

Modeling the Behavior of
Traffic Information Providers

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Abstract:

This working paper discusses two primary models which might be used to represent the locational behavior of (lone or competing) traffic information providers. The paper examines characteristics which make traffic information unique as a service good and explores how it is exploited in the models to show how the behavior of information providers differs from that of firms in a traditional market. Questions are addressed regarding the entry of competing providers and the efficiency of the resulting output. The paper is to contribute to a study regarding the future of the traffic information market and the role of public financing versus private competition.

Keywords: Information Providers, ATIS

Executive Summary

In recent years, traffic information providers have appeared in many media for lessening the effects of congestion, particularly congestion information, however, is a service good which can not be produced and marketed similar to that commonly analyzed for fixed goods. Many of traffic information characteristics can influence the behavior of a provider, which can of course be received from this market, in terms of travel time saved or some other quality. A user of the good often bears no transportation cost in acquiring the good. The relationship between the information provider and the consumer of his good must first go through some media such as a radio station or the Internet. This is not common in this market. Finally, individuals can only consume a traffic information multiple reports produced (e.g. reports from different providers) generally. The content; the differences resulting from competition among providers is more a matter of packaging of their goods. These factors (and others) can greatly influence the behavior of information providers with regard to the location about which he collects information. A population segment to whom his good is marketed. Our future research will attempt to define precise relationships between information providers and disseminators to be used to define the models in this report.

In this paper we will introduce and discuss two models which represent the behavior of information providers. Each model will attempt to include the demand for traffic information which a provider seeks to capture. In particular, we will attempt to exploit the spatial element of the demand for information. The first model is theoretical in nature and employ a model of the overall distribution of traffic information. The second model will be more representative of the individual characteristics of the individual trip which might influence one's demand for traffic information. The model for many reasons might be easily extended to the multiple drivers a provider seeks to capture in his market. In conclusion, methods by which the positive attributes of these models might be combined will be discussed.

1. Introduction

Many characteristics of traffic information force it to be marketed in a way that is different than that common for other goods. For example, traffic information is not tied to a specific destination such as the grocery store and thus bears no transportation costs. Various forms of information are immediately available to any driver (e.g. radio broadcast, cellular phone connection, etc.). As a result, the methods by which competing firms in the industry might position themselves differ from the methods by which suppliers of other goods would locate their operations.

The positioning of providers should be of interest because multiple firms are competing to produce the same good. From our early observation of the information providers in the San Francisco Area, as well as unscientific sampling of each providers' reports, the costs of providing information are essentially identical. This could be justified because the manner used by providers to gather information is virtually identical, as each provider uses 3-4 aircraft, receives a large number of phone calls/day, has access to the CHP's computer-aided dispatch, etc. In addition, each provider certainly has access to the reports broadcast by the other over the radio. The differences that appear to result not from the accuracy or the amount of information collected, but from the manner in which the providers choose to package their product. (Of course, in some situations, one provider may learn of an incident before the other. But which provider is first is arbitrary and can vary from incident to incident.) The differences in the way providers position themselves are more often than not at the request of the distributors, e.g. radio stations.

As a result, a competing information provider which covers a common area would experience decreasing marginal benefits to society in the gathering of his information (since all information could be gathered by the first provider). The marginal costs of providing information, however, is likely not decreasing, as he still incurs the costs of gathering or receiving cellular phone calls, etc.; also influencing this is the lack of ability to share their information. As a result, the net social benefit is reduced. The entry of the second provider, one more difficult to observe, would be the increased

expected from the first provider due to the presence of competition. This is addressed in this paper but will hopefully be addressed in a later phase.

The overall objective of this research project is to determine the information traffic information which result from competition and then compare these information which are lost as a result of the providers' clustering. This paper will discuss the research, a phase designed to develop models by which we could attempt to describe which clustering occurs in the industry. The two models which are described in this section will attempt to represent the spatial element of the demand for information. We will address questions such as: how does the overall demand for information vary at certain locations, and how might this affect the (optimal) behavior of information providers. These questions will help us to understand how much clustering results among information providers, and the effect this has on the system's efficiency.

2. Proposed Demand Models

With each of the demand models to be discussed in this section, our objective is to find one which effectively represents the dimensions of the market which an information provider would try to capture. It is the authors' belief that an information provider would try to maximize his revenue, which can be done by capturing more listeners. (In the information market, radio broadcasts, more listeners leads to more revenue from the sale of traffic reports.) Thus, the models must somehow be related to the number of drivers passing a certain point, however, is a function of the time and location of the point. As a result, the models to be discussed must be shown to vary with time and space.

2.1. A Theoretical Model

The first model uses a theoretical form to represent the distribution of information providers (listeners) along a corridor. Imagine a corridor (e.g. a corridor of a freeway) of length a on a line $[0,1]$:

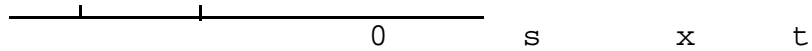


Figure 1. A segment along which all trips are made, in the

All trips being in the direction from 0 to 1, imagine a formula $n(s,t)$ number of trips from origin s to destination t . A simple observation would be that all trips would pass through all locations along its path. Thus an information provider would have a chance of "capturing" this driver as a customer if he gathers any segment of that trip.

The total number of trips to pass through any one point s can be represented by the number of trips beginning upstream of s and ending downstream of s ($x : s < x < 1$). These intervals can be represented by the integral:

$$\int_s^1 \int_0^s n(x,y) dy dx$$

This model allows for quick calculations of the total number of vehicles passing any point of the road. Difficulties arise, however, in determining a realistic model for the number of trips along the line. Without a continuous formula, the integration becomes cumbersome. The advantages of the theoretical model are lost.

A second complicating factor is that along a typical segment, vehicles do not necessarily exit the segment at fixed locations. (For example, a highway has designated exit ramps.) As a result, many of the vehicles which travel through a certain region also travel through an adjacent region. If an information provider were to report on both regions, the number of vehicles captured would likely not be much greater than if he only covered one location. The benefit captured as a result of covering the new region would be those whose trips end in the region immediately upstream. Each listener's benefit would increase (having information about two areas rather than one), but the net benefits of the provider might actually decrease.

constant customer base and higher operating costs. These higher operating costs are from more cellular phone calls having to be received, or more closed-circuit television cameras to be installed, etc. For an information provider to maintain the same level of service over a larger area, some additional investment would likely be necessary.

Because of the limited access, a more typical vehicle-count model might be

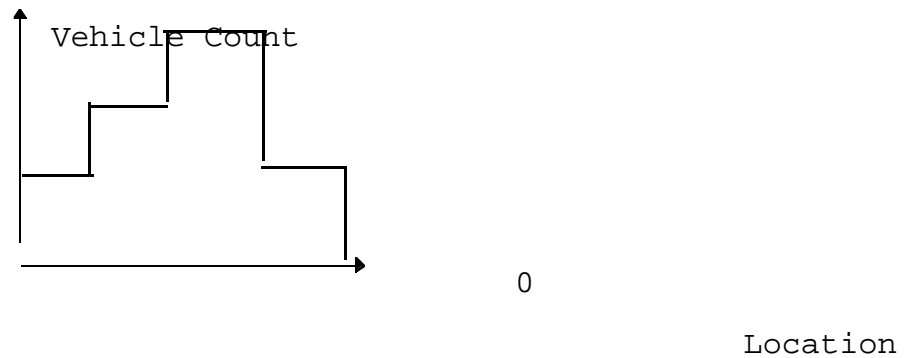


Figure 2. A sample distribution of vehicles along a segment.

2.2. Simplifications to the Model

If the segment $[0,1]$ were assumed to represent a fairly long segment, the number of entry/exit locations would also be much larger. As a result, the entry/exit locations, when scaled for the $[0,1]$ graph, would approach zero. The distribution shown above could be represented by a continuous line:

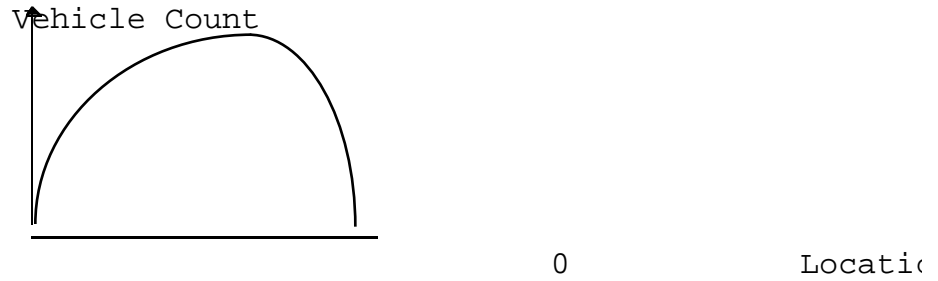


Figure 3. A continuous distribution of vehicles along an expressway.

2.3. Overcoming Redundancy among Vehicles

Unfortunately, this still does not eliminate the redundancy of vehicle counts. For example, a high correlation would exist between the vehicles counted in adjacent segments. One method for overcoming this might be to count the number of vehicles or the number of drivers at a specific location. This could be used in combination with a measure such as the average trip length (and its distribution) to estimate the number of "new" drivers in an area (i.e. those who have not been perceived as customers upstream). Given the average trip length and the probability of varying lengths, one could calculate the likelihood that a vehicle driven in a segment has previously driven past location x_0 . Based upon these probabilities aggregated over all segments, an information provider could estimate the number of "new" customers in a segment starting at location x_1 (and thus the incentive to incur the costs of covering a new location).

A simple means by which this issue could be sidestepped would be to count the number of trips that continue to one location (e.g. the CBD, at the end of the segment). This could be represented by either of the two curves in the graph below:

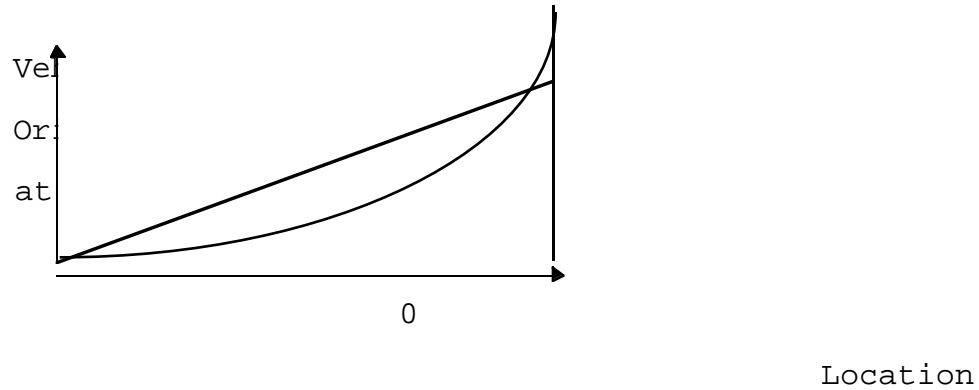


Figure 4. Sample distribution of vehicles with a common destination

It is important to recognize from this distribution that because no trips end at the CBD, the vehicle count continues to increase. As a result, the number of vehicles at a particular location can only increase with the location's proximity to the CBD.

Before continuing, the authors wish to recognize that a number of other factors can affect the value of information at a particular location, in addition to the characteristics mentioned above. Such characteristics would be the frequency of incidents at a specific location, the opportunity for vehicles to divert, and the expected payoff from using the information (related to the value of information is proportional to the number of times information will be used (related to incidents) and the expected payoff from using the information (related to the value of information available)). Each of these characteristics will be explored further in the more representative model; for now, we can proceed as though these characteristics are included in the initial estimation of the demand.

The most interesting observation which might be made from this scenario is the optimal positioning of competing information providers. To capture the largest number of vehicles, a provider in this environment would position himself as close to the CBD as possible because all drivers pass through the segment nearest the CBD. Thus, a lone provider could capture all drivers if it covered a segment of the drivers' trips long enough in the sense that the average individual benefits, in proportion to the length of the segment covered, exceed the individual's

Extending this model one step further, the behavior of information providers can be affected by the length of trips (if they don't all continue to a common destination). The average length of a trip (L) can be included as follows:

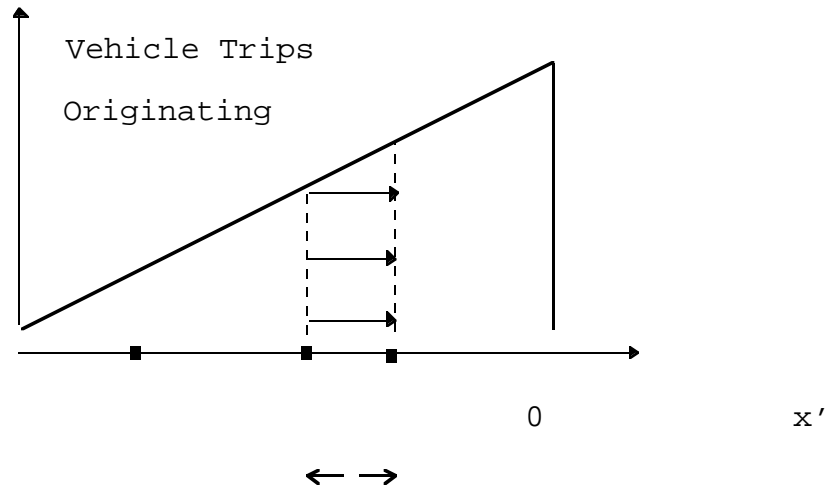


Figure 5. The segment of interest to individuals can be to vary among drivers if a common destination does not

Clearly, for a driver originating at location x to receive any beneficial information, the information must be relevant to his itinerary $[x, x+L]$. Similarly, for a driver originating at x' , the information must be relevant to his itinerary $[x', x'+L]$. An information provider would then be understood as covering the portion of the road which would contain the largest number of listeners. In the case of a lone provider, this would again be the segment furthest to the right (or closest to the origin).

For a lone provider, simple economics (profit maximization) will show that the provider will cover all areas to the left of $x = 1$ until the benefits received (in terms of revenue resulting in more revenue from sponsors) no longer exceed the marginal cost of providing information for that segment. The precise location of this we hope to add to the model as we explore the costs of providing information.

2.4. Introducing Competition

This model involving trip length can also be used to envision the behavior of competing information providers. First examine the model given earlier:

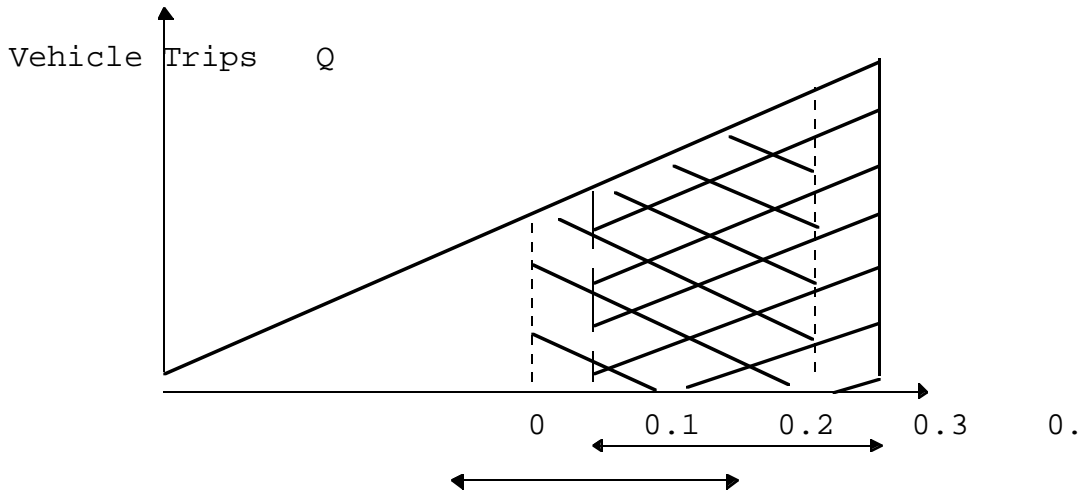


Figure 6. The positioning of competing information providers when all trips are not to a common destination (for $D = 0.2$).

In a situation which involves two competing providers, the first information provider would again position himself as close to the end as possible (e.g. local information provider, if maximizing his profits, would not necessarily position himself at the beginning). Assuming that all vehicles whose trips are covered equally by both providers, the second provider would rather capture all drivers at some point than half of those closest to the end. In one instance, the positioning of providers X_1 and X_2 as shown in the above diagram. (Note that the demand captured by the provider at the left extreme would equal one-half that at the right extreme. Other factors in the model that might affect this slightly, but this is a good model of the behavior. The relationship would ensue regardless of the length of the area to be covered.

Furthermore, the center of the area to be covered by the second provider can be determined using the following formulas (assuming that the provider can only cover on the average trip length and D the length of the segment covered. (This assumes that providers will cover a segment of equal size; our interest here is on relative positioning, not precise positioning.)

$$\begin{aligned}
 (L + D) < 1/3 & \quad \text{then } x_2 = 1 - 3D/2 - L \\
 (L + D) > 1/3 \quad \text{and } D < 1/3 & \quad \text{then } x_2 = 1/3 + D/2 + L \\
 D > 1/3 & \quad \text{then } x_2 = 3D/2 + L \\
 (2D + L) > 1 & \quad \text{then } x_2 = 1 - D/2
 \end{aligned}$$

The method used to determine these positionings can be found in the appendix.

Another scenario exists in which the second provider can choose any segment to cover, i.e. the areas covered do not have to be adjacent. This provider would prioritize areas as such:

1. Cover all areas in which the demand exceeds one-half the maximum demand not covered by the first provider, starting as near to the highest demand as possible. With linear distribution, this is $\{x: 0.5 < x < 1\}$

2. Move left from this region and from the location of highest demand as far as possible. With linear distribution, move left from $x = 0.5$ at twice the rate at $x = 1$.

The behavior can still be estimated using this model if the demand is not linear. If multiple local maxima exist. If the positioning of providers does not need to be adjacent, the locations could be rearranged on the segment for simpler analysis, which would yield similar results. In addition this model can be easily extended to more than two providers algebraically, by adjusting the locations at which behavior changes.

As one can see from these models, the areas which have the largest number of providers (e.g. the CBD) will contain a number of competing providers. Each of the providers incurs similar costs for gathering the same information. On the other hand

will receive no coverage at all. This results because an information provider covers one area with his competition (and capture 1/2 the market) rather than covering the entire area. This raises the question of the efficiency with which the market will be served.

2.5. Questions Remaining

Many issues remain that could influence this model, since we do not have a complete understanding of the traffic information industry. Some of these issues are, in particular, as mentioned earlier, it appears that many of the information providers are not fixed-location. Information providers upon initial observation have shown to cover an entire metropolitan area if a radio station so desires. This is due to the use of aircraft, cellular phones, etc., which are not fixed-location themselves. The model might be used to model less mobile sources (cameras, loop detectors, etc.). It is uncertain how representative this model is of an information provider's operation.

In addition, it remains uncertain what percentage (or portion) of an information provider would have to cover to "capture" a driver as a customer. For a customer, the drivers' benefits must exceed his costs. The benefits (e.g., time saved in the event of an incident) would be proportional to the likelihood of an incident, which would in turn be proportional to the length of the segment covered. The cost of the information and using it would include listening to the station's other programs, an alternate route (unless it were contained in the report), etc. Clearly, as the segment covered increased, the benefits received from information would increase. The length of coverage at which the benefits exceed the costs, and thus the length of coverage to capture an individual as a customer, remains uncertain. This could be a significant factor to influence the behavior of the providers.

Note also that different models of demand would be necessary for different locations. This results because the number of trips made during the peak periods is not uniformly distributed concentrated in terms of the destination (generally to or from the CBD). A model of the peak period would involve a lesser demand and a broader distribution in terms of destination dimension. In addition, transportation planning has seen today the growth

development, and the resulting trips outside the CBD. Without a centralized authority for trips, the demand for information will again become more broadly distributed. Competition would exist between information providers; each provider would need a larger area to capture the same number of listeners (and thus the same amount of revenue). This could have significant effects on the scale of investment in information technologies.

Finally, as the models which we attempted to use became edited or simplified, the model which was involved in our initial formulation ($\int n(s,t)$) became lost. As a result, the model almost seems to have been modified in the direction of the model which we used next. What is perhaps most important to understand here is that clustering (which is justified) in the provision of traffic information.

3. A Representative Model

Let us now turn our attention to a second model. This model is similar to the diagram commonly used in transportation and involves the trajectory of an individual driver. Initially, our description of the model will focus on its application for a single driver; at the end of the subsection, we will discuss the adjustments one might find in applying this to multiple drivers.

3.1. A Description of the Model

A vehicle (as shown in the following diagram) begins a trip at location x_0 . The speed of his travel determines the slope of his trajectory ($v = dx/dt$). The trajectory will represent the driver's location at the corresponding time t .

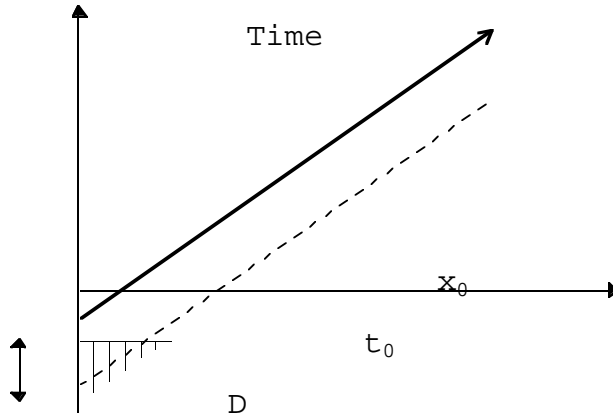


Figure 7. A representative model of an individual's trip and

The dashed line below the driver's trajectory represents the space-time region where the driver might seek information. The dashed line parallels the trajectory, where D represents the duration of an incident (typically defined as the time from when an incident is removed and for traffic to return to its previous state). If a driver intended to depart from location x_0 at time t_0 , he would not care about an incident that occurred earlier than $t = (t_0 - D)$ at x_0 because this incident and its effects on traffic would be removed from the roadway before he entered it. Traffic would be flowing as if the incident had occurred when the driver passed x_0 .

Similarly, because incidents are characterized as random events, we are concerned with incidents ahead of time. Thus, the area of concern must be closed by a horizontal line representing the anticipated time of departure, the time at which a decision must be made.

Since drivers tend to make decisions only at certain locations, the model must incorporate this characteristic. Imagine a node-link diagram as shown below.

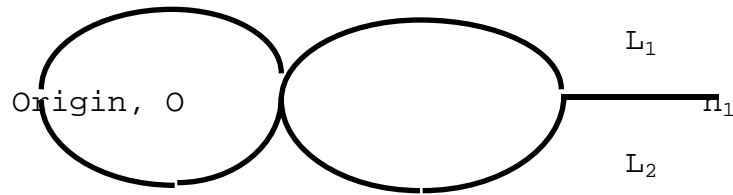


Figure 8. A sample network faced by an individual decision maker.

A driver who begins his trip at origin 0 (e.g., home) and ends his trip at work) would have two decision points along his trip (on this simplified network). His first decision point occurs before departure, when he must decide whether to take link L_1 or L_2 . The second decision would come as he approaches node 1, when he decides whether to take link L_3 or L_4 . When the driver reaches node 2, he faces no decision because there is only one link between node 2 and his destination. Thus, information regarding this link is not needed.

Significant works in decision theory have shown that the value of information is proportional to the probability that one's action will change (Marschak, 1992). Although there is always the option to terminate the trip or turn back, the value of the driver's action changing because of an incident along L_5 is much less than the value of his action changing because of an incident along one of the other links (with the other alternatives). Thus, the following graph might represent the space-time network faced by a driver along his path to work:

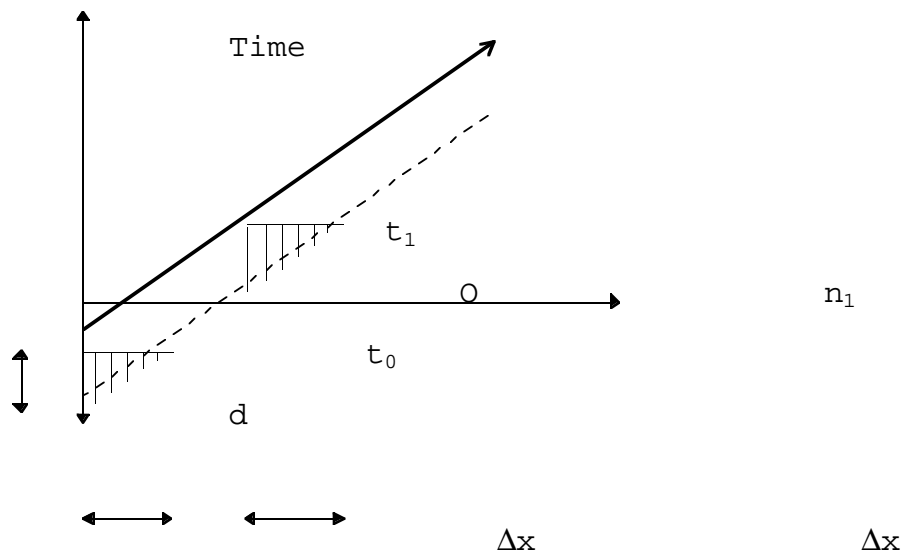


Figure 9. A representation of the area of concern to an in

The first shaded region represents the decision faced by the driver as he time at the origin, O . Information would be of value about any incident of frame. An incident occurring outside of this region will have been removed before the driver arrived at its location. The implication that this has information gathered outside of this triangle will not be of (as much) interest driver. Thus the information provider would have no incentive to gather in this triangle if his sole objective is to capture listeners.

In analyzing this diagram, a number of questions can be raised, such as:

- incidents are shown to have a range for their durations, which can affect the area of concern.

What effect does this have on the triangle of concern? Are there incidents that truly not be of concern?

- information providers attempt to capture the maximum number of customers within a certain coverage affected if their attention is not on the path of one traveler?

- how do customers value the information they receive?

These questions will now be addressed further.

3.2. Effect of Incident Duration

Incidents have been shown to have a distribution among their duration. An incident can be significantly affected by the severity of the incident, the incident removal team, the level of traffic surrounding the incident, as well as other factors. Studies (Giuliano 1989; Skabardonis 1996) have analyzed data regarding incident duration to have a distribution similar to the following:

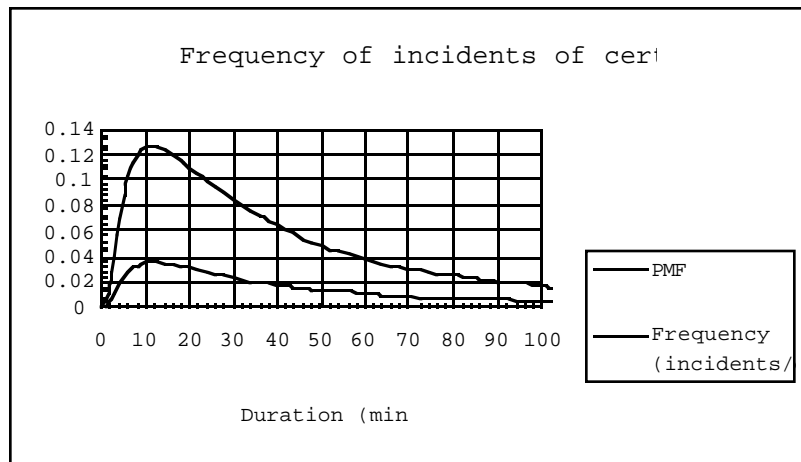


Figure 10. A representation of the probability and frequency
(Source of data: Giuliano 1989)

The cumulative distribution function for incident durations would be shown in the following graph. It can be seen that approximately 75% of the segment) have a duration of 18 minutes or greater and that 50% have a duration greater, etc.

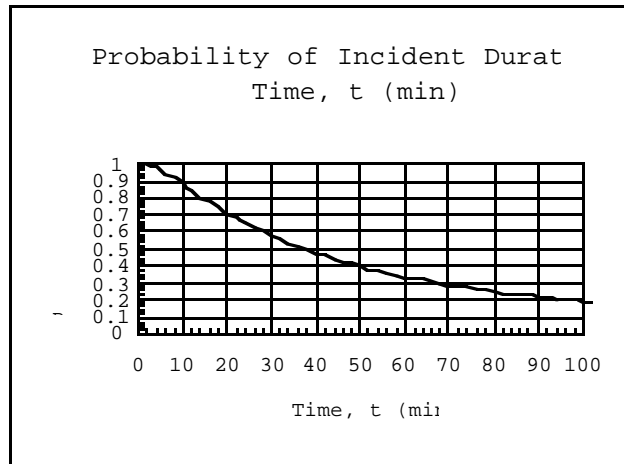


Figure 11. Cumulative distribution of incident durations (1)

In many cases, the distance between two decision points is significant distance which could be traveled in 36 minutes. Thus, in reality there are which would ever be truly irrelevant with respect to decision points (except have no significant alternative). The primary market for traffic information which typically has travel times less than 36 minutes, with a few decisions (The median commute time in the Bay Area is approximately 24 minutes, one the nation (Nolte, 1996).)

However, this does not remove the relevance of incident duration from information. Clearly, from the distribution one can see that an incident's likely to exceed five minutes ($p = 0.95$) than it is to exceed twenty minutes. location of an incident occurs further downstream from a decision point, the affect the drivers presently at the decision point decreases. Because the proportional to the probability that an individual's action will change well as the reward, in terms of time saved), the information would be more influences more drivers. Thus, the information gathered about a location (a decision point) would hold more value than information about a location dc

Analogously, if two incidents were of the same duration, the one closer to the decision point would influence more drivers. This results because the period during which drivers (approaching the decision point) would be interested about a certain location is longer for locations closer to the decision point. (This can be seen intuitively or from Figure 3.1.)

Resulting from this trend is a difference of interest between traffic information providers and incident removal crews (who might also use information). As shown, traffic information providers would care most about incidents closest to decision points. Conversely, incident removal crews would place greater concern on incidents which occur further from major decision points. Vehicles traveling downstream would have a higher probability of encountering an incident on their route. Thus the impact of the incident on the movement of vehicles is greater for incidents closer to the decision point. Fewer vehicles are able to divert onto other routes. The resulting delay would be greater and affect even more vehicles.

This also raises a question about the future of the two industries. The current fieldwork is presently being pursued toward improving the operations of incident removal crews. As this work progresses, and the resulting distribution of incident durations becomes known, traffic information providers should ideally cluster to a greater extent around major decision points.

3.3. How quickly does information have value?

Another important factor to remember is that drivers are not always interested in information immediately, if the information is to provide user-optimal route guidance. For example, a diversion would usually warrant immediate diversion, but will not be discussed until the arrival-departure curve below. An incident can be seen as a delay on the arrival curve, where the slope of the departure curve (the rate at which vehicles are able to reach the destination) is zero. The delay can be seen as the horizontal distance between the arrival and departure curves.

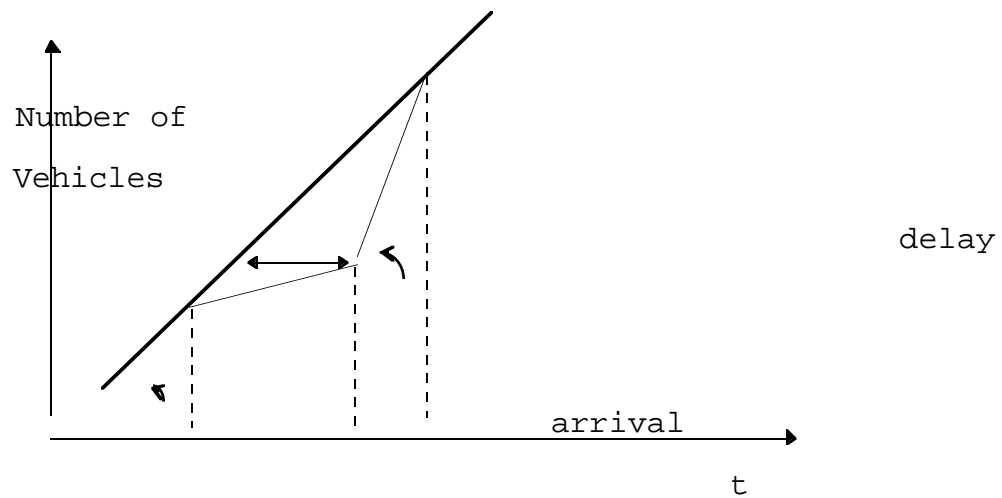
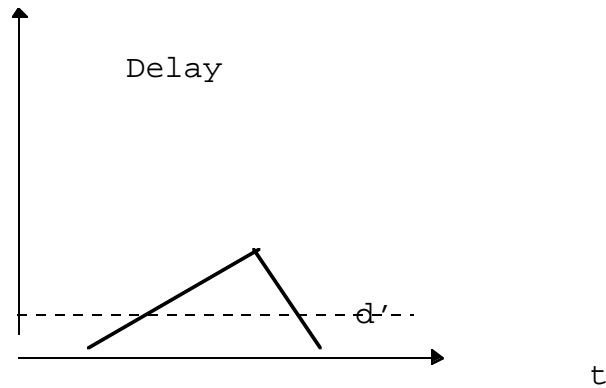


Figure 12. The delay on an incident-bearing route (and the delay on an alternate route) varies during the duration of an incident.

departure curves. Assuming that vehicles continue to arrive at the same rate as before the incident, the delay incurred by each vehicle will increase as the incident duration increases. When the incident is removed and the departure rate reverts to the road's designed capacity (as shown in Figure 12), the delay will increase at a rate proportional to the arrival rate of vehicles. As a result, the delay incurred by vehicles will increase with the time since the occurrence of the incident, until time t' , at which time the capacity of the freeway returns to its original level; at this time the delay will begin to decrease until it has returned to zero, in a manner similar to the following:



Tir

Figure 13. The distribution of delay during the duration t

Remember that the incident-bearing route is likely being traveled initially for its travel-time advantage over the alternate routes. A delay of some amount (d) may be present on the primary route before diversion would be preferred (and t would be used by the customers). (The authors do recognize that this threshold varies between different drivers (Malchow et al. 1996), in part because the available alternatives will vary. But the principle still holds, and many drivers will use these structures.)

This raises another difference between information providers and incident responders. Once an incident has occurred, immediate notification of the removal crew can help to remove an incident faster; thus, the quicker the information is received the more value to society. Immediate response from an information service would not be a high value. Immediate value would be a function of how long the delay will be when the potential users arrive at the incident location. For example, if the only information were at the nearest upstream decision point, and the incident was removed before they would arrive at the scene of the incident, then information would be of no value. Similarly, it may be that the delay resulting from the incident increased enough (to the level of d') before drivers presently at the decision point arrived at the location; thus, information to them would be of no value, because they

change. It is thus conceivable that the information may not be of immediate interest to providers' customers, or thus to any of the providers themselves.

3.4. Aggregation of Drivers

The second figure used to model the demand for information represents only one vehicle. The objective of a traffic information provider, however, is to reach the maximum number of customers. Many of the customers along this trajectory have specific sets of origin-destinations and departure times.

In addition to having a number of vehicles located along this trajectory, there are many other trajectories along which vehicles travel. For example, major cities' networks of highways and major arterials. The demand for traffic information could be modeled in a similar manner along each route. Consequently, traffic information providers have many potential decision points and routes on which they could focus their resources. Many alternatives must be evaluated. (Remember the first model, in which location was a decision point along the segment if providers could choose any arbitrary segment, or could choose which to focus his resources. This procedure would not change if alternatives were independent segments.)

Fortunately, many of the vehicles on the roadway during major periods are heading toward common destinations (e.g. the CBD). Thus these drivers each face a set of decision points, as drivers heading from nearby origins to nearby destinations make decisions regarding their route. Many routes involve a network's major segments that are easily accessible. In addition, most drivers face similar arrival times (e.g. starting times). This will likely cluster around certain decision points at certain times, allowing providers to focus their resources more effectively.

4. Value of Information

As discussed earlier, the primary objective of present traffic information providers is to capture as large an audience as possible. Thus these providers have little regard for the actual value each listener associates with their information (as long as t

information providers do not market their goods directly and can thus not
information providers do not directly attempt to capture those drivers who
value on their information.

Before continuing, the authors wish to note that the growth of value-
those provider who might sell information directly for a price, has only a
years. Many of the operations proposed are still in their developmental stages
difficult to make observations about their behavior. In addition, much of
VARs market is only repackaged information from the primary providers, which
much concern on the individual users' value of information.

Two categorizations can be made for the value which a driver would as
time saved from using information. The first category considers the direct
stated-preference studies have found that drivers could (if asked) associate
with the amount of time they might save. Information providers may use this
focus their resources on areas where listeners may be more easy to capture
higher value-of-time, he may be more eager to listen to information.) Thus
provider might capture a greater percentage of listeners in an area where
But this is not easily observable. In addition, this also raises question
information provider were publicly funded; the attention of the provider
on wealthier neighborhoods.

The second category involves what could be considered an opportunity
to the time which could be saved. For example, imagine the traffic informa
average of five minutes. A driver going to the grocery store would likely
much less than a driver planning to catch an airplane. This results because
missing a flight would hold much more disutility for a driver than being late
thus the airport-bound driver would value information more than the other
an opportunity cost, reflecting what could have been done during the time
(This is similar to the studies which have shown that drivers will change

home-to-work trips than on work-to-home trips, likely since the consequences of arriving late at work would be worse than that for arriving home late (Khattak 1991).)

Unfortunately, we have already described how drivers heading from different destinations tend to travel along similar medians. (Not everybody heading toward the airport.) However, it is possible that an aggregate median segment would show the value of information, on average, is relatively large. (The drivers nearest the airport would, on average, show an increased value.)

5. Conclusion

Before confidence is to be placed with either of these models, we must compare our initial observations from the survey of traffic information providers with the tendency of primary information providers to gather information for an entire region and then disseminate information over the regions of concern for a particular region. (That each provider's clientele generally consists of many radio stations in some extent at least) an entire region (or an entire segment). As a result of these models might be toward the distribution of fixed information-gathering devices, for example CCTV or automatic-vehicle identification, etc. Another application is the distribution of disseminating media such as changeable message signs.

Another important factor is the differences in the media which are used for the dissemination of information. The radio stations' selection of certain regions is a decision to allocate only 60-90 seconds for traffic information. Because a personalized information source has much more space available, such a provider would have a greater interest for information about any region which could be added. Each of these issues must also be addressed further in a later report.

To now discuss the models proposed, we recognize that each has its own strengths. The strongest qualities of the first model include the representation of the region along the roadway, the quantity which an information provider would attempt to disseminate, and the representation enables one to visualize the benefits (in terms of number of drivers) an information provider might receive by positioning in certain locations. The

potentially be modified to include the interaction between competing providers. These models could be used for different time periods or different locations.

The second model allows the analyst to easily conceptualize the behavior of an individual driver. The incorporation of incident duration and the effect of incident duration (which could be added by weights to the first model, if desired) allows for a more detailed decision process being undergone by a driver, and the methods by which an analyst might be most successful in influencing this.

A very interesting question raised, one which we also hope to address in future research, involves the differences in the detection time desired for incident response. The primary differences result from the immediate detection vs. delayed detection. Immediate detection is beneficial in all cases for incident removal; the earlier an incident is detected, the sooner it is removed. In most situations, the earlier an incident is removed, the smaller the impact on traffic; clearly the objective of the publicly-funded freeway maintenance program is to minimize the delay resulting from incidents, thus making immediate detection a high priority. From the perspective of information providers, particularly those providing route guidance, immediate detection may not be as productive in all cases. One situation in which this is true is the occurrence of an incident on a roadway which bears no alternate route; if the provider of the information, could not change their actions and could thus gain no benefit from the information, at least in terms of travel time saved. A similar example would be one in which an alternate route exists, but the delay resulting from the incident (relative to the utility of the main route) is not sufficient enough to warrant diversion. In such a situation, an information provider would not benefit as much as the freeway maintenance program from immediate detection.

These differences are of importance because the incident detection search process in metropolitan areas involves a high degree of coordination between these two entities. Hopefully our future research will explore further the precise methods used by these information gatherers in their detection of incidents and search for ways to improve and combine their operations.

Finally, we must say again that the observations made in this paper 1 revolve around our initial observations of information providers. The next will involve a much deeper discussion of the information providers and the us to check many of the assumptions which were used to develop the models

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Appendix

The primary objective of this research, as well as this particular p issue of whether clustering would exist at all between competing informati precise optimal positioning of information providers in a competitive env: important as the fact that at some level, it will happen. Nevertheless, t estimating the locations will be described here for detail. It should also positioning which was modeled was only to maximize the demand to be captur (or the profit) is of course a function of the operating costs and the rev number of listeners; this is information which we do not yet have but hope stages of our research.

To represent the location of information providers relative to their few key assumptions had to be made (and could be argued against):

1. An individual driver will subscribe to that information provider v information regarding the longest segment of his trip relative to other pr
2. An individual will not change providers (by changing stations) onc from the area of one provider into the area of another provider. The indiv service and maintains his allegiance.

In the next phase, the different relationships which might result bet of competing providers with respect to the length of trips were addressed would be if the two competing providers were to position themselves immed: other, with no locations being divided. Thus, if the length of the segment provider would position himself at $x = 1-d/2$ and provide coverage for the driver whose trip entered his segment would listen to his information; th would capture all listeners whose trip originated in the segment $[1-d-L, 1$ of the individual's trip. The second provider would position immediately with a central location of $x = 1-3/2d-L$ ($d/2$ units upstream from the locat provider's listeners begin). Thus, the segment of listeners which he will $L]$.

This behavior will occur so long as the marginal benefit of moving to listeners at $x = 1-2d-2L$ is less than that gained by moving right (gainin $x = 1-d-L$). When this behavior becomes no longer optimal, the two values j equal. Because the demand is linear (with Q being the demand at $x = 1$) wit location, set:

$$\begin{aligned} Q(1-2d-2L) &< Q(1/2)(1-d-L) \\ 2-4d-4L &< 1-d-L \\ 1 &< 3d + 3L \\ 1/3 &< (d+L) \end{aligned}$$

Thus, the second information provider will position himself immediately at
provider's segment = $(1+3d/2 - 1/(d+L)) \leq 1/3$

The second scenario occurs when the segments covered by the two providers no individual's trip is covered entirely by both providers. (In other words, the trip does not exceed the trip length, and one provider will be preferred to the other. Note that this overlap does not occur if the trip originating furthest downstream is contained in the second provider's area, at $x = x_2 + 1/2d - L$, starts downstream of the first provider's area, which starts at $1-d$. Thus, $(x_2 + 1/2d - L) < (1-d)$ or $x_2 < 1 - d + L$.

The position of the first provider will again be $x_1 = 1-d/2$. The position of the second provider will again be such that the demand captured on the upstream side is equal to the demand captured on the downstream side (thus, the marginal benefits of moving in either direction are approximately zero, the property of a maximizing location). The second provider will capture all trips which originate upstream of the segment he covers and all trips which originate somewhere along the trip, as well as those trips which travel in both directions. The first provider will have a greater portion of their travel in his segment. Thus, we must determine the position of the second provider which these two extremes are equal.

$$Q(x_2 - d/2 - L) = (1/2)Q(x_2 + d/2 - L) + ((1/2)(x_2 + d/2 - L) - (1 - d - L))Q(1 - d - L)$$

where the latter term on the right represents the segment of overlap between the two providers where listeners could listen to either provider. This segment is divided in half because a listener in the upstream half will choose the second provider, all drivers on the downstream half will choose the first provider.

Setting these equal,

$$\begin{aligned} x_2 - d/2 - L &= (1/2)(x_2 + d/2 - L) + ((1/2)(x_2 + d/2 - L) - (1 - d - L)) \\ 2x_2 - d - 2L &= x_2/2 - d/4 - L/2 + 1/2 \\ 3x_2/2 &= 3d/4 + 3L/2 + 1/2 \\ x_2 &= d/2 + L + 1/3 \end{aligned}$$

Thus, in the second scenario, in which information providers' segments overlap, the second provider should have a clear favorite, the second provider will position at $x_2 = 1/3 + d/2 + L$ if $x_2 < 1 + L - 3d/2$, or if $(1/3 + d/2 + L) < (1 + L - 3d/2)$, or $d < 1/3$.

Thus, the second provider will position at $x_2 = 1/3 + d/2 + L$ if $d < 1/3$ and $(d < 1/3)$

The third scenario arises when an individual's trip is entirely contained within one of the providers' segments. In this scenario, it was assumed that an individual would choose the provider closest to their location. In the case of an overlap between the two providers, and as a result, listeners whose entire trip is within the overlap between the providers would be shared between providers. All individuals upstream of this segment would choose the second provider, and all individuals downstream would choose the first provider.

The area of overlap between the two providers' segments would be $(x_2$ trips which originate within $[1 - d, x_2 + d/2 - L]$ would be indifferent be margins for the second provider should be such that:

$$\begin{aligned} Q(x_2 - d/2 - L) &= Q(1/2)(x_2 + d/2 - L) \\ 2x_2 - d - 2L &= x_2 + d/2 - L \\ x_2 &= 3d/2 + L \end{aligned}$$

Thus, in the third scenario, in which $(d > 1/3)$, the second information provider positions himself at $x_2 = 3d/2 + L$.

The fourth scenario is quite simple in that an information provider will position himself in a manner such that the entire segment for which he is gathering information is the $[0,1]$ segment. This scenario only arises when that location given in the text, L , exceeds $1 - d/2$ (or if $(2d + L > 1)$). In this scenario, the information provider will position himself at $x_2 = 1 - d/2$, immediately on top of the first provider.

Thus, in the final scenario, the second information provider will position himself at $x_2 = 1 - d/2$ if $(2d + L > 1)$.

$$\begin{aligned} \text{Summarizing } x_2 &= 1 - 3d/2 \quad \text{if } (L + d) < 1/3 \\ x_2 &= 1/3 + d/2 \quad \text{if } (L + d) > 1/3 \text{ and } d < 1/3 \\ x_2 &= 3d/2 + L \quad \text{if } (d > 1/3) \text{ and } (2d + L) < 1 \\ x_2 &= 1 - d/2 \quad \text{if } (2d + L) > 1 \end{aligned}$$

Clustering would occur between competing information providers under three scenarios. This would raise questions regarding the efficiency of the second provider would not likely gather information that provided much of a marginal benefit over the information gathered by the first provider.

