Simulation of Advanced Traveller Information Systems (ATIS) Strategies to Reduce Non-Recurring Congestion from Special Events

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ABSTRACT

The design and implementation of Advanced Traveller Information Systems (ATIS) providing real-time enroute information to drivers should follow insightful analyses into the dynamics of driver decisions and the resulting traffic flow under information to prevent counter-intuitive and counter-productive results. An important yet often neglected aspect of this problem is the distribution of benefits both over the driver population and for different origins and destinations in the network. This paper presents modifications to and an application of DYNASMART (DYnamic Network Assignment Simulation Model for Advanced Road Telematics) for this problem. DYNASMART is a simulation framework for ATIS experiments which incorporates: 1) real-time traffic flow and control simulation, 2) dynamic network path processing, and 3) microscopic consideration of driver response to information. A boundedly-rational behavioral model is assumed for driver route-choice under non-prescriptive route information. The information strategies are based on multiple paths rather than a single shortest path. Initial paths of drivers were generated from dynamic equilibrium assignments using the CONTRAM program and used as input to DYNASMART. ATIS-equipped drivers change their paths based on a behavioral model (with stochastically assigned parameters) and provided information, while unequipped drivers change routes based on self-observation of traffic conditions. The application presented involves the evaluation of ATIS strategies to alleviate traffic congestion due to spectators leaving a major sports event at Anaheim Stadium. A dynamic traffic demand matrix was estimated from partial link-counts. Interesting insights are derived regarding the higher benefits from ATIS to drivers on congested parts of the network. Robustness of the benefits under various information supply strategies and behavioral scenarios are also discussed.

1. INTRODUCTION

The design and implementation of Advanced Traveller Information Systems (ATIS) are proceeding with limited insight into the dynamics of traffic flow under real-time information, a condition which possibly can introduce counter-intuitive and counter-productive effects. This paper presents a system of models for the simulation of traffic flow under a variety of congestion, information-supply, and route guidance scenarios. An assessment is made of potential gains in network efficiency which are achievable as a result of the implementation of In Vehicle Navigation Systems (IVNS) in a traffic system characterized by special-event generated congestion.

Transportation engineers considering deployment of IVNS require a capability to realistically simulate the flow of traffic under information to fully assess the potential benefits of IVNS under alternate deployment scenarios. There is currently no available software which can model the non-recurrent, short-term, high-impact congestion associated with incidents and special-events, in which drivers do not have perfect information concerning travel times and the traffic flow is not in user-equilibrium. These are the conditions under which IVNS can be most effective.

To accurately capture the underlying phenomenon which characterizes traffic flow under information, a model requires three specific capabilities (Hu et al.,1992):

(1) real-time traffic flow simulation which updates vehicle positions and link conditions at each time step to reflect the real-time flow of traffic,

(2) dynamic path processing, necessary to simulate enroute diversion of vehicles in response to the real-time effects of congestion, and

(3) driver behavior emulation, required to reasonably emulate driver behavioral response to in-vehicle, enroute information.

The research presented herein continues the development and application of the DYNASMART model (Mahmassani et al., 1991) which integrates these three capabilities. The CONTRAM model (Taylor and Leonard, 1989), a static, multiple time slice user-equilibrium assignment package, and a CONTRAM utility program, COMEST (used to adjust trip tables based on observed link counts), are the remaining components of the model system. DYNASMART was modified to allow for the assignment of both unequipped vehicles to dynamic equilibrium paths provided by CONTRAM and of special-event vehicles according to different behavioral assumptions Modifications also allowed for separate analyses of benefits which accrue to special-event attendees and non-attendees. The DYNASMART model was then applied to a network for Anaheim, California to evaluate the possible benefits of implementing IVNS in both background traffic and in conjunction with the added congestion of special-event traffic generated by Anaheim Stadium. Simulations were conducted for scenarios in which the variable factors were driver behavior parameters, level of IVNS-equipment market penetration, and level of congestion.

2. PRIOR RESEARCH

Many assignment-based models have been developed for ATIS/IVNS research but these models are restricted in their predictive capacity by their inability to capture the dynamic phenomenon which underlie the flow of traffic under real-time information. Results suggest that a dynamic simulation approach may be the only method which can adequately incorporate these underlying phenomenon. Two efforts to develop such a simulation framework are INTEGRATION (Van Aerde et al., 1989) and DYNASMART (Mahmassani et al., 1992; Jayakrishnan et al., 1993). INTEGRATION is a microscopic model designed for integrating the modeling of freeways and signalized arterials in a real-time simulation. While incorporating the modeling of "on-board driver information systems", INTEGRATION always assigns vehicles to the shortest path and is, therefore, incapable of modeling variations in information supply strategies or driver behavior. It also lacks the large-scale path processing capability necessary for a real-time framework. DYNASMART, while lacking the ability to fully model intersections, contains the capability of modeling driver behavior and information supply strategies, and also is capable of large-scale path processing. It models the flow of traffic where a specified percentage of drivers are equipped with an IVNS which provides a continually updated list of k-shortest paths to their destination, and assumes drivers respond to the information in a boundedly rational manner. A simulation of Austin, Texas under a variety of deployment scenarios indicated that maximum IVNS benefits may be realized at market penetrations of 30 percent, and that system performance could deteriorate at higher levels of penetration. The maximum possible benefits appeared to be in the range of a total travel time reduction of eight percent.

3. STRUCTURE OF DYNASMART

DYNASMART is a time-based microscopic simulation-based approach for modeling traffic flow under information It combines, in a modular structure, the three key elements of dynamic traffic simulation under information. The main module is responsible for data input, initializing and controlling the simulation, and calculating the necessary statistics and summaries. The required input data consists of network data, demand data, and simulation parameters.

The traffic flow module is responsible for the generation and movement of individual vehicles through the network and the updating of link traffic conditions. Each vehicle is generated and loaded onto the network on an initial path and is labeled as IVNS-equipped or -unequipped. Unequipped vehicles follow the initial path, whereas equipped vehicles can switch paths enroute. Macroscopic traffic flow equations are used to calculate link flow characteristics.

The driver behavior module performs a simple but realistic emulation of boundedly rational driver behavior where drivers are indifferent to route changes which offer minimal travel time benefits. As an equipped vehicle approaches the end of a link, the travel time to the destination on the vehicle's currently assigned path is calculated and compared to the corresponding time on the minimum of the k-shortest paths. If the improvement in travel time achieved by changing paths exceeds a defined threshold (based on an indifference bandwidth), then a path change occurs (unequipped vehicles remain on the initial path) If the driver switches routes when there is any shorter route, then "myopic" switching occurs.

The path processing module applies an efficient label-correcting algorithm to find the k-shortest paths based on updated link and arc travel times from every destination to every node (Jayakrisnan, 1991). In the interest of computational efficiency, k equal three paths are re-enumerated every twenty time steps, for other steps, travel times on existing k-shortest paths are updated as an approximation. The CONTRAM program provides DYNASMART with dynamic equilibrium routes for initial path assignment. CONTRAM loads vehicles in discrete packets which are individually tracked, producing a record of path assignments and node arrival times.

4. DATA PREPARATION

The data requirements consists of a coded network and associated dynamic trip tables with which to perform both the DYNASMART simulation and the CONTRAM assignment. The network and trip table were developed for a sub-area of the City of Anaheim, California. The trip table was created utilizing observed traffic counts. The network consists of 440 nodes, 931 links, and 41 zones. Dynamic trip tables for the assignment of background traffic and various magnitudes of special-event traffic were produced from time-varying link counts using the CONTRAM-based COMEST trip table estimation package (Taylor and Maher, 1989), which performs a series of entropy-maximizing and Furness balancing iterations on a seed trip table to reproduce a set of observed link counts.

The time period chosen for the simulation period is the 90-minute time span from 7:45 pm to 9:15 pm, modelled as six fifteen-minute time slices. This time span is chosen on the assumption that the special-event would end at 8:00 pm and the event attendees would egress the stadium parking lots within one-hour. The first time slice is a warm-up period. Statistics are collected for vehicles which egress the stadium from 8:00 to 8:45 pm. The final 30 minute period allows for tagged vehicles to exit the network; only 5 percent of the total volume egresses during this period.

Traffic counts for 163 arterial links and 14 freeway links were obtained from tube or detector counts recorded at fifteen-minute intervals; counts for remaining links were estimated from AADT counts. An estimate of total demand in the area over the specified time period of approximately 70,000 vph was split as 15,000 vph and 55,000 vph for local trips and non-local trips, respectively. A CONTRAM assignment produces path records which are input to

COMEST with observed counts and the seed trip table to produce an adjusted trip table, which is then reassigned in CONTRAM to provide the equilibrium paths needed for DYNASMART.

The base trip table was modified to incorporate special-event traffic of varying magnitudes. Special-event trips were distributed to destinations in proportion to the corresponding distribution in the background traffic trip table. Trips were distributed over the six time slices for stadium egress according to historical distribution curves; the corresponding percentage of trips is 0, 45, 35, 15, 5, and 0. Trip tables were produced for special-event scenarios of 5,000, 10,000, and 15,000 vehicles

5. GENERAL NETWORK PERFORMANCE

Simulations were first performed with the background traffic trip table to establish a base-case scenario against which alternative scenarios can be compared. This scenario assumes no IVNS implementation, and no special-event traffic. The resulting average travel time for all vehicles of 12.28 minutes is judged valid. During the summary period, over 47,000 vehicles entered the network. The external sufficiency statistics indicate that although 42 percent of the vehicles did not receive an external equilibrium path at their time of generation, no vehicle was unable to find an external path during the simulation. Density profiles for selected links established the adequacy of the base-case scenario. Average travel time is taken as the key measure of system performance; benefits from the deployment of IVNS will be assessed relative to this measure.

Thirty IVNS deployment scenarios were simulated with the background traffic trip table (no special-event traffic). Variable factors were IVNS market penetration (10, 25, 50, 75, 90, and 100 percent) and driver propensity to switch (0.0, 0.1, 0.2, 0.3 and 0.5). A maximum propensity to switch of 0.0 indicates myopic switching. Table 1 summarizes these behavioral scenarios, presenting the mean indifference bandwidth, the maximum benefits achievable from IVNS (measured as the percentage reduction in the base travel time for all vehicles), the optimal level of market penetration, and the percentage of the maximum achievable benefits which accrue by a market penetration of fifty percent (identified as the point of diminishing returns).

Table 1. Benefits of IVNS for Background Traffic

Indifference Bandwidth	Maximum Benefits (percent)	Optimal Market Penetration (percent)	Percent of Maximum Benefits at 50% Market Penetration
0.0	9.3	90	93.0
0.1	9.5	100	89.9
0.2	8.5	90	86.7
0.3	7.3	90	82.1
0.5	5.7	90	80.2

In general, the first vehicles which install IVNS achieve significant savings (10 percent reduction of travel time in the myopic case), and benefits continue to increase slightly as market penetration increases to fifty percent. Beyond this point, the benefits to the equipped vehicles actually decrease for scenarios with high driver propensity to switch (indifference bandwidth of 0.2 or less) and the benefits level off in the scenarios with low driver propensity to switch.

Maximum potential benefits vary from a high of 9.3 percent in the case of myopic switching, to 8.5 percent in the more realistic case where drivers require a 20 percent travel time reduction to induce a switch, to a low of 5.7 percent in the case of extreme aversion to switching.

Under no behavioral or market penetration scenario does the system ever perform worse with information than without information. System performance does appear to deteriorate slightly as market penetration increases from ninety percent to one-hundred percent; thus ninety percent is a market penetration point of negative returns. The simulations indicated that IVNS can produce significant benefits to drivers even in the case of the moderate to low congestion resulting from background traffic. Maximum benefits of between a five and ten percent reduction in total travel time appear to be feasible, with a large proportion of these benefits realized at a market penetration level of fifty percent.

6. NETWORK PERFORMANCE WITH A SPECIAL EVENT

DYNASMART simulations were performed with three special-event trip tables, corresponding to 5,000, 10,000, and 15,000 vehicles egressing from the event traffic generation zones. Performance statistics are disaggregated by vehicle status as event attendee or non-attendee and by status as equipped or unequipped. Unequipped vehicles which egress from the three designated special-event origins are assigned to the post warm-up period shortest paths instead of the externally-provided equilibrium paths. This reflects the assumption that special-event attendees are not familiar with the recurring traffic patterns.

For each special-event scenario, nine simulations are performed (assuming market penetration levels of 0, 10, 25, 50, 75 percent and indifference bandwidths of 0 0 and 0.2). Table 2 presents the base travel times of attendees and non-attendees for each scenario, the occurrence of a special-event increases the average travel time of non-attendees (by 3.7, 7 3, and 8.1 percent for the 5,000, 10,000 and 15,000 vehicle special-event scenarios, respectively).

Table 2. Base Travel Times

Event Magnitude (vehicles)	Vehicle Class	Base Travel Time (mins)
5,000	Attendees	11.62
	Non-attendees	12.74
10,000	Attendees	15.24
	Non-attendees	13.18
15,000	Attendees	17.15
	Non-attendees	13.27

Table 3 presents the maximum combined benefits which will accrue to attendee and non-attendee vehicles in each scenario. Since the results for total vehicles indicate no points of negative returns, all of these maximum benefits occur at 75 percent market penetration; it is reasonable to assume slightly greater benefits may occur at higher market penetrations. Each of the three special-event scenarios may be summarized by six graphs: average travel time as a function of IVNS market penetration for equipped, unequipped, and all vehicles, for both event attendees and non-attendees. The horizontal axis of each graph is the market penetration of the IVNS, measured as the percentage of vehicles with access to information. The vertical axis of the graph is the average travel time for that class of vehicles, measured as the percentage of the base travel times which are presented in Table 2. Sample results are provided in Figures 1 to 3 illustrating the average travel times for attendees of the 10,000 vehicle magnitude special-event. Overall results indicate that IVNS benefits up to a 35 percent reduction in travel time are achievable for special-event attendees, maximum benefits for non-attendees range from 10 to 13 percent.

Table 3. Potential Benefits of IVNS

Special-Event Magnitude (Vehicles)	Vehicle Class	Mean Indifference Bandwidth	Maximum Travel Time Reduction
5,000	Attendees	0.0	17.0 percent
		0.2	14.6 percent
	Non-Attendees	0.0	11.6 percent
		0.2	10.4 percent
10,000	Attendees	0.0	33.3 percent
		0.2	30.0 percent
	Non-Attendees	0.0	12.9 percent
		0.2	11.5 percent
15,000	Attendees	0.0	34.7 percent
		0.2	27.1 percent
	Non-Attendees	0.0	12.7 percent
		0.2	10.5 percent

Although increases in market penetration appear to never have a negative effect on total average travel time, the results indicate the existence of points of diminishing returns. The point of diminishing returns increases with special-event magnitude (from 25 percent for a 5,000 vehicle event to 50 percent for larger events) In no case does the provision of information cause total average travel time to be higher than the base case. The results indicate that IVNS could be of great benefit to drivers egressing from a special-event, with benefits to attendees approaching a 30 percent reduction in travel time for events with attendance greater than 10,000 vehicles. These benefits are greater than the 5 to 15 percent benefits reported in the literature for normal traffic scenarios and thus underscore the increased usefulness of IVNS for congestion relief under special-events conditions.

7. SUMMARY

This paper has demonstrated the feasibility of analyzing the potential benefits of IVNS deployment via simulation. The CONTRAM equilibrium assignment model has been successfully utilized to provide dynamic equilibrium paths to DYNASMART for initial route assignment of unequipped vehicles. The modeling of the specific case of traffic egress from a special-event was performed. Special-event attendees and non-attendees were initially assigned to the network according to different ATIS assumptions, and benefits for each class of vehicle were presented separately.

Results of simulations of the background traffic suggest achievable system-wide benefits of up to a ten percent reduction in average travel time for all vehicles, with benefits for both equipped and unequipped vehicles increasing as market penetration increases (until a penetration of fifty percent when decreasing returns to scale are identified). Greater benefits may occur under large magnitude special-event scenarios (i.e., greater than 10,000 vehicles); drivers egressing from such special-events can expect travel time reductions of up to thirty percent. Under no condition of market penetration, driver behavior, or congestion, does the provision of information result in system performance worse than the base 'no information' case.

The driver-behavior scenario of myopic switching, which assumes a very high propensity to switch routes, appears to offer the greatest benefits at low levels of market penetrations. This indicates that system operators may wish to implement a strategy of misrepresenting travel times in order to induce drivers to switch in cases where drivers demonstrate high aversion to switch; it also indicates the desirability of prescriptive systems which compel the driver to follow shortest paths.

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Special-Event Magnitude : 10,000 Vehicles
Special-Event Attendees

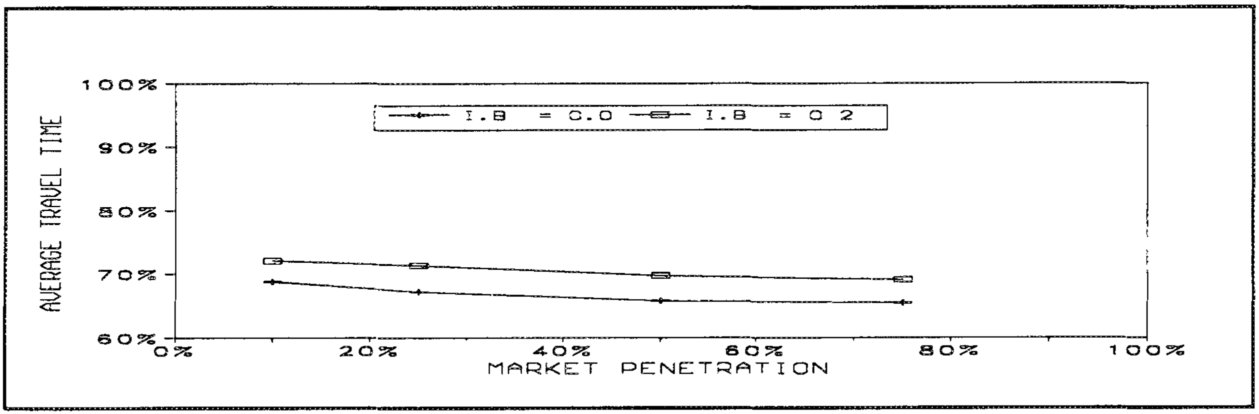

Figure 1. Equipped Vehicles

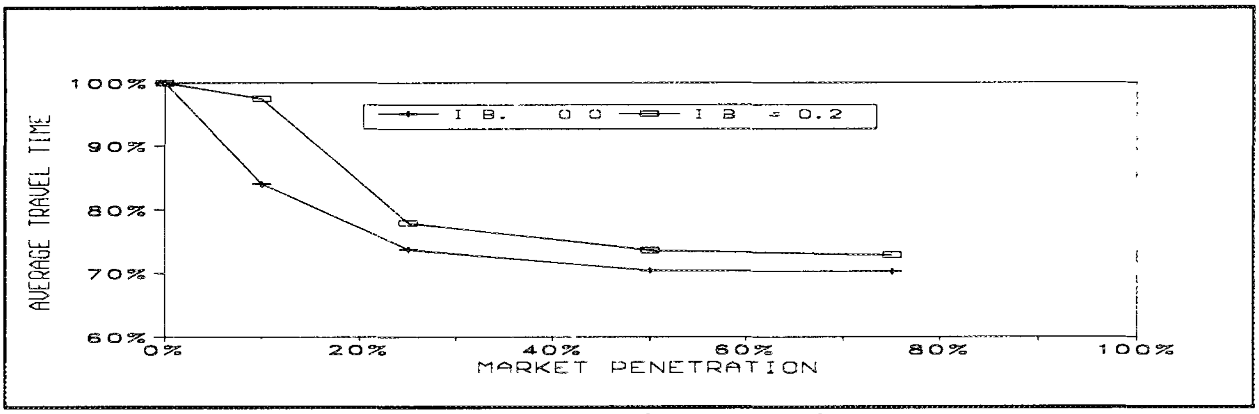

Figure 2. Unequipped Vehicles

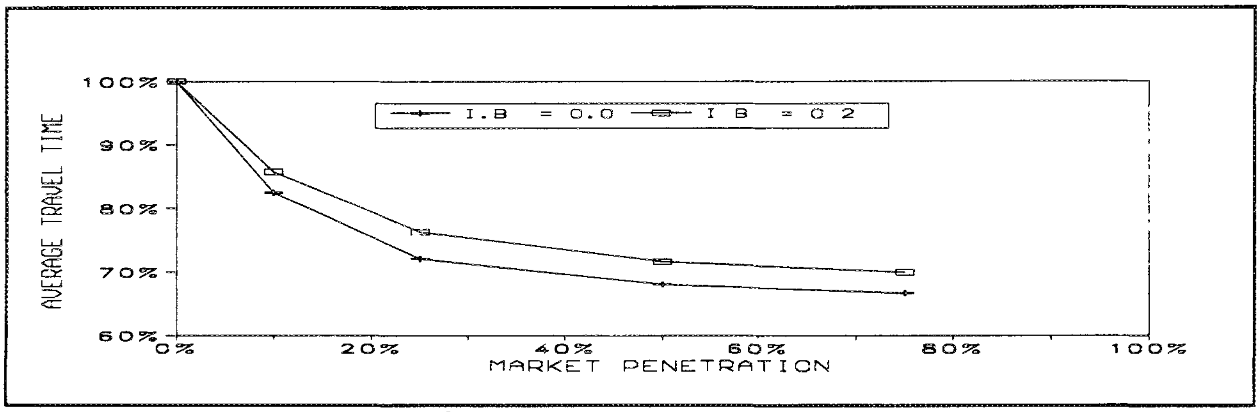

Figure 3. All Vehicles

Special-Event Magnitude : 10,000 Vehicles
Non-Attendees

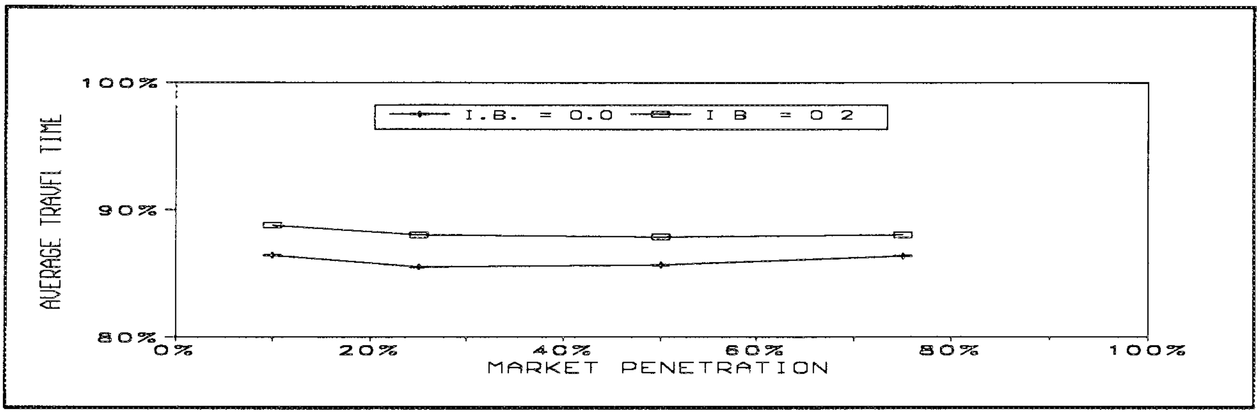

Figure 4. Equipped Vehicles

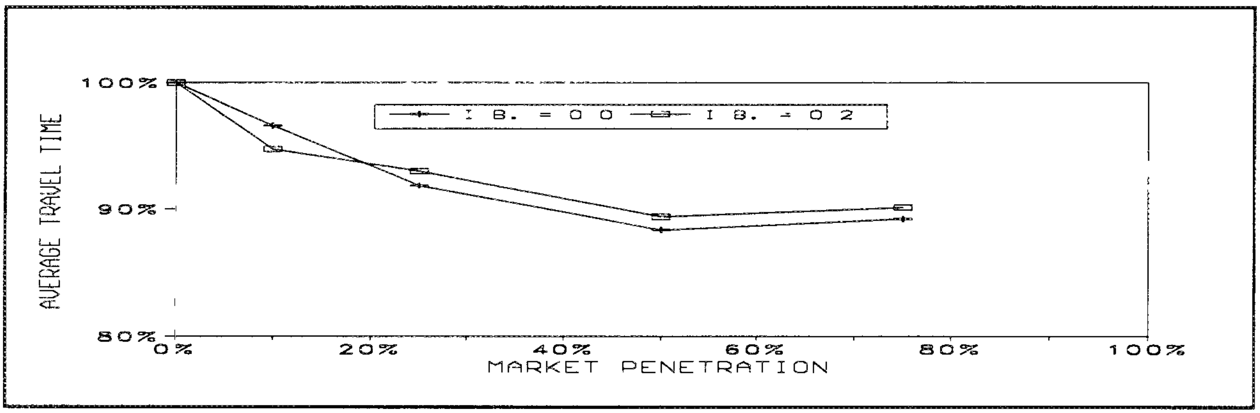

Figure 5. Unequipped Vehicles

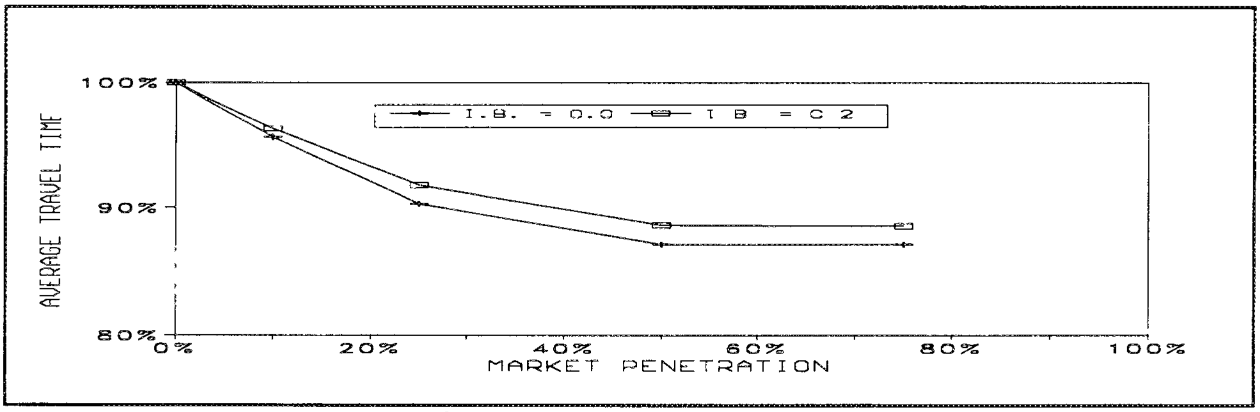

Figure 6. All Vehicles