In each case, individual trip performance is tracked for over 180,000 travelers in a simulated three-hour morning rush period over a 90 square-mile area served by a range of transportation facilities. Smart-Shift is developed by Mitretek System Inc. as a part of an on-going FHWA ITS benefits assessment effort.

Assume that every traveler may choose from two modes: "on-roadway" and "off-roadway". "On-roadway" trip time can be computed from traffic simulation output and varies with demand. In contrast, "off-roadway" trip time is assumed to be constant as a generalized representative of rail transit or other alternative mode choice. It is computed for each origin and destination pair in the demand pattern.

Two pre-trip ATIS services are modeled in the study. A traveler may choose to shift mode based on a real-time prediction of roadway travel time for a set of historically fastest-paths (Pre-Trip Modal Shift). Another group of travelers (Pre-Trip Route Selection) receive a non-predictive estimate of roadway travel time based on the best route at the time of trip start. The third group of travelers receive a best path when they begin their trip as well as periodic updates en route.

Three scenarios are tested. Rainstorm causes a network wide reduction in capacity. In the test network, a 25% global reduction in network roadway capacity is chosen. The impact of construction is localized, but

predictable. The M-10 Lodge Highway effective capacity drops 50% along a seven-mile stretch of highway to reflect the impact of construction on the facility. An incident is considered as an unpredictable event. The scale of impact of the incident is compatible to construction. In this case, mode shifters have 20 minutes time to get updated information.

10% market penetration is assumed for each service.

Primary Conclusions

Overall System Delay Reduction Impacts of ATIS User Services

	Construction	Rain	Incident
ATIS User Services in Isolation			
10% Dynamic Route Guidance	18%	12%	6%
10% Pre-Trip Route Guidance	19%	15%	6%
10% Mode Selection	14%	6%	6%
ATIS User Services in Combination			
10% Route Guidance + 10% Route Selection	34%	22%	21%
10% Mode Selection + 10% Route Guidance	34%	15%	22%
10% Mode Selection + 10% Route Selection	33%	23%	8%

User Delay Reduction Impacts of ATIS User Services

	Construction	Rain	Incident
ATIS User Services in Isolation			
10% Dynamic Route Guidance	72%	45%	49%
10% Pre-Trip Route Guidance	71%	46%	41%
10% Mode Selection	32%	-39%	-27%
ATIS User Services in Combination			
10% Route Guidance + 10% Route Selection			
Route Guided Vehicles	78%	39%	36%
Pre-Trip Selectors	70%	35%	32%
10% Mode Selection + 10% Route Guidance			
Route Guided Vehicles	90%	46%	61%
Mode Shifters	25%	-46%	-38%
10% Mode Selection + 10% Route Selection			
Pre-Trip Route Selection	84%	53%	48%
Mode Shifters	26%	-50%	-26%

Adler, J. L., V. J. Blue & T. L. Wu (1999) “Assessing Network and Driver Benefits From Bi-Objective In-vehicle Route Guidance”, presented in the 78th TRB Annual Meeting, TRB, 1999.

Objective

A network simulation model is build to investigate the effect of market penetration of in-vehicle route guidance systems on network and driver performance. In this paper, a bi-objective path search algorithm that aims at finding optimal paths based on the (linear) trade-off of in-vehicle travel time and travel complexity. Travel complexity represents effects that impact upon both the safety and comfort of the driving task, which can be indexed as number of turns and road changes or so.

Free Flow Condition (800vph):

- When the split of travel time and complexity is 60/40, the improvement in travel time achieves at the low market penetration. The highest reduction (4.2%) for equipped vehicles occurs at market penetration rate 10%.

- Travel time benefits decrease as market penetration increases. AT 100% penetration, only 2.7% improvement over the base case.
- The complexity value increases up to 20% for equipped vehicles. System delay was reduced by 6%-19% when deployed in isolation, and 8% - 34% in combination.

Congestion Condition (1500vph):

- When the split of travel time and complexity is 60/40, interestingly, the generalized cost of all drivers decreases from market penetration levels from 0% to 40%, and then begin to rise.
- Equipped vehicles enjoy 5.2% of reduction in travel time at 10% penetration level and remain very well at 100% penetration rate.

Sengupta, R. & B. Hongola. (1998) **Estimating ATIS Benefits for the Smart Corridor**, PATH Research Report UCB-ITS-PRR-98-30.

The potential benefits of using Changeable Message Signs (CMS) for the management of non-recurrent congestion during the AM peak in the Smart Corridor were estimated by a simple simulation model. Smart Corridor consists of a section of the Santa Monica freeway (I-10) and six parallel arterial roads lying between the Harbor freeway (I-110) in the east and the San Diego freeway (I-405) in the west.

The impact four different control strategies, different level of market penetration were modeled, assuming that incident duration is 20 min.

- Strategies that continue to divert traffic after the incident clearance yield more time saving.
- The more the traffic is diverted, the more the travel time saving. The time saving at 15% of diverted traffic range from 6% to 16%, and from 11% to 20% in case of 20% and 40% reduction in capacity, respectively.
- When incident duration reduces from 20 min to 10 min, 5.7% of time would be saved even no diversion.

Stated Preference Surveys

Khattak, A. J. (1993) **Behavioral Impact of Recurring Incident Congestion and Response to Advanced Traveler Information Systems in the Bay Area: an Overview**, Path Research Report, UCB-ITS-PWP-93-12.

Objective

To understand how people deal with congestion and how might they respond to a multi-modal ATIS.

Methodology:

Mail-back questionnaires were distributed to peak period automobile commuters across the Golden Gate Bridge in both morning and afternoon peak rush hours. A total of 3238 surveys were coded and checked.

Primary findings:

Currently available real-time traffic information broadcast through the electronic media provides a basis for making travel decisions.

Revealed from the survey, 45% of people didn't change their route in spite of having advance information. When faced with the hypothetical situation of having an ATIS device give them information, respondents were inclined not to change routes unless the device specifically advised this or gave specific information about delay times on the usual route.

When monetary incentives were offered to ATIS equipped travelers for following system optimal advice, particularly when the advice conflicts with their usual route and departure time selection, potential participants showed a willingness to change route and departure time. When offered \$25, \$50, \$75, and \$100, about 20%, 29%, 42%, and 76%, respectively, would definitely leave 30 minutes earlier than normal once a week.

Khattak, A., A. Polydoropoulou, M. Ben-Akiva. (1996) **Commuters' Normal and Shift Decisions in Unexpected Congestion: Pre-trip Response to Advanced Traveler Information Systems**, PATH Research Report UCB-ITS-PRR-96-7.

Objective

To understand how people deal with unexpected congestion during the pre-trip stage and how they may respond to ATIS. Travelers' route, departure time, and mode selection decisions were investigated.

Methodology

The revealed preference approach was used to investigate the factors that have effect on travelers' route choice, departure time, and mode selection under unexpected congestion. The stated preference approach was used to explore travelers' response to future ATIS technology, which was assumed to provide either qualitative or quantitative, or predictive, or prescriptive delay information.

The mail-back questionnaires were distributed to peak period automobile commuters crossing the Golden Gate Bridge, during both the morning and the evening rush hours (6A.M. to 10AM and 4 P.M. to 6P.M.) in February of 1993. People were asked to respond only if they used a vehicle regularly (at least once a week) for their work trips in the Bay Area. A total of 3238 surveys were coded and error checked. A total of 586 home-to-work trips during which pre-trip information was acquired were reported.

Then, data from report preference and stated preference were combined to develop a multinomial logit model for each behavioral alternative, such as changing route, leaving earlier, leaving later, taking public transportation and etc.

Primary Findings

From revealed preference:

- Travelers learned of congestion by observing it directly before entering their vehicles, or by radio and television reports.
- These travelers initially expected congestion to add about half an hour to their trips, and later found their expectations to be somewhat shorter.
- In spite of having advanced information, 37% of travelers did not change their travel plans.
- Those who did change their plans departed either earlier or later than usual (37%) and /or took an alternate route (20%); only 2% used public transportation and 2% canceled their trip altogether. About 5% added or canceled intermediate stops.

Travelers' response to ATIS (stated preference survey):

- Across various ATIS messages, 24-45% would leave earlier than usual, 7-22% would leave later, and 12% would take an alternate (43% if the ATIS device specifically suggested to do so). Only 2% were willing to take public transportation (22% if the device specifically suggested to do so).
- Observations from the model:
- Negative constant term indicates that travelers have behavioral inertia when they faced with unexpected delays. Accurate delay information can somehow help commuters to overcome this and change their habitual patterns.
- Lack of experience with alternate modes and routes was a critical factor in travelers' willingness to divert.
- When travelers become aware of the delay, they tend to switch immediately to their available alternatives. When delay increases over 20 minutes, no change in the behavior are observed. Beyond a certain threshold travelers seem to become indifferent to delay increases.

Field Operational Tests

ADVANCE (Advanced Driver and Vehicle Advisory Navigation Concept), Chicago (1997)

was an in-vehicle advanced traveler information system (ATIS) that operated in the northwest suburbs of Chicago, Illinois. It was designed to provide origin-destination shortest-time route guidance to a vehicle based on an on-board static (fixed) data base of average network link travel times by time of day, combined as available and appropriate with dynamic information on traffic conditions provided by radio frequency communications to and from a traffic information center.

Schofer, J. L., F. S. Koffelman, and W. A. Charlton. (1997) "Perspectives on Driver Preferences for Dynamic Route Guidance Systems", *Transportation Research Record 1588*, TRB, National Research Council, Washington, D. C., 1997, pp. 26-31.

Saricks, C. L., J. L. Shofer, S. Sööt, and P. A. Belella. (1997) "Evaluating Effectiveness of Real-Time Advanced Traveler Information System Using a Small Test Vehicle Fleet", *Transportation Research Record 1588*, TRB, National Research Council, Washington, D. C., 1997, pp. 41-48.

INFORM (Information for Motorist), Long Island, New York. (1990)

INFORM is an integrated corridor on Long Island, New York, including information via variable message signs (VMSs) and control using ramp meters on parallel expressways and some coordination on arterial. The implementation progressed in phases starting with VMSs, followed by ramp meters in 1986 and 1987, and completed implementation by early 1990.

Estimates of delay savings due to motorist information reach as high as 1900 vehicle-hours for a peak period incident and 300,000 vehicle-hours in incident related delay annually.

Smith, S., and Perez, C., "Evaluation of INFORM – Lesson Learned form and Application to Other Systems", presented at 71st Transportation Research Board Annual Meeting, January 1992.

SmarTraveler, Boston, MA. (1993)

The SmarTraveler ATIS was introduced in January 1993. It offers real-time, route-specific, traffic and transit information to travelers in the Boston metropolitan area via telephone. Real-time information on 61 monitored highway segments and four public transportation services can be accessed by entering a key code. The MOBILE5a model was used to estimate the impact on emissions.

Assuming 30% of 96,000 daily callers change travel plans according to the breakdown:

- 45% of change route of travel,
- another 45% change time of travel
- an additional 5%-10% change travel mode.

Surveys performed indicate that 30% -40% of travelers frequently adjusted travel patterns based on travel information. Emissions of VOC were reduced by 25% (498kg/day), NOx by 1.5% (25kg/day), and CO by 33% (5032kg/day) as a result of introducing the system.

Tech Environmental, Inc. (1993) Air Quality Benefit Study of the SmarTraveler Advanced Traveler Information Service, July 1993.

Pathfinder, Los Angeles, CA (1998)

Pathfinder was a real-time, in-vehicle navigation and motorist information system operational field test, conducted in 1991-1992 on the Santa Monica freeway Smart Corridor. The in-vehicle system shows a map with vehicle's location, and highlighted freeway congestion area. Audio and text messages were complementary. More than 10,000 surveys were collected for evaluating the user perception of the system.

A yoke driver study was conducted to evaluate the performance of real-time information and navigation assistance. Data from over 70,000 miles drive on more than 8,400 trips were collected. Surveys suggest

- 64% of regular commuters believed the system helped them to save time,
- 75% of those driving to an unfamiliar destination thought so.

Sengupta, R. & B. Hongola. (1998) Estimating ATIS Benefits for the Smart Corridor, PATH Research Report UCB-ITS-PRR-98-30.

SIRIUS, Paris, France (1996)

SIRIUS is a traffic management system and drivers information service on the motorway in the Paris region. The SIRIUS system has been in operation since January 1994 on 275 km of interconnected motorways. The traffic information was delivered on the VMS. After two year of operation, the data drawn from behavioral change (route diversion), alone with a simple queueing model was employed to estimate travel time savings. (not clear)

- For each one percent of people who divert, the total time saving of the whole users is 8% of the initial in-queue travel times.
- Diverted traffic gained 94% of the total benefits in terms of travel times. (not clear)
- The saving in terms of safety represent roughly 15% of the saving in travel times. (no clear)

Durand-Raucher, Y., Jean Orselli & M. Frybourg. (1996) "The User's Behavior Faced with << SIRIUS >> Travel Times: Surveys and Socio-Economic Evidences in the Paris Region", in the 3rd Annual World Congress on Intelligent Transport Systems: Intelligent Transportation: Realizing the Future, OCT 14-18 1996, Orange County Convention Center, Orlando, Florida, ITS America.

STORM, Stuttgart, Germany, (1996)

The STORM data network is a pilot for traffic information systems in Stuttgart region. It was implemented in the period 1993-1995. Several telematics systems for special applications were combined with existing traffic control, traffic operations and traffic communications system to form an integrated traffic information system. The data network collect information available from all areas of transport and result in the current traffic report for all means of transport. On-line pre-trip information and individual route guidance are both available. Several surveys were conducted after testing various route guidance systems. A simulation model was used to estimate travel time savings. A market penetration of 10% was assumed.

- 87% of participants felt that the individual route guidance system helpful.
- 40% of participants reported to change routes for regular trips according to system recommendations.
- Over two thirds of the interviewees felt that the system helped to save travel time.
- According to simulation results, equipped vehicles save 20% less time, while non-equipped vehicles also take slightly less time to complete the trip.

Note: the details of simulation are not clear.

Peckmann, M. (1996) "STORM Stuttgart Transport Operation by Regional Management-Results on the Field -Trials and Assessment", in the 3rd Annual World Congress on Intelligent Transport Systems: Intelligent Transportation: Realizing the Future, OCT 14-18 1996, Orange County Convention Center, Orlando, Florida, ITS America.

TravTek, Orlando, FL (1998)

TravTek was an in-vehicle navigation system operational field test, conducted in 1991 through 1994. Local information, navigation information, route selection information, route guidance information, real-time traffic information as well as emergency assistance were provided. A total of 2,298 visitors and 51 locals user questionnaires were received to provide the data and system performance under naturalistic situation. A yoked driver study was conducted to evaluate the ability of TravTek to provide navigation assistance,

avoid congestion reduce trip travel times, enhance driving safety, decrease congestion and increase fuel economy. A simulation model INTEGRATION was used to evaluate network performance.

- Two-thirds of those surveyed would be willing to pay about \$1,000 for a device similar to TravTek.
- The simulation states total trip time decreases by about 11% when market penetration reaches 50%.
- Fuel consumption decreases but at a slower rate.
- Higher NO_x emission rates were obtained at moderate market penetration level.
- TravTek vehicles have a “one-minute” average trip time “advantage” over non-Trav-Tek vehicles. Improved network performance is not obtained at the expense of non-TravTek vehicles.
- A small safety risk benefit at moderate market penetration levels was found under non-recurrent condition. However, TravTek vehicles suffer from higher risk under recurrent conditions.

Picado, R. (1998) Route Guidance, PATH on the web:

http://www.path.berkeley.edu/~leap/TTM/Route_Guidance/index.html

Annotated Bibliography: Demand Elasticity with respect to Time and Capacity

The issue of demand elasticity or induced demand is a controversial topic in research. Researchers are trying to identify the extent to which trips are induced, shifted, and lengthened due to capacity expansion. Because ATIS systems have similar effects, to capacity expansion, the literature on demand elasticity is pertinent. The most recent results are suggesting overall demand elasticities between -0.5 and -1.0 . Indicating that a 1% increase in capacity or reduction in travel time will increase demand by between 0.5% and 1.0%. Clearly, this is still a broad range, and results vary with assumptions, methodologies, locations, and other background information, but it is important to note that these results are significantly different from 0%, so some elasticity should be considered in analysis. These results are detailed in the annotated bibliography.

Table: Summary of Literature on Induced Demand

Author	Methodology	Results
Phil B. Goodwin (1996)	<p>A simple demand function is proposed to estimate the (point) elasticity with respect to travel time roughly.</p> <ol style="list-style-type: none"> 1. Suppose that the travel demand is the function of money cost, which is fully captured by fuel costs, and travel time. 2. The demand elasticities are assumed proportional to the relative importance of money and time. 3. The effect of fuel price on traffic levels was calculated by previous studies. -0.15, -0.3 was selected as the elasticity with respect to fuel price in the short-term and long-term, respectively. 4. The value of time is said to be 6 pence per minute, average time spent travelling by car per day is said to be 25 minutes, and spending on fuel costs per person per day is assumed to be 50 pence. 	<p>Demand elasticity with respect to travel time:</p> <ul style="list-style-type: none"> ♦ Short-term (within the first year): -0.5 ♦ Long-term: -1

J. P. Dunne (1982)	<p>A measure of aggregate <u>share elasticity</u> is built upon the assumption on underlying individual behavior, represented by a binary (car/bus) logic choice model, and connection between disaggregate elasticity and aggregate counterpart. The choice model is developed based on a study of mode choice for the work trip between Livingston New Town and Edinburgh, UK., in 1982. (This paper just presents but shows how to get the model).</p> <ol style="list-style-type: none"> 1. Point elasticity is calculated as well as arc elasticity. 2. Weighted elasticity and the elasticity of representative individual are compared. 3. To reduce heterogeneity of commuters, the demand elasticity for a sub-sample of car-available people only is calculated as well. 4. <u>Time is the time difference between using two modes</u>, not absolute value of travel time. 	<ul style="list-style-type: none"> ◆ Point elasticity: Total sample: 0.077 Car-available: 0.02 ◆ Arc elasticity: -40 (40) % change- Total : 0.089 (0.064) Car-available: 0.033 (0.035) -20 (20) % change- Total sample: 0.083 (0.071) Car-available: 0.022 (0.018) -10 (10) % change- Total sample: 0.081 (0.073) Car-available: 0.021 (0.019) -5% (5) change- Total sample: 0.079 (0.075) Car-available: 0.02 (0.019)
Gómez-Ibanez, J. A. & G. R. Fauth (1980)	<p>In this paper, they compared demand elasticity with respect to travel time from three models. The first model is calibrated by Charles River Associates, Inc. (CRA) with 1967 survey data from Pittsburgh. The second one is estimated by Ben-Akiva and Albright (SCI) with 1968 data from Washington, D. C. The third one is built by McFadden and Train with 1975 San Francisco survey data.</p> <ol style="list-style-type: none"> 1. Two modes available: transit and auto. 2. Three explanatory variables: cost, in-vehicle time, and out-vehicle time. 3. Two scenarios are compared: <ul style="list-style-type: none"> A. A hypothetical commuter to downtown Boston. (6-mile trip, initial mode split is 50/50, out-of-pocket cost of \$1 for transit and \$2 for auto, round trip in-vehicle times of 80 minutes for both modes, a 15 minute transfer time on transit, and a 6-minute transfer time on transit, and a 6-minute park and unpark and walk time for auto. B. commuters to downtown Boston by using zonal data on 1975 work trips. 	<ul style="list-style-type: none"> ◆ Scenario A: Auto direct elasticities- CRA: -1.6 SCI: -0.62 McFadden/Train: -1.85 ◆ Scenario B: Auto direct elasticities- drive alone CRA: -1.77 SCI: -0.55 McFadden/Train: n.a.

Patrick S. McCarthy (1997)	<p>Two aggregate share models for inter-city travel are established and compared. One is “linear logic” and the other one is “logic captivity” model. The later is used as an effort to avoid the unpleasant property of IIA in “linear logic model”.</p> <ol style="list-style-type: none"> Four groups of explanatory variables are used to develop the model: modal attributes (including travel cost, travel time, fatality rate, and mileage), population characteristics, regulatory environment, and time trend. Four alternatives are presented: air, rail, inter-city bus service and car. Annual data from 1960 to 1981 (total = 32) is used. 	<p>Demand elasticity with respect to auto travel time:</p> <ul style="list-style-type: none"> ♦ Linear Logic Model <ul style="list-style-type: none"> Air: 0.006 Rail: 0 Inter-city Bus: 0.001 Car: -0.008 ♦ Linear Captivity Model <ul style="list-style-type: none"> Air: 0.002 Rail: 0 Inter-city Bus: 0 Car: -0.002
Hansen, Mark (1998)	OLS	<p>Demand Elasticity: 0.3-0.4 Highway-segment level Long-run: 10 year Demand Elasticity: 0.62 Area-wide: county level Long-run: 2 year Demand Elasticity: 0.94 Area-wide: metropolitan level Long-run: 4 year</p>
Dowling, R. G. & S. B. Colman. (1998)	Survey	<p>3% increase in daily trips per person A five minute saving in travel time on average 5% increase in daily trips per person A 15 minute or more saving in travel time on average</p>
Sullivan, E. (1998)	Before-after comparison	<p>Less than 10% of increase in ADT induced by improved travel conditions</p>