The value of advanced traveler information systems for route choice

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Abstract

Over the next few years, driver behavior should become more informed with the advent and deployment of in-vehicle navigation systems. This paper analyzes systems that provide the driver the fastest path between his or her current location and final destination, updated in real-time to consider recurring and non-recurring congestion. The traveler's full cost per trip is a bundle comprised of both expected travel time and its reliability. This paper explores these topics from a theoretical economic perspective and then simulates stylized cases. Simulation results indicate that typical information benefits are at a maximum on the precipice of congestion, when vehicles are arriving at a rate of 95% of the capacity, while non-recurring congestion benefits are much greater.

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1. Introduction

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 drivers the fastest path between a current location and final destination, updated in real-time to consider recurring and non-recurring congestion. In the absence of choice, information is of relatively little use. However, many drivers have the opportunity to select dynamically between alternative routes (as well as modes, schedules and activity locations). Over the long term, such systems may reduce the need to construct additional highway infrastructure, or they may induce additional demand. With advanced traveler information system (ATIS) each traveler individually, and the road network as a

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Table 1
Summary of time saved with ATIS by study

Author	Congestion level/type	Time saved (%)	Market share (%)
Adler et al. (1999)	Free flow (800 vph)	2.7	100
	Congestion (1500 vph)	3.1	80
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
Emmerink et al. (1996a,b)	Recurrent congestion	1–4	100
Emmerink et al. (1995a,b,c)	Recurrent congestion	7	
Wunderlich (1995)	Congestion but not reaching saturation	8–20	5
	Saturation	7–12	5
Wunderlich (1995)	Capacity-reducing incident	15	
Al-Deek and Kanafani (1989)	Difference in SO and UE	3–4	
Al-Deek and Kanafani (1993)	Modeling of incident conditions	30–40, 25–55	
STORM, Stuttgart, Germany, (Peckmann, 1996)	Field operational test simulation	20	
Inman and Peters (1996)	Field operational test simulation	5	10
		8	30
		11	50

Note: Time saved **overall** or *equipped vehicles only*.

Reference: Levinson et al., 1999.

whole, could be made more productive. 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 considers the economics of alternative route choices from those systems. Previous research (summarized in Table 1) suggests that ATIS not only reduces the driver's travel time and vehicle operating costs, but also affects (either positively or negatively) the travel time of other commuters (Al-Deek et al., 1998; Durand-Raucher et al., 1996; Emmerink et al., 1994, 1995a,b,c; Khattak et al., 1994, 1996; Khattak, 1993; Levinson et al., 1999; MITRE Corporation, 1996; Saricks et al., 1997; Schofer et al., 1997; Sengupta and Hongola, 1998; Smith and Perez, 1992; Tech Environmental Inc., 1993).

This paper begins by considering the microeconomic theory of traveler information. Our model is developed, which allows us to calculate the time saved and the change in trip variance associated with ATIS as market share and congestion levels vary. This model is then systematically applied to some stylized cases with incidents of various degrees of severity and without incidents. The paper concludes with a discussion of the effects of traveler information and some consequences for public policy.

2. The microeconomics of traveler information

We can model the effect of traveler information as shifting both the supply and demand curves for travel. Previous research has suggested that information can increase the reliability of the

system and lower the total cost of travel between two points. In the absence of information, a driver may always choose the freeway, with a low typical time but an occasional (and unpredictable) much higher time. But with information, the driver can confidently select an arterial on those particularly slow days and bear a lower time. If informed drivers do not shift demand curves, then it is anticipated that the travel time goes down. However, if the demand curve does shift, travel time may rise or fall. The change depends on the magnitude of the shift relative to its intercept with the new supply curve. The total cost of a trip is comprised of a bundle of costs, which include factors such as expected travel time ($E(T)$), the quality and reliability of the trip (for the variance in travel times) ($V(T)$) and the cost of information ($C(I)$).

As illustrated in Fig. 1, we can represent lowering the expected travel time by moving the supply curve. Because the average travel time between two points connected by multiple routes (called the supply curve from now on) moves downward from S_U to S_I as drivers move from being uninformed to informed, demand (in flow past a cordon for instance) increases along the original (uninformed travelers') demand curve (D_U). The magnitude of the increase is constrained by the time savings. Informed individuals may 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_U to D_A or D_B), reflecting a higher quality of service.

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_U 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_U to T_B).

The amount individuals will pay for information will depend in part 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 as

Fig. 1. Shifting supply and demand for travel with traveler information.

well as the magnitude of the reduction in $E(T)$ and $V(T)$ resulting from the presence of information. Furthermore we should know the distribution of risk aversion and risk seeking individuals. A risk averse person will trade a higher $E(T)$ for a lower $V(T)$, while a risk seeking person will trade a higher $V(T)$ for a lower $E(T)$. A large shift in the demand curve (from D_U to D_B) implies that the population begins as relatively risk averse, and is willing to spend longer in travel in exchange for lower $V(T)$, while a small shift (from D_U to D_A) in demand implies that the population is relatively risk-seeking.

The benefits can be broken into two groups:

- benefits accruing to “old” trips (Q_U) made with or without information, and
- benefits accruing to “new” trips ($Q_A - Q_U$) or ($Q_B - Q_U$) only made because of the presence of information. The new trips can be viewed as increasing the productivity of the system. The new trips may be substitutes from other markets (different destinations or modes for instance) or generated entirely anew. Whether they represent the same or different travelers than before is not important.

A small shift in the demand curve may indicate risk-seeking behavior, a reduction in travel time variance does not affect risk-seekers as much as the risk averse. There are three parts to the benefits. First, benefits to “old trips” (users who were on traveling before information was introduced and the supply and demand curves were shifted) resulting from a reduction in travel time, (Area T_AjiT_U , the area between the old and new travel times). Second, benefits to old trips resulting from an increased willingness to pay for the same trip due to the improved quality of the trip (Area $zihy$, the area between the demand curves). These benefits are hard to measure, as the demand curve is not generally well specified far away from equilibrium. Third is the benefits to new trips, which could not be justified in the absence of traveler information (Area $jllh$).

The benefits due to information in the case of a large shift of the demand curve, suggesting a risk-averse population, are somewhat more complicated. In this case, there is a loss to old travelers due to the increase in travel costs, shown by Area T_UigT_B , the rectangle between T_U and T_B . Those old travelers also gain because trips are more reliable, shown by Area $yegfx$ between the original and new demand curves. There are also gains to new trips, shown by the triangle, Area $gkcf$, between Q_U and Q_B , which of the two cases, a small or large shift in demand, is more realistic 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 more substantial than the changes in variance, then we can probably assume that we are operating in a situation much more akin to a small change rather than a large change and there will be few gains for risk-averse travelers.

Bringing these ideas directly into the modeling discussed below is difficult, as finding an equilibrium between demand and a traffic simulation is computationally intensive. Few models even integrate demand and aggregate route assignment techniques, which is a much less difficult problem to solve. Clearly, this is an area for future research. However, we have identified two attributes which we want to measure: travel time (measuring movement along the demand curve) and reliability (the shifting of the demand curve). Our traffic modeling can give us a sense of the magnitude of the changes in these two factors.

3. Modeling approach

By its very nature, the ATIS lends itself to analysis using a simulation approach, because deterministic traffic flow coupled with invariant network times does not require real-time information, only experience. In our model, there are two classes of drivers: informed and uninformed. A driver who has an information system in his vehicle, and accepts its advice, is called *informed*, one who does not is considered *uninformed*. However because of queueing externalities, even uninformed drivers are affected by information. The analysis presented here assumes two parallel and identical links (Fig. 2), one labeled a “freeway” and the other an “arterial” for convenience. 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 assess 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. In the model presented here, the information for informed drivers is the expected time on each route. This expected time depends on the link’s service rate (capacity) and the number of vehicles ahead of the driver on each route who have yet to be served.

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

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

where $\text{RAND}()$ indicates a random real number between 0 and 1, λ is the 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. The simulated service time (τ) in seconds per vehicle is given by the equation below:

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

where τ_v is the service time for vehicle v , τ is the average service time in seconds, assumed to be 2 s unless otherwise given, σ is the service time range (s), assumed to be 0.5 s. (This random number is distinct from that in the previous equation.)

This equation means that the service time for vehicle v is equal to a fixed (average) component τ plus a random component, which is between plus or minus 0.5σ . Given the assumed values $\tau = 2$ s and $\sigma = 0.5$ s, this means that service times vary smoothly and randomly between 1.75 and 2.25 s.

Fig. 2. Network.

The queue on each link operates as first in first out, and there are assumed to be no spillovers between links. A flowchart of the modeling method is shown in Fig. 3.

The strategy we used for modeling was to first do a series of runs for the case with no incidents, and then to repeat those runs when there are incidents. We examined the cases over a range of information levels (from 0% to 100% informed in 16.67% increments). However, when 0% are informed, we could not generate a travel time for informed travelers; and when 100% are informed we could not generate a travel time for uninformed travelers, hence the gaps on the graphs. In the model, for comparability, we assume 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

Fig. 3. Flowchart of modeling methodology.

graph) was the average of 30 distinct simulation runs. Uninformed travelers took as historical information that both routes have equal expected times and variances.

4. Modeling results

4.1. No incidents

In the section examining recurring congestion, we examined information levels over a range of congestion levels (volume to capacity (λ/μ) of 0.50, 0.67, 0.95, 1.00, 1.05) which highlights the levels around capacity that preliminary investigation suggested were interesting. Fig. 4 shows the average travel time (in seconds) of informed drivers as both the percent of informed drivers and the congestion level, measured as the arrival to service rate (λ/μ), vary. This suggests that increasing the share of population with information will do little to reduce travel times for informed drivers. 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. Of course travel times are higher as capacity utilization increases. Fig. 5 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

Fig. 4. Average time (informed drivers) by congestion level and percent informed.

Fig. 5. Average time (uninformed drivers) by congestion level and percent informed.

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. Overall, as more drivers are informed, the average travel time generally drops.

Fig. 6 shows that, 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 (Fig. 7), 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. We believe this is due to the high variability in simulation results around congestion, and not a particularly meaningful result of itself. With more simulation runs, this anomaly should disappear.

Fig. 6. Percent of time saved (informed travellers) by congestion level and percent informed.

Fig. 7. Percent of time saved (uninformed travellers) by congestion level and percent informed.

Fig. 8. Standard deviation (informed drivers) by congestion level and percent informed.

Fig. 9. Standard deviation (uninformed drivers) by congestion level and percent informed.

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 Fig. 8. For uninformed drivers, however, standard deviation tends to fall slightly as traffic becomes more ordered, shown in Fig. 9. As drivers become more informed, the effect of any given individual becoming informed shrinks. The difference in the standard deviation between informed and uninformed travelers tends to approach 0 as the percent informed approaches 100%.

4.2. 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 (including accidents or 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 s 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). Incidents were modeled as an unexpected reduction in capacity on the “freeway” for the entire period. Incidents of different degrees were considered by increasing the service time per vehicle (2.0, 2.2, 2.4, 2.6, 2.8, 3.0, 4.0, 6.0, 8.0), suggesting the incident’s intensity.

Fig. 10 considers the average travel time for informed travelers as the freeway service rate on the affected link is worsened from 2 s 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 s per vehicle (reducing from 3 to 1 lanes open), those informed drivers could switch to the parallel route and take only 10 s. However, when more drivers are informed, more switch, so the parallel route gets more congested. Fig. 11 shows the effects 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, information is a net good, the more informed drivers there are, the lower the average travel time.

Fig. 10. Average time (informed travellers) by service rate and percent informed.

Fig. 11. Average time (uninformed travellers) by service rate and percent informed.

Fig. 12. Standard deviation (informed travellers) by service rate and percent informed.

Fig. 13. Standard deviation (uninformed travellers) by service rate and percent informed.

In percentage terms, the greatest gains come from the most severe incidents. The worse the freeway service rate, the greater the 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, 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 Figs. 12 and 13. 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 makes travel more reliable.

5. 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-informed travelers. The utility of ATIS presupposes viable alternative routes, which are admittedly not

available everywhere, but are common on arterial networks. It also presupposes a 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 at the precipice of capacity, when small changes in traffic flow can make large differences in travel times. When traffic is much lower than capacity and in the absence of incidents, dynamic route guidance has few opportunities to save time, while for super-saturated conditions, uncongested alternatives may not be available either. Fortunately for the technology of 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 time-savings 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 and variance reduced. Empirical research is still needed on the relative importance of reliability vs. average travel time. Robust modeling techniques should be developed to integrate the demand and traffic sides of these problems. Then this approach or more sophisticated simulations can be applied to understand ATIS on networks that are more complex.

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