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Genesis Modeling Evaluation

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OVERVIEW

Genesis is an Advanced Traveler Information System (ATIS) that utilizes Personal Communication Devices (PCD), which include pagers and PDA's, to distribute information to drivers. Travel data is collected in real-time from a variety of sources by a data collection' system and stored in the Traffic Management Center (TMC). The sources of traffic data include surveillance cameras, traffic detectors and other sensors throughout the metropolitan area. The travel data is processed, formatted and distributed to travelers via Radio Frequency (RF) transmission to PCDs on demand or, as exceptions, within the travel network.

The Genesis system is evaluated using a combination of operational field and modeling tests. These tests are described in six test plans, namely; an Overall Test Plan, a System Effectiveness Test Plan, a User Perception Test Plan, a Modeling Test Plan, a Global Test Plan, and a Human Factors Test Plan. This report presents the results of the Modeling Study of the Genesis system.

Field experiments and surveys collected data and information on the performance of the Genesis test drivers. These data indicated how the system performed for the configuration that was tested and for the conditions that were encountered in Metropolitan Minneapolis/St. Paul by the vehicles during the time frame of the operational field test. It was not always possible to systematically collect all types of potential data on all test driver trips. It was also not possible to observe the system's performance for conditions that were not encountered in the field. Examples of the former data gaps are the fuel consumption, emissions and risk exposure of all of the 403 test vehicles, whereas examples of the latter are the potential performance of the Genesis system for higher levels of market penetration.

The desire to examine these unobservable factors resulted in the inclusion of a modeling activity as part of the Genesis evaluation using the microscopic INTEGRATION simulation/assignment model This modeling activity was intended to permit an objective and systematic extension of the findings from the operational field test to generate performance estimates for a range of other conditions and configurations that would be of interest to those contemplating the deployment of similar systems on a wider scale.

The modeling study that was undertaken as part of the Genesis evaluation demonstrated that Personal Communication Devices (PCD's) can achieve benefits within the following ranges.

1. PCD's can reduce the average travel time of the entire system by upto 15 percent. Most of these benefits are achieved through a 20 percent utilization of these devices. Further benefits can be achieved during non-recurring congestion depending on the severity of the incident.

2. The benefits of PCD's, in terms of savings in average travel time, increase as the level of congestion in the network increases.

3. PCD's provide little benefits in average travel distance, CO emissions and accident risk (benefits less than 1 percent).

4. PCD's can reduce vehicle stops, fuel consumption, HC emissions by up to 5 percent. Most of these benefits are achieved through a 20 percent utilization of these devices.

5. PCD's can increase NO, emissions by up to 5 percent.

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1. INTRODUCTION

Minnesota Guidestar is a state Intelligent Transportation System (ITS) program that is being developed and implemented in order to provide a better statewide transportation system. The Minnesota Guidestar involves a number of projects that include the following.

- **Genesis.** which evaluates the effectiveness of providing real-time travel data via personal comnmnication devices.
- **Trilogy.** which tests and evaluates in-vehicle means of providing real-time traffic and travel time information to travelers.
- **St. Paul Advanced Parking Information System.** which provides motorists with accurate real-time information about the availability of space in parking facilities as well as directions to parking facilities.
- **Portable Traffic Management System (PTMS).** which adapts to various locations to improve traffic to and from major events.
- **St. Paul Incident Management.** which provides traffic guidance and control during freeway incidents by coordinating traffic along designated city streets.
- **LIDAR.** A laser-based scanning system that monitors the migration of aerosol plumes.
- **Integrated Corridor Traffic Management (ICTM).** which implements a corridor-wide adaptive traffic control system using advanced technologies.
- **Adaptive Urban Signal Control and Integration.** which implements an adaptive signal timing plan generation algorithm that is integrated with ramp meters on I-394 and I-94 in the downtown central district.
- **Travlink.** which evaluates several technologies including ATIS software, kiosks, electronic signs and display monitors, AVL and AVI units on buses, CAD/AVL software and video text.
- **SmartDARTS.** which evaluates the benefits of a combination of advanced Technologies within a paratransit environment.
- **Advanced Rural Transportation Information Coordination (ARTIC).** which tests and evaluates communication systems of several public agencies through the establishment of a centralized dispatching site.
- **Field Test of Non-intrusive Traffic Detection Technologies.** which tests alternative traffic detection technologies under various urban conditions.
- **Commercial Vehicle Operations (CVO).** which involves three tests, namely. testing of a one-stop electronic delivery system, testing imaging technology for vehicle verification, and evaluating a Global Positioning System (GPS).

The focus of this report is to describe and present the results of the modeling evaluation of the Genesis system.

1.1 OVERVIEW OF GENESIS PROJECT

Genesis is an Advanced Traveler Information System (ATIS) that utilizes Personal Communication Devices (PCD), which include pagers and PDA's, to distribute information to drivers. Travel data are collected in real-time from a variety of sources by a data collection system and stored in the Traffic Management Center (TMC). The sources of traffic data include surveillance cameras, traffic detectors and other sensors throughout the metropolitan area. The travel data is processed, formatted and distributed to travelers via Radio Frequency (RF) transmission to PCDs within the travel network.

The pagers receive a ***bundle*** of all currently active incidents and planned events within a single message for a geographic zone. The pagers only receive messages when they are powered, and when they do receive a new message a flashing message indicator is activated. Each new pager message overwrites the previous contents resulting in a lose of old messages unless saved. The pagers can only provide up to 460 numbers/letters to describe all the activities at any given time which means that it can only store 3-4 incidents, depending on the length of the text description. The events are stacked on top of each other with a blank line between entries to facilitate readability.

Genesis uses the International Traveler Information Interchange Standard (ITIS) message to describe traffic related activities. Incidents are described as occurring on roadway ***x*** in the north/south/east/west bound direction from location y to location z (e.g. I-494 EB From. Center Ridge To. Harper). Incidents or planned events occurring on instrumented arterials and freeways are transmitted to the PCDs.

1.2 OVERVIEW OF GENESIS EVALUATION

The Genesis system is evaluated using a combination of operational field and modeling tests. These tests are described in six test plans.

- Overall
- System Effectiveness
- User Perception
- Modeling
- Institutional Issues
- Human Factors

The Overall Test plan provides a summary of the five other individual Genesis evaluation tests. The Genesis System Effectiveness Test measures, in the field, the user benefits provided by PCD provided traffic information. In the System Effectiveness Test two classes of drivers are recruited, namely. individuals who are already using alphanumeric pagers (existing users) and individuals who have not use alphanumeric pagers (new users). A total of 403 drivers are recruited in the System Effectiveness Test. These include 129 existing pager users, 229 new pager users and 45 PDA users. The System Effectiveness Test involves telephoning the users and interviewing them in order to determine how they are using the Genesis information and how they responded to incidents. The results of the System Effectiveness Test are utilized in calibrating the INTEGRATION model.

The Genesis User Perception Test is intended to assess user perceptions of the ease of use, utility, and value of the Genesis system through two data collection techniques. a questionnaire and focus groups.

The objectives of the Genesis Modeling Test is twofold. firstly, to assess the effects of Genesis on variables that cannot be measured directly during the operational test, and secondly, to project the impact of a Genesis system for larger levels of market penetration. The measures that cannot be measured directly in the Genesis operational test include fuel consumption, vehicle emissions, and safety effects. Fuel consumption and emission measurements would require instrumentation that is not feasible for continuous measurement in the field. Safety cannot be measured because the traditional measure of effectiveness for safety is vehicle crashes per million vehicle kilometers which renders the sample size used in the operational test (403) to be too small and the duration of the field test too short to support collection of reliable crash data.

The Genesis Institutional Issues test gathers information regarding legal and institutional impediments to the operational test and lessons to be learned in order to overcome these difficulties. It also identifies PCD future applications and improvements, and documents existing institutional cooperation.

Finally, the Genesis Human Factors Test evaluates the messaging provided and reviews the literature regarding the use of electronic devices in automobiles.

1.3 OVERVIEW OF MODELING STUDY

The field experiments and surveys, described earlier, collected data and information on the performance of the test drivers. These data indicated how the system performed for the configuration that was tested and for the conditions that were encountered in Metropolitan Minneapolis/St. Paul by the vehicles during the time frame of the operational field test. It was not always possible to systematically collect all types of potential data on all test driver trips. It was also not possible to observe the system’s performance for conditions that were not encountered in the field. Examples of the former data gaps are the fuel consumption, emissions and risk exposure of all of the 403 test vehicles, whereas examples of the latter are the potential performance of the Genesis system for higher levels of market penetration.

The desire to examine these unobservable factors resulted in the inclusion of a modeling activity as part of the Genesis evaluation using the microscopic INTEGRATION simulation/assignment model. This modeling activity was intended to permit an objective and systematic extension of the findings from the operational field test to generate performance estimates for a range of other conditions and configurations that would be of interest to those contemplating the deployment of similar systems on a wider scale.

To date the use of traffic simulation models remains the main and virtually only means to extrapolate Level of Market Penetration (LMP) effects from field studies on a limited number of subjects. While these traffic models have advanced rapidly during the past decade, many deficiencies remain. The INTEGRATION microscopic simulation/assignment model was selected because of its rather unique traffic features that provided the flexibility for modeling the traffic engineering features of the existing traffic in addition to the Genesis system logic.

1.4 OVERVIEW OF MODELING STUDY REPORT

Initially the configuration of the INTEGRATION model and the logic that was utilized in modeling the Genesis system are described in section 2. This section provides the reader with an overview of the INTEGRATION model in order to appreciate why the model was selected for the evaluation of the Genesis system.

Section 3 initially describes how the input parameters to the INTEGRATION model were derived. Subsequently, section 3 describes how the INTEGRATION model, in the absence of Genesis, was calibrated to the existing traffic network conditions for a freeway corridor in the Genesis network. The intent of this calibration exercise was to establish the before conditions prior to analyzing the impact of the Genesis system on the traffic conditions.

In section 4 the impact of increasing the level of market penetration of the Genesis system is studied on nine Measures of Effectiveness (MOE’s). During this examination, the base runs are modeled with proportions of pager equipped vehicles ranging from 1 to 99 percent while maintaining the total number of vehicles in the system constant.

Finally, section 5 presents a summary the conclusions of the report.

2. MODELING GENESIS USING THE INTEGRATION MODEL

2.0 INTRODUCTION

This section initially describes the INTEGRATION model in terms of its domain of application, its traffic simulation logic, and its routing logic. The intent of this description is twofold: firstly, it provides the reader with a basic understanding of how the model operates, and secondly, it demonstrates why the INTEGRATION model was selected as the evaluation tool of the Genesis system. A more detailed description of the capabilities and the logic of the INTEGRATION model can be found in the INTEGRATION user's guide (Van Aerde and Transportation Systems Group, 1995).

Following the description of the INTEGRATION model, this section describes how, within this study, the background traffic and the Genesis system were modeled in the INTEGRATION model.

2.1 CONFIGURATION OF THE INTEGRATION SIMULATION AND ASSIGNMENT MODEL

The INTEGRATION model was conceived during the mid 1980's as an integrated simulation and traffic assignment model (Van Aerde, 1985; Van Aerde and Yagar, 1988a and b; Van Aerde and Yagar, 1990). What made the model unique was that the model utilized the same logic to represent both freeway and signalized links, and that both the simulation and the traffic assignment components were also microscopic, integrated and dynamic. In order to achieve these attributes, traffic flow was represented as a series of individual vehicles that each followed pre-specified macroscopic traffic flow relationships. The combined use of individual vehicles and macroscopic flow theory resulted in the model being considered mesoscopic by some.

During the past decade the INTEGRATION model has evolved considerably from these original mesoscopic roots. This evolution has taken place as the addition, enhancement and refinement of various new features. Some of these improvements have enhanced the fundamental traffic flow model, such as the addition of car-following logic, lane-changing logic, and more dynamic traffic assignment routines. The model's application domain has also extended to model toll plazas, vehicle emissions, weaving sections, and High Occupancy Vehicle (HOV) facilities. In addition, some features, such as the real-time graphics animation and the extensive vehicle probe statistics, have been added to simply make the model easier to understand, use, validate and calibrate.

2.1.1 Domain of Application

In order to appreciate INTEGRATION's intended domain of application, it is useful to view travel within an urban area as an interrelated sequence of six decisions that the traveler typically must make in order to complete a particular trip. Three of these decisions are made prior to drivers leaving their driveway, and usually cannot be revisited during that same trip. The three others, however, need to be revisited repeatedly, once a particular trip has been initiated.

a. Pre-trip decisions

At the highest level of the trip making process, are decisions related to where a particular trip maker may decide to live and work/shop. The trip maker must therefore decide how many trips to make towards each potential destination during each particular departure time window. Once the decision, to make a particular trip to a given destination has been made, the traveler must decide whether to utilize some form of transit (if available), or whether to utilize a private car, either as a single vehicle occupant or as a car pool participant. The third set of pre-trip decisions relates to the particular time at which the trip maker may elect to start the trip. Each of these first three types of decisions may be interdependent but are usually not made more than once for a particular trip.

b. On-route decisions

In contrast, the next three types of trip decisions need to be made once the trip has commenced and usually need to be revisited several times as the actual trip progresses. Specifically, when initiating the trip, the trip maker must select what route to take. This decision, even when the trip has commenced, is usually not fixed, as a driver usually may still elect to change any remaining portion of the trip. Once a vehicle has entered a particular link along this route, the driver must also select the speed at which to drive at and which lane to utilize. Again, a driver’s speed and lane choice are likely to change, at a minimum from one link to the next but usually several times along the same link. However, speed and lane changes often also occur along a link as a result of interactions with other vehicles. Finally, when a driver arrives at the end of a link, the driver may be required to cross an opposing traffic stream, and must decide whether to accept or reject any available gaps and/or how to merge with a converging traffic stream.

c. Domain of application

The current domain of application of the basic INTEGRATION model consists of the latter set of on-route driver decisions, starting from the time when the driver has elected to depart from a particular origin to a particular destination, at a particular time, and by means of a specific vehicle type. This implies that, at present, INTEGRATION does not directly model the impact of someone who elects to depart at a different time, by means of a different mode, or to an alternate destination.

However, in order to reflect the increasing interest, in being able to explore the potential traffic impacts on these latter decisions, an outer loop is being developed around the current INTEGRATION model. This outer loop will permit estimates of the expected changes in trip mode, departure time and/or destination to be made through systematic iterative applications of the model.

2.1.2 Basic Traffic Flow Simulation

The manner in which INTEGRATION represents traffic flows, can be best presented by discussing how a typical vehicle initiates its trip, selects its speed, changes lanes, transitions from link to link, and also selects its route.

a. Initiation of vehicle trips

Prior to initiating the actual simulation logic, the individual vehicles that are to be loaded onto the network need to be generated. As most available Origin-Destination (O-D) information is macroscopic in nature, INTEGRATION permits the traffic demand to be specified as a time series histogram of O-D departure rates for each possible O-D pair within the entire network. Each histogram cell within this time series can vary in duration from 1 second to 24 hours, and the duration of each cell is independent from one O-D pair to the next, or one time period to the next. When the same O-D is repeated within the departure list for an overlapping time window, the resulting vehicle departures are considered to be cumulative.

The actual generation of individual vehicles occurs in such a fashion as to satisfy the time-varying macroscopic departure rates that were specified by the modeler within the model's input data tiles, as illustrated in Figure 1. It can be noted that the model simply disaggregates an externally specified time varying O-D demand matrix into a series of individual vehicle departures prior to the start of the simulation. For example, if the aggregate O-D input data requests departures at a uniform rate of 600 veh/hr between 8:00 and 8:15 AM, a total of 150 vehicles will be generated at headways of 6 seconds.

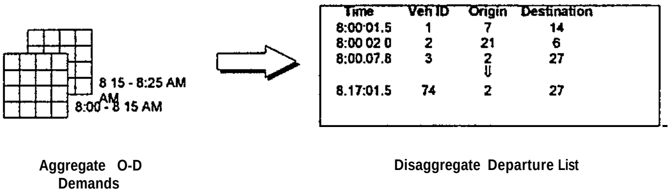


Figure 1. Conversion of aggregate O-D traffic demands into disaggregate departure list

It should be noted that, as the externally specified demand file is disaggregated, each of the individual vehicle departures is tagged with its desired departure time, trip origin and trip destination as well as a unique vehicle number. This unique vehicle number can subsequently be utilized to trace a particular vehicle towards its destination. It can also be utilized to verify that subsequent turning movements of vehicles at, for example, network diverges are assigned in accordance to the actual vehicle destinations, rather than some arbitrary turning movement probabilities, as is the case in many microscopic models that are not assignment based.

b. Determination of vehicle speed

When the simulation clock reaches a particular vehicle's scheduled departure time, that vehicle is entered into the network at its origin zone, from which the vehicle will begin to proceed in a link-by-link fashion towards its final destination. Upon entering this first link, the vehicle will then select the particular lane in which to enter. This is usually the lane with the greatest available distance headway.

Once the vehicle has selected which lane to enter, the vehicle computes its desired speed on the basis of the distance headway between it and the vehicle immediately downstream of it but within the same lane. This computation is based on a link specific microscopic car following relationship that is calibrated macroscopically to yield the appropriate target aggregate speed-flow attributes for that particular link (Van Aerde, 1995; Van Aerde and Rakha, 1995). Having computed the vehicle's speed, the vehicle's position is adjusted to reflect the distance that it travels during each subsequent deci-second. The updated positions, that are derived during one given deci-second, then become the basis upon which the new headways and speeds will be computed during the next deci-second.

The macroscopic calibration, of the microscopic car-following relationship, ensures that vehicles will traverse each link in a manner that is consistent with that link's desired free-speed, speed-at-capacity, capacity and jam density. Figure 2 illustrates the direct correspondence between the more familiar macroscopic speed-flow and speed-density relationships, and the less familiar car-following relationship that is plotted in terms of speed-headway. This correspondence is illustrated for three different traffic conditions, which are identified as points ***a*** , ***b*** and c.

It can be noted from the speed-flow relationship that point ***a*** represents uncongested conditions, point ***b*** represents capacity flow and point c represents congested conditions. However, speeds ***a*** and c can be noted as occurring at the same flow rate. The attributes of points ***a, b*** and c are more difficult to discern from the speed-density and speed-headway relationships, which simply represent mathematical transformations of the same relationship. However, in this case speeds ***a*** and ***c*** have unique densities and headways associated with them.

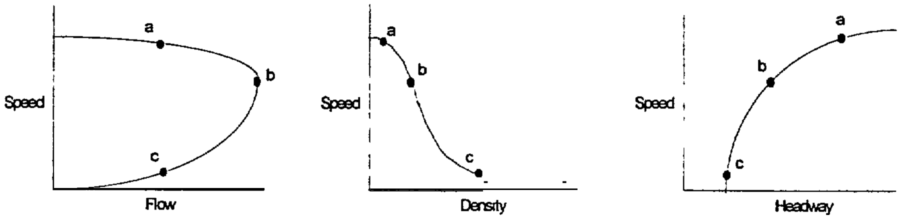


Figure 2. Determination of microscopic speed from corresponding macroscopic relationships

Qualitatively, it can be noted from the speed-headway relationship that vehicles will only attain their desired free-speeds when the headway in front of them is very large. In contrast, when the distance headway becomes sufficiently small, as to approach the link's jam density headway, the vehicle will decelerate until it eventually comes to a complete stop.

A natural by product, of the above car following logic, is that INTEGRATION represents all queues as horizontal rather than vertical entities. The representation of horizontal queues ensures that queues spill back upstream, either along a given link, or potentially across multiple links. Furthermore, the representation of horizontal queues also ensures that the number of vehicles in the queue will be greater than the net difference between the arrival and departure rate, as the tail of the queue grows upstream towards the on-coming traffic. Furthermore, the use of the above speed-headway relationship also enables these horizontal queues to exhibit a variable density, depending upon the associated speeds of vehicles within the queue.

c. Lane changing logic

When a vehicle travels down a particular link, it either may make discretionary lane changes, mandatory lane changes, or both, as illustrated in Figure 3. Discretionary lane changes are a function of the prevailing traffic conditions, while mandatory lane changes are usually a function of the prevailing network geometry.

In order to determine if a discretionary lane change should be made, each vehicle computes three speed alternatives at deci-second increments. The first alternative represents the potential speed at which the vehicle could continue to travel in the current lane, while the second and third’ choices represent the potential speeds a vehicle could travel in the lanes immediately to the left and to the right of the vehicle’s current lane. These speed calculations are made on the basis of the available headway in each lane and a pre-specified bias, for a vehicle to remain in the lane in which it is already traveling, and to move to the shoulder lane.

The vehicle will then elect to try to change into that lane which will permit it to travel at the highest of these three potential speeds. For example, in Figure 4 vehicle D may elect to leave the shoulder lane for the center lane in order to increase its headway and therefore also the speed at which it can comfortably travel. Such lane changing, while discretionary, is still subject to the availability of an adequate gap in the lane to which the vehicle wishes to move.

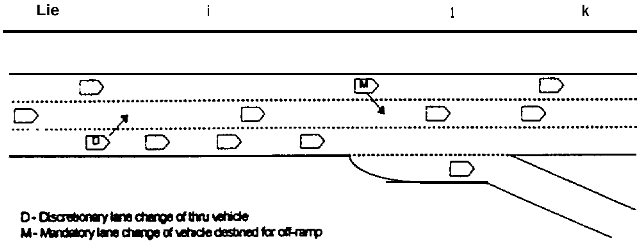


Figure 3. Illustration of discretionary and mandatory lane changes

While discretionary lane changes are made by vehicles in order to maximize their speed; mandatory lane changes arise primarily from a need for vehicles to maintain lane connectivity at the end of each link. For example, in Figure 2.3 vehicle *M* would ideally desire to remain in the median lane, in order to maintain a higher speed. However, since this vehicle must access the off-ramp, it must first enter the deceleration lane prior to exiting link *j*.

In general, lane connectivity requires that eventually every vehicle must be in one of the lanes that is directly connected to the relevant downstream link onto which the vehicle anticipates turning. A unique feature of INTEGRATION’s lane changing model is that the lane connectivity at any diverge or merge is computed internal to the model, saving the model user the extensive amount of hand coding that would be necessary in representing link connectivity in networks with several thousands of links.

Once a lane changing maneuver has been initiated, a subsequent lane change is not permitted for a pre-specified minimum amount of time. In the first instance, this minimum ensures that lane changes usually involve a finite length of time to materialize and that two consecutive lane changes cannot be executed one immediately after the other. Furthermore, while an actual lane changing maneuver is in progress, the vehicle is modeled as if it partially restricts the headway in both the lane it is moving from, and the lane it is changing into. This concurrent presence in two lanes will result in an effective capacity reduction beyond that which would be observed if the vehicle had not made any lane change. The relationship of this impact to the speed and capacity of weaving sections is beyond the scope of this report, but can be found in other sources (Van Aerde et ***al.,*** 1996; and Stewart et ***al.,*** 1996).

d. Link-to-link lane transitions

Upon approaching the end of a link, the above mandatory lane changing logic will ensure that vehicles will automatically migrate into those lanes that provide direct access to the next desired downstream link. When the end of the first link is actually reached, the vehicle is automatically considered for entry onto the next downstream link.

The entry onto this downstream link is subject to the availability of an adequate minimum distance headway that is required in order to absorb the new vehicle, without violating the downstream link’s jam density. In addition, any available headway beyond this minimum is also utilized to set the link entry speed of the vehicle in question. If the maximum headway in the downstream link is insufficient to accommodate the vehicle in question, the vehicle will be retained on its original link until an acceptable headway becomes available. Consequently, congestion in one link can constrain the outflow rate of one or more upstream links, such that queues can spill back across multiple links.

Any available downstream capacity is also implicitly allocated proportionally to the number of inbound lanes to the merge. For example, if at a diverge all lanes have a saturation flow rate of 2000 veh/hr/lane, and two 2-lane sections merge into a single 3-lane section, the combined inflow from the two inbound links will be limited to 6000 veh/hr when the downstream link is not congested. However, if an incident were to have reduced the capacity of the 3-lane section to, say 4000 veh/hr, the two inbound approaches would then only have a reduced combined outflow capacity of 4000 veh/hr available to them.

The exit privileges of a particular link may also be constrained by a conflicting opposing flow. In this case, the opposed vehicles would need to delay their entry into their next downstream link until a sufficient gap appeared in the opposing traffic stream. On a single lane approach, such gap seeking would also delay any subsequent vehicles, even if subsequent vehicles are not opposed. However, on a multi-lane approach, unopposed vehicles may be able to utilize the residual capacity in the remaining lanes. When discharges in multiple directions occur from the same link, shared lane calculations are performed automatically.

On the basis of the above logic, vehicles proceed towards their destination in a link-by-link fashion, where their speeds, as well as longitudinal and lateral positions, are updated each deci-second until the vehicle’s final link is reached. When the vehicle reaches the end of this final link, the vehicle is removed from the simulation, any trip statistics are tabulated, and any temporary variables assigned to that vehicle are released.

2.1.3 Route Selection and Traffic Assignment

One of the most significant sources of complexity in modeling traffic is the need to consider traffic assignment in addition to simulation. The need to model traffic re-routing and assignment stems from the fact that traffic is both dynamic and responsive to changes in the traffic flow conditions. A unique feature of the INTEGRATION model is the extent to which these two elements have been integrated. This section briefly describes the route selection and traffic assignment module within the INTEGRATION model.

The selection of the next link to be taken by a vehicle is determined by the model's internal routing logic (Rilett and Van Aerde, 1991 a and b). There exist many different variations to the model's basic assignment technique, these variations fall into two main categories, namely; a macroscopic rate-based assignment and a microscopic feedback based assignment. Within these two main categories the assignment techniques can vary from a static to a dynamic assignment and/or from a deterministic to a stochastic assignment.

a. Macroscopic rate-based assignrnent

This is the most familiar traffic assignment technique to most transportation engineers and planners. The deterministic rate-based assignment technique assumes drivers have perfect knowledge of the prevailing link travel times and considers that an analytical expression exists that can fully capture the impact that changes in traffic demand may have on link travel times. Furthermore, it assumes that drivers, in selecting their routes, attempt to either minimize their own travel time (user optimum assignment) or the entire system travel time (system optimum assignment) (Wardrop, 1952).

The Frank-Wolfe algorithm has been shown to be very effective in solving convex network problems (Frank and Wolfe, 1956) and thus has been successfully used in estimating traffic flows in a static fashion (static traffic assignment). Another method that is also utilized in estimating link flows is the method of successive averages. The advantage of the method of successive averages over the Frank-Wolfe algorithm is that it does not require a well behaved traffic flow relationship that can be integrated in order to assign traffic. However, the method of successive averages requires a larger use of the tree builder in order to iteratively find the optimum solution. Consequently, because the solution of the dynamic traffic assignment problem is non-convex, the method of successive averages is the preferred solution technique while for a static assignment the Frank-Wolfe algorithm is the preferred method.

The current version of INTEGRATION uses the Frank-Wolfe algorithm to search for the optimum assignment of traffic. Each of the five vehicle classes in the INTEGRATION model is assigned five trees. The relative split in tree weights is computed using the Frank-Wolfe technique. If the link travel time error is greater than zero all five trees are assigned equal weights. The INTEGRATION model makes available an implementation of this approach to the model user by approximating an entire dynamic time series of traffic conditions as a series of piece-wise static demands. The assignment for each of these demands is computed independently of any prior or subsequent demands. The macroscopic rate based assignment is updated at a user specified interval.

b. Microscopic feedback based assignment

The other major class of traffic assignment is the microscopic feedback oriented traffic assignment. Unlike the rate based traffic assignment, the feedback assignment, updates the five trees in a staggered fashion. The logic is best described using an example illustration. If the vehicle class has a tree update frequency of 100 seconds, the feedback oriented assignment would initiate all five trees at time zero, tree 2 would be updated at times 20, 120, 220, and 320, while tree 3 would be updated at time 40, 140, 240, and 340 seconds, and so on. The feedback based assignment, unlike the rate based assignment, builds its trees based on the latest real-time traffic conditions within the simulated network.

c. Simulation of vehicle routings

Regardless of the technique that is utilized to determine the vehicle routings, all of these routings are eventually conveyed to the simulated vehicle using a look-up table format, as shown in Figure 4. This routing look-up table format provides, for each vehicle class, an indication of the next link to be taken towards a particular destination. The look-up table is also indexed based on the current link that is being traversed.

Upon the completion of any link, the vehicle simply queries this look-up table, based on the current link that is being traversed, in order to determine which link it should utilize next to reach its ultimate destination in the most efficient manner. When this next link is completed in turn, the process is repeated until eventually a link is reached whose downstream node is the vehicle's ultimate trip destination. In addition, in order to provide for multipath traffic assignments a set of multiple trees may be utilized concurrently during a given time period, while different sets of trees may be utilized to represent time-varying multipath routings.

The key simulation feature to be noted within this traffic assignment process is that turning movements, and therefore all mandatory lane changes are vehicle-specific path based turning movements, rather than more arbitrary turning increment percentages.

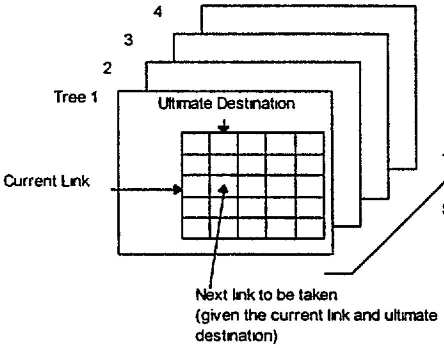


Figure 4. Illustration of the routing tree table concept

2.1.4 Advanced Traffic Simulation Features

a. Modeling of Traffic Signals and Ramp Meters

The extent of any signalization (or ramp metering) is specified to the INTEGRATION model with reference to a traffic signal number. The traffic signal number is selected with reference to the timing plans that are provided in the signal file, while the phase numbers allow the appropriate phase timings to be picked up within each plan.

Within INTEGRATION, a signalized link is identical in virtually all respects to a non-signalized link, except that the exit privileges to this link may periodically be suspended (Rakha, ***et. al.,*** 1993).

The suspension of exit privileges is set to occur when the traffic light indicates an effective red. When the light is red, vehicles must still obey the link's car-following logic, except that a red traffic signal is considered as an additional vehicle that is positioned just beyond the end of each lane on the link. This ***virtual*** vehicle creates a reduction in the vehicle's perceived headway, and causes subsequent vehicles that approach a red signal to slow down as their headway to the traffic signal decreases. Eventually the first vehicle to approach the red signal comes to a complete stop upstream of the stop line. Subsequent vehicles then automatically queue upstream of the first vehicle in a horizontal queue, where the minimum spacing of vehicles in this horizontal queue is governed by the user specified jam density.

As shockwave theory applies to both freeways and arterials, the rate at which the tail of queue moves upstream along the link can be determined in a standard fashion, as the ratio of the "arrival rate at the tail of the queue", divided by the "net difference between the density of the queued vehicles and the density of the arriving traffic". The dynamic nature of the model's car-following logic also permits the rate, at which this queue grows, to vary dynamically when the arrival rate varies as a function of time during the cycle.

Within INTEGRATION, a microscopic gap acceptance model is utilized to reflect the impact of opposing flows on opposed left turners and right turners on red (Velan and Van Aerde, 1996). This opposition is automatically customized by the model at each intersection by means of built in logic that specifies which opposing movements are in conflict with the movement of interest. This internal logic also determines which of the turning movements are opposed within a shared lane or shared link. Given the above data, the model automatically provides opposition to left turners, when the opposing flow link discharges concurrently. However, it also automatically allows the discharge rate to revert back to the unopposed saturation flow rate when the opposed movement is given a protected phase.

The explicit modeling of opposing and opposed links allows the INTEGRATION model to explicitly simulate traffic signals, stop and yield signs.

b. Link use and turning movement restrictions

One of the features, which allows the model to better represent the operational characteristics of many actual networks, is the restriction of the use of either specific link lanes, and/or specific turning movements.

Restrictions of links can be implemented for a specific subset of vehicle types. It therefore may be utilized to represent either the restricted availability of a certain link to only HOV vehicles, or the availability of a certain toll booth to a vehicle that possesses a specific toll collection technology (Robinson and Van Aerde, 1995). Alternatively, this feature can also be utilized to model the impact of a truck network within a more general road network.

It is also possible to restrict certain lanes to specific vehicle types in order to model, for example, an HOV lane that is exclusive to one vehicle type. Alternatively, a given vehicle may be constrained to utilize only a given lane, for example, a truck lane, by restricting this vehicle from utilizing all other lanes. In either case, this restriction is sufficiently flexible to permit vehicles turning onto or off of the link to pass through these restricted lanes in order to complete their turning movement

A third type of restriction is that vehicles can be confined to only make certain turning movements from certain lanes. This ability permits the modeling of exclusive versus shared lanes, and is critical to properly model the impact of advanced/leading phases and/or estimating the number of vehicles that maybe able to make a right-turn-on-red before a through vehicle blocks the lane.

The final restriction can be applied to specific turning movements. It is typically utilized to represent banned turning movements at intersections for certain periods of time. However, the same feature can also be utilized to represent time dependent access restrictions to the use of a particular reversible lane or on-ramp.

c. Simulation of incidents and diversions

The continuous nature of the model permits incidents to start at any time (to within one minute), be of any duration, and be of any severity (blocking from 0 to 99% of the available capacity). In addition, any specific group of lanes can be blocked at any point along the link, and the blockage can be of any length. Incidents may be modeled concurrently at different locations, or different incidents may be modeled at the same location at different instances of time. The net effect of the incident is that it reduces the saturation flow and/or the maximum speed of each targeted lane on the given link.

At present, INTEGRATION’s routing logic does not directly respond to the occurrence of an incident. Instead, it responds to any delay that arises from the flow or speed restrictions associated with the incident. This indirect response has the effect that diversion does not occur until the delay experienced by vehicles becomes sufficiently large as to make an alternative route more desirable. Similarly, the model may sustain diversions, even after the actual blockage at an incident site has already been cleared, but when some residual queues remain to produce on-going delays.

2.1.5 Measures of Effectiveness

It is implicit, in the earlier discussion of the use of speed-flow and car-following relationships, that the INTEGRATION model does not contain an explicit link travel time function in a fashion similar to most macroscopic or planning oriented traffic assignment models. Instead, link travel time emerges as the weighted sum of the speeds that vehicles experienced as they traversed each link segment. This distinction introduces both a level of complexity and accuracy not present in most other models.

Specifically, the dynamic temporal and spatial interactions of shockwaves, which form upstream of a traffic signal, or along a freeway link that is congested, are such that the final link travel time is neither a simple function of the inflow nor the outflow of the link. Instead, the travel time is a complex product of the traffic flow time series and associated dynamics along the entire link, and the temporal interactions of this flow with the signal timings and flow oppositions at the end of these links. The strength of a microscopic approach is that, beyond the basic car-following/lane-changing/ gap-acceptance logic, there is no need for any further analytical expressions to estimate either uniform, over-saturation, coordination, random, left-turn or queue spill-back delay. While such complexity precludes the simplicity of a functional relationship, such as the Bureau of Public Roads relationship, it also permits two distinct travel times to be properly considered for the same flow level, depending on whether forced or free-flow conditions prevail, and can deal much more readily with the concurrent presence of multiple vehicle/driver types on the same link.

a. Estimation of link travel time and number of stops

The model determines the link travel time for any given vehicle by providing that vehicle with a time ***card*** upon its entry to any link. Subsequently, ***this time card*** is retrieved when the vehicle leaves the link. The difference between these entry and exit times provides a direct measure of the link travel time experience by each vehicle. Furthermore, each time a vehicle decelerates, the drop in speed is recorded as a partial stop. The sum of these partial stops is also recorded on the above ***time card*** and provides again a very accurate explicit estimate of the total number of stops that were encountered along that particular link.

It is noteworthy that INTEGRATION will often report that a vehicle has experienced more than one complete stop along a link. Multiple stops arise in this case from the fact that a vehicle may have to stop several times before ultimately reaching the link stop line. This finding, while seldom recorded by or permitted within macroscopic models, is a common observation within actual field data for links on which considerable over-saturation queues occur.

b. Estimation of fuel consumption

The INTEGRATION model computes the speed of vehicles each deci-second, permitting the steady state fuel consumption rate for each vehicle to also be computed each second on the basis of its current instantaneous speed. In addition, by tracking the change in speed from one time second to the next, it is also possible to determine the amount of additional fuel that is likely to have been consumed by the vehicle due to any acceleration and deceleration cycles.

The default coefficients, that are utilized to estimate the above steady speed and acceleration oriented fuel consumption, are derived internal to the model, where the default vehicle is a 1992 Oldsmobile Toronado (Van Aerde and Baker, 1993; Baker and Van Aerde, 1995). The derivation of these coefficients for any other vehicle can be performed on the basis of the published EPA city and highway mileage ratings. The above base fuel consumption rates are modified in view of the prevailing ambient temperature. Therefore, additional fuel consumption penalties are typically assigned while a vehicle’s engine is warming up during the first part of its trip.

The above fuel consumption analysis features are built into the model and are executed every second for every vehicle in the network. They are applied in a fashion that is also consistent across all facility types, operating regimes, and control strategies. This consistent internal use of the same general fuel consumption model permits a very objective assessment of the fuel consumption implications across a wide range of potential traffic or demand management strategies.

c. Vehicle emissions

A series of compatible vehicle emissions models have been developed that are fully coupled to the above fuel consumption model. These models, which estimate hydrocarbon, carbon monoxide and nitrous oxide emissions, also operate on a second by second basis (Baker and Van Aerde, 1995). They are sensitive to the vehicle speeds, the ambient temperature and the extent to which a particular vehicle's catalytic converter has already been warmed up during an earlier portion of the trip.

Applications of these models have shown that the emission of these three compounds is related to vehicle travel time, distance, speed and fuel consumption in an often highly nonlinear fashion. Consequently, traffic management strategies, which may have a significant positive impact on one measure, are not always guaranteed to have an impact of either the same magnitude or sign on any of the other measures. The types of analyses, that can be performed with these models, extend far beyond the capabilities of EPA's MOBILE5 model (USEPA, 1993), which considers a single fixed speed profile for any given average speed and considers primarily the number of vehicle miles traveled as the main predictor variable. However, INTEGRATION does not explicitly consider vehicle age or maintenance level.

The execution of the INTEGRATION model, for the EPA city and highway speed profiles, has yielded emission estimates consistent with those estimated by MOBILE5 for comparable standard conditions. However, the analyses of other speed profiles, which still yield the same average speed, have been shown to often yield very different emission quantities.

d. Aggregation of statistics by link and O-D pair

The same time card concept, that is used for recording a vehicle's travel time and number of stops on a particular link, is also utilized to track the fuel consumption and emissions for each vehicle on each link. Internal to the model, these statistics are further aggregated, both for all links traversed by a particular vehicle, and for all the vehicles that have traversed a particular link. The former statistics can be aggregated at the O-D level by time period or vehicle type, or they can be aggregated by time period for each link or by cell within a latitude/longitude grid. When emission data are tracked by latitude and longitude as a time series, these data can in turn be provided as input to an external air quality emission model of the atmospheric conditions for an entire urban area.

In addition to tracking the number of lane changes occurring within the network and counting the number of vehicle passes, the model also provides an estimate of cumulative accident risk. This accident risk is again estimated on a second by second basis by cross-multiplying the distance driven by a particular vehicle against the accident rate per unit distance for that link. The latter unit distance accident risk can be facility type dependent, reflect the impact of the presence of congestion, and may also reflect the use by a particular vehicle of a given ATIS technology. The use of the model in this capacity permits the estimation of accident risk reduction as a function of the level and quality of ATIS deployment.

2.2 MODELING OF BACKGROUND TRAFFIC AND GENESIS SYSTEM

This section describes how the background traffic (non Genesis users) and the Genesis users were modeled within the INTEGRATION simulation model.

2.2.1 Modeling of Background Traffic

The first issue in an evaluation study is to define the before conditions (i.e. traffic conditions prior to the introduction of the Genesis system). It is common to assume that drivers typically attempt to minimize their individual travel times (user equilibrium assignment). Consequently, the background traffic was modeled using the deterministic macroscopic rate-based traffic assignment method.

2.2.2 Modeling of Genesis System

The results of the Genesis Operational Test Evaluation indicated that out of 292 user responses only 18 respondents changed their departure time and only 5 respondents changed their trip destination in response to a reported incident. Of the 292 respondents, 192 changed their route of travel in response to the reported incident. Consequently, the current domain of application of the basic INTEGRATION model which starts from the time when the driver has elected to depart from a particular origin to a particular destination, at a particular time, and by means of a specific vehicle type, was considered sufficient for modeling the Genesis system.

The Genesis Operational Test Evaluation also revealed that 52 percent of the users of Genesis first learned about the incidents from Genesis messages. Consequently, it was assumed that only Genesis users would be updated with real-time traffic information and that this information was provided by the Genesis system.

Because Genesis only provides the user with a description of the location and severity of an incident, leaving the driver the choice of selecting the optimum route, it was assumed that the margin of error associated with the link travel time estimation would be the same as that of the background traffic (0 percent).

The microscopic feedback based traffic assignment method was utilized for modeling the Genesis users, because it utilizes real-time traffic information. The tree frequency update was set to fifteen minutes which results in an update of each on of the five trees every five minutes.

2.3 SUMMARY

1. The INTEGRATION model was selected for the evaluation of the Genesis system for the following reasons:

- INTEGRATION models traffic microscopically and thus information is available on an individual vehicle basis. This microscopic nature allows for modeling of real-time traffic information that is provided to a specific class of vehicles.
- INTEGRATION can simulate five different vehicle classes. These vehicle classes allow for the modeling of Genesis and non-Genesis users.
- INTEGRATION models routing and assignment, thus allowing for the modeling of traffic re-routing in response to real-time traffic information.
- INTEGRATION allows for the integrated modeling of freeway and arterial systems. This capability allows for modeling of traffic diversion between the freeway/arterial facilities.
- INTEGRATION models a number of routing capabilities including a macroscopic rate based assignment and a microscopic feedback based assignment. These assignment techniques can range for static to dynamic assignment or from deterministic to stochastic.
- INTEGRATION has been utilized in the evaluation of the TravTek route guidance system (Van Aerde and Rakha, 1995) and the Intelligent Transportation Systems (ITS) architecture study.

2. The background traffic (non-Genesis users) would be modeled using the deterministic macroscopic rate-based traffic assignment.
3. The Genesis users would be modeled using the deterministic microscopic feedback traffic assignment logic and a routing update frequency of fifteen minutes.

3. CALIBRATION OF THE INTEGRATION MODEL TO THE I-35W NETWORK

3.0 INTRODUCTION

As described in the previous section, the INTEGRATION microscopic simulation/assignment model was selected for the modeling evaluation of the Genesis system because of its unique modeling features that enable it to model both the background traffic and the Genesis system.

This section describes how the INTEGRATION input files were generated for the evaluation of the Genesis system. The intent of this description is to provide the reader with an understanding of the level of effort involved in creating the input files in order to attain a reasonable quality of input data.

Following the description of the input data coding, this section describes how the model was calibrated to the network and traffic conditions for a freeway corridor within the Minneapolis/St. Paul metropolitan area. Field data measurements are compared to simulated results in order to verify the before conditions (before the Genesis system). The establishment of the before conditions is a necessary first step in establishing the base case to which any benefits of the Genesis system can be measured against.

3.1 CONFIGURATION OF SIMULATION NETWORK

The INTEGRATION model requires a minimum of five input files in addition to a master control file. These input files include a node characteristic file, a link characteristic file, a signal timing file, an Origin-Destination (O-D) demand file, and an incident file. The procedure in which these input files were generated for the Genesis evaluation are discussed in this section while a printout of the input files is provided in Appendix (A).

3.1 .1 Node/Link Characteristics

The generation of the INTEGRATION node and link characteristic files was based on a TRANPLAN node/link file of the metropolitan area of Minneapolis/St. Paul as demonstrated in the flow chart in Figure 5. Consequently, this section initially describes how the TRANPLAN input file was created by the Minnesota Department of Transportation (Mn/DOT). Subsequently, this section describes how the INTEGRATION input files were generated from the TPANPLAN file and other sources of input data.

a. TRANPLAN input files

The TRANPLAN input file was generated using the 1990 Highway network provided by the Metropolitan Council in Minnesota. This network included all major and minor roads with an Average Annual Daily Traffic (AADT) exceeding 1000 veh/day. The process of building the 1990 highway network started with Mn/DOT's 50 Series digitized maps. These are 1:24000 scale maps maintained by Mn/DOT and updated annually which show all metro area streets and highways along with water and political boundaries. The centroid locations were identified by locating the zones on aerial photographs and approximating the center of activity as represented by developed land or other significant features on the photo. Centroid connectors were added manually by observing logical highway access to the zones. A maximum of four connectors were used to connect a centroid to the highway network. Link lengths were extracted from the Geographic Information System (GIS) database. The final TRANPLAN node/link file included a total of 7393 nodes, of which 1200 were trip generation zones, and a total of 20380 one-way links.

The network links were related to geographical areas termed areatypes in order to reflect key traffic parameters such as typical speeds and link capacities. The designated areatypes included: rural, developing, developed, center city, central business district (Minneapolis and St. Paul CBD), and outlying business area. Furthermore, links were categorized by facility type as follows: metered freeway, unmetered freeway, metered ramp, m-metered ramp, divided arterial, undivided arterial, collector, High Occupancy Vehicle (HOV) links, HOV ramp and centroid connector.

The metered freeway links were defined as facilities operating with controlled access at all intersections on which all ramps for at least 3.2 kilometers were metered. Unmetered freeways were defined as facilities with controlled access but on-ramps were not metered. Metered and unmetered ramps were defined to simply indicate the existence of a meter on the ramp.

A divided arterial link was defined as a multi-lane facility divided by a physical barrier with the intersections controlled by traffic signals. An undivided arterial link was defined as a roadway with signals at the intersections but no physical divide between the lanes. A collector was defined as an undivided roadway with access to controlled signs (e.g., stop or yield).

An HOV facility was described as a freeway type facility restricted to use by multi-occupant vehicles. An HOV ramp was a ramp that entered or exited an HOV facility.

A centroid connector was a hypothetical link that connected the regional highway network to a zone centroid. Up to four connectors were used to represent all the roads entering or leaving a traffic zone.

b. Generating INTEGRATION node and link files

The final network that was selected for the modeling of Genesis was the I-35W corridor because it consisted of four of the O-D field trials that were used for testing. In addition, the I-35W served as a major corridor for traffic leaving downtown Minneapolis during the PM peak. The I-35 W network included the I-35 W freeway from I-94 in the north (Downtown Minneapolis) to 90th Street in the south (Bloomington) as illustrated in Figure 6. In order to model the alternative diversion routes, this network extended from Park Ave. in the east to Penn Ave. S in the west.

The I-35W network was composed of 401 nodes, of which 58 were zone centroids, and a total of 1034 one-way links. Of the 1034 links in the I-35W network, only 17 percent represented freeway/ramp links as demonstrated in Table 1. The freeway/ramp sections amounted to 20 percent of the total network length, while the remaining links, that composed the alternate routes, composed the majority of the network length. Appendix (A) presents a printout of the INTEGRATION node and link characteristic files.

The traffic flow parameters that were utilized for the different road types are summarized in Table 2. Some of these parameters were extracted from the TRANPLAN node/link file, while others were modified in order to reflect typical traffic flow parameters. The parameters for the freeway sections were based on the following: the free-speed was based on the TRANPLAN input files, the capacity was increased from 1950 veh/h/lane, as used in the TRANPLAN input file, to 2200 veh/h/lane as identified by the latest version of the Highway Capacity Manual (Tranportation Research Board, 1994). The speed-at-capacity is typically approximately 20 percent lower than the free-speed as illustrated in the fit of Figure 7 using 5-minute loop detector data. The approximately 20 percent lower speed-at-capacity relative to free-speed has also been found along other freeway sections like, for example, the I-4 freeway in Orlando, the Amsterdam Ring Road in Holland, and Hwy 401 in Toronto.

The jam density was found to typically range from 110 veh/h/lane to 150 veh/h/lane along freeway sections (May, 1990). Consequently, the jam density for the freeway links was selected to be the mean of this typical range (130 veh/h/lane).

The traffic flow parameters for the ramps was scaled down relative to the freeway sections in order to capture the lower geometric standards that typically exist on ramps.

The free-speed for collector, undivided arterial and divided arterial facilities was provided by the TRANPLAN node/link file. While the capacities were estimated by doubling the capacities that were provided in the TRANPLAN input file, assuming a green to cycle length ratio of 50 percent. The logic behind doubling the link capacities rests in the fact that link capacities supplied to TRANPLAN include the reduction in capacity caused by the traffic signal timings, while the INTEGRATION model requires the link capacity without accounting for the signal timings. The INTEGRATION model, unlike TRANPLAN, explicitly models traffic signal timings.

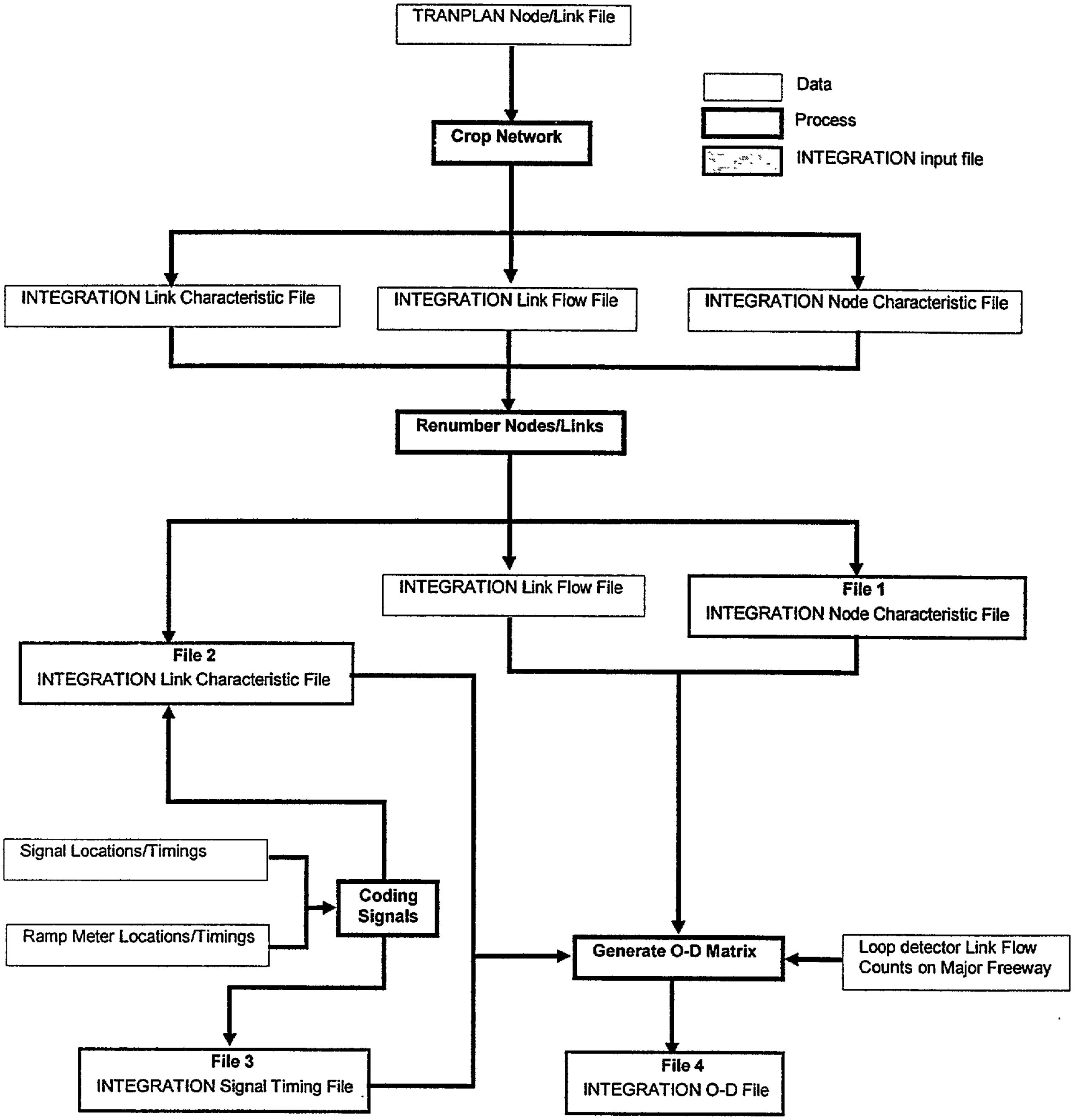


Figure 5. Derivation of INTEGRATION input files for Genesis modeling

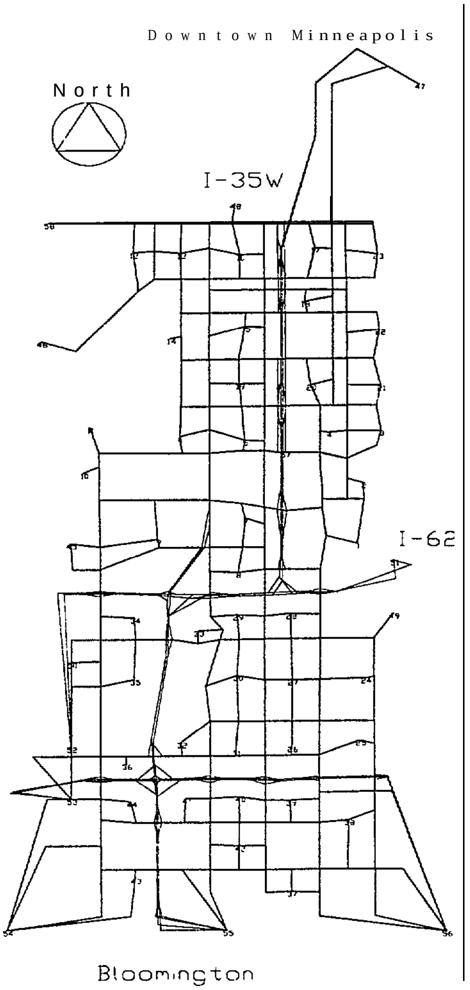


Figure 6. I-35W traffic network

	Total Number	Percentage Number (%)	Total Length (km)	Percentage Length (%)
Centroid Connector	286	27	69.3	23
Collector	231	22	60.0	21
Undivided Arterial	290	28	74.4	26
Divided Arterial	60	6	29.7	10
Unmetered Ramp	38	4	6.0	2
Metered Ramp	33	3	5.5	2
Unmetered Freeway	26	3	7.7	3
Metered Freeway	70	7	36.6	13
HOV Ramp	0	0	0.0	0
HOV	0	0	0.0	0

Table 1. Link summary of I-35W network

	Free-Speed (km/h)	Capacity (veh/h/lane)	Speed-at-Capacity (km/h)	Jam Density (veh/km)
Centroid Connector	100	2000	80	120
Collector	50	1500	40	120
Undivided Arterial	65	1600	45	120
Divided Arterial	70	1750	50	120
Unmetered Ramp	80	1900	60	120
Metered Ramp	80	1900	60	120
Unmetered Freeway	100	2200	80	130
Metered Freeway	100	2200	80	130

Table 2. Link traffic flow parameters for Genesis modeling

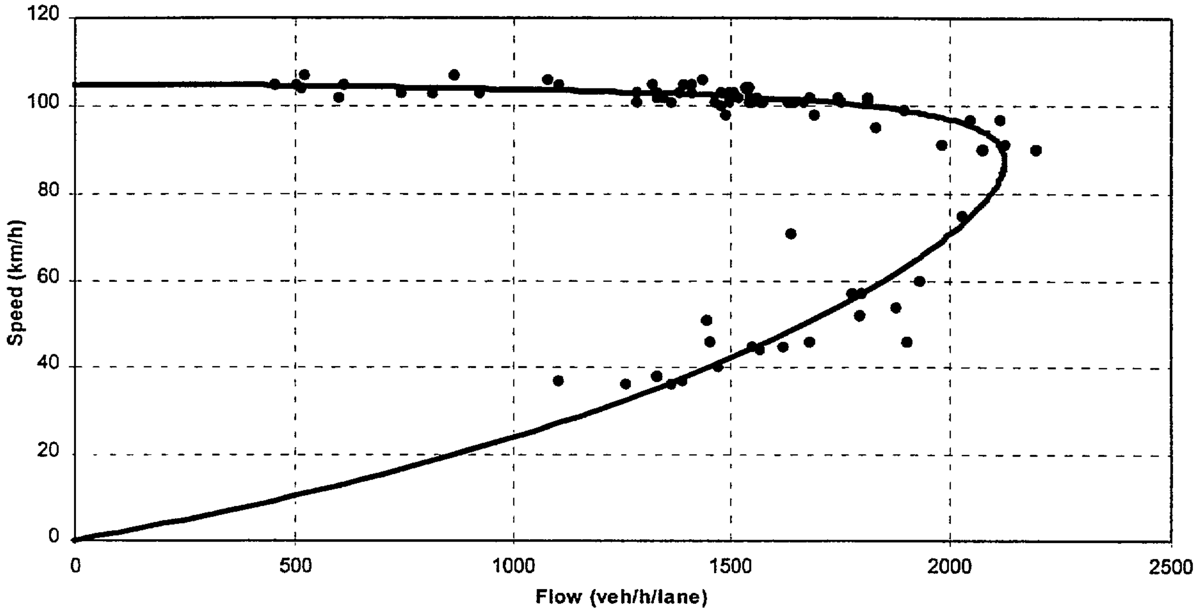


Figure 7. Typical speed-flow relationship along the center lane of the QEW freeway (Toronto, Canada)

3.1.2 Traffic Signals and Ramp Meters

Traffic signals along Park Ave., Portland Ave., and Nicollet Ave. were explicitly modeled at major intersections within the INTEGRATION model. A total of 30 traffic signals were coded allowing the INTEGRATION internal signal optimizer to optimize the traffic signal timings. The logic utilized within INTEGRATION to model traffic signals together with the signal timing optimization logic have been described in the previous section and thus are not described further in this section.

In addition, ramp meters were explicitly allocated at the downstream end of all metered links. A total of 33 ramp meters were modeled in the I-35W traffic network. The ramp metering signal timings were fixed to meter at a fixed rate of 700 veh/h to be consistent with the link capacities supplied by the TRANPLAN node/link file.

3.1.3 Origin-Destination Demand Generation

The INTEGRATION model requires, as one of its input files, an Origin-Destination (O-D) demand file. In order to generate this O-D file for the I-35W network, the **QUEENSOD** model was utilized (Hellinga, 1994) as illustrated in Figure . QUEENSOD estimates O-D traffic demands based on observed link traffic flows, link travel times, an optional seed matrix and drivers' route choices using a maximum likelihood procedure. The QUEENSOD model is capable of estimating both static and dynamic traffic demands.

The PM peak link flows that were used as input to the QUEENSOD model were generated from two sources, namely: the TRANPLAN node/link file, and average loop detector measurements along the I-35 W freeway. The loop detector link flows only comprised 5 percent of the total number of link flows that were input to QUEENSOD. The link travel times were estimated based on the link free-speed travel times.

The synthetic O-D matrix that was generated resulted in a link flow coefficient of correlation *(r)* of 98 percent. It is evident from Figure 8 that the observed link flows that were supplied to the QUEENSOD model and the estimated link flows based on the synthetic O-D that was generated are highly correlated with most of the data close to the line of perfect correlation.

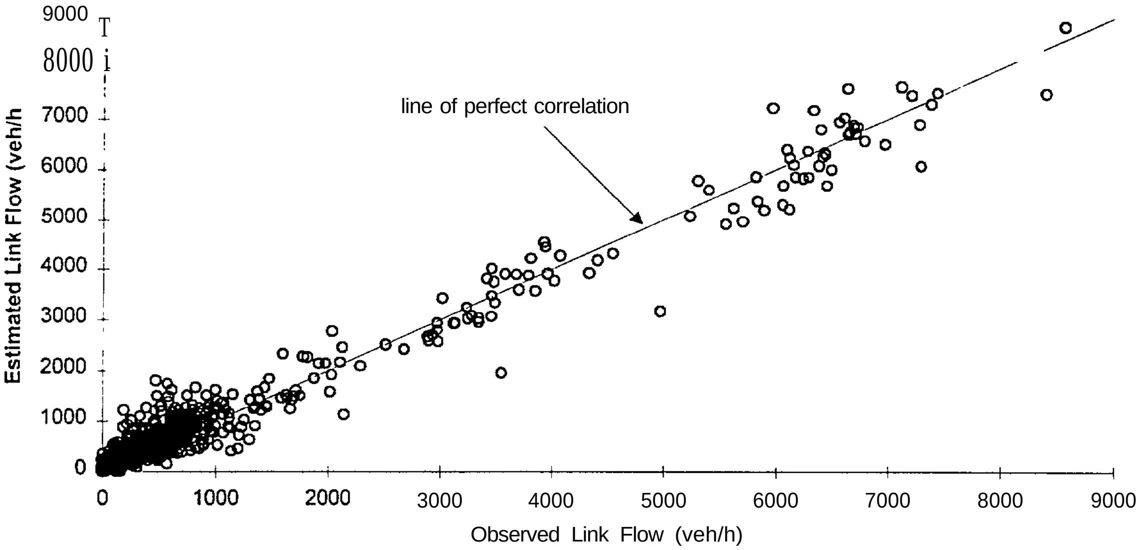


Figure 8. Observed versus estimated link flows for I-35W network

Based on the PM peak synthetic O-D demand, a time varying demand was created as illustrated in Figure 9 to replicate a typical build up and decay of peaking conditions. The peaking demand included three half hour demands of 50 percent, 100 percent, and 50 percent the base PM peak demand, respectively. An extra half hour, with no demand, was included in order to allow all vehicles to clear the network prior to ending the simulation.

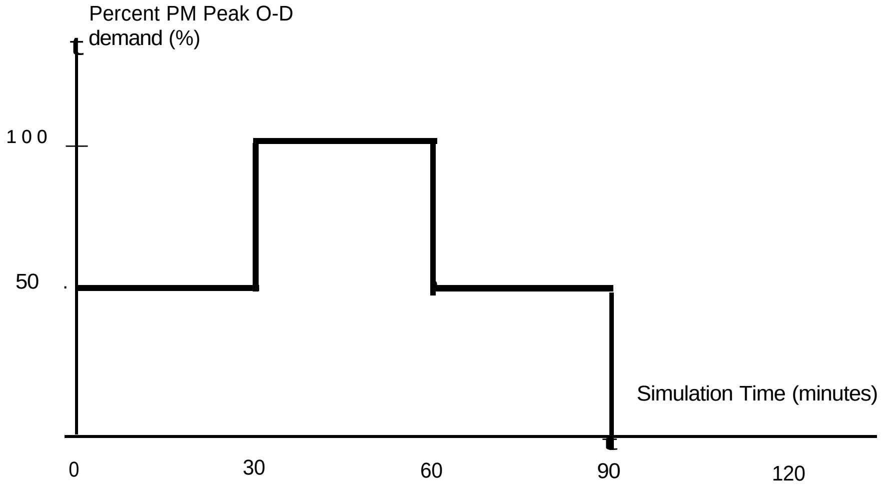


Figure 9. O-D demand peaking profile modeled for I-35W network

3.2 CALIBRATION OF INTEGRATION TO OBSERVED LINK FLOWS

The base case was simulated for two hours using the five input files that were created as described in the previous sections and illustrated in Figure 5.

The next step was to verify that the simulated traffic conditions replicated the existing conditions on the I-35W network prior to modeling the impact of the Genesis system on the overall performance of traffic. The following sections describe how the simulated results, for the base case, were tested for consistency with the existing traffic conditions on the I-35W network.

The first of these tests was to compare the simulated link flows to the observed link flows that were provided from the TRANPLAN model and the field data. Figure 1 illustrates qualitatively how the simulated and observed link flows compared for a 15 minute time slice during the peak 100 percent demand (45 to 60 minutes of simulation). A Pearson correlation test revealed a high correlation between the simulated and observed link flows (92 percent). However, as illustrated in Figure 10, for high link flows (greater than 3000 veh/h) the link flows simulated by the INTEGRATION model were lower than those provided by the TRANPLAN model. This inconsistency in link flows for higher flow rates can be explained as follows. The TRANPLAN model, as with the case of all static models, assigns traffic to links without explicitly capturing capacity restraints and thus link flows downstream a bottleneck can exceed the bottleneck capacity. Thus, because the TRANPLAN model does not hold back traffic that is queued from proceeding to any downstream links the flows on the downstream links would be unrealistically high. The **QUEENSOD** model that was utilized to generate the synthetic O-D demands suffers from the same limitation of the TRANPLAN model (no explicit modeling of capacity restraint impacts) and thus explaining the higher match of flows in Figure 8 versus Figure 10.

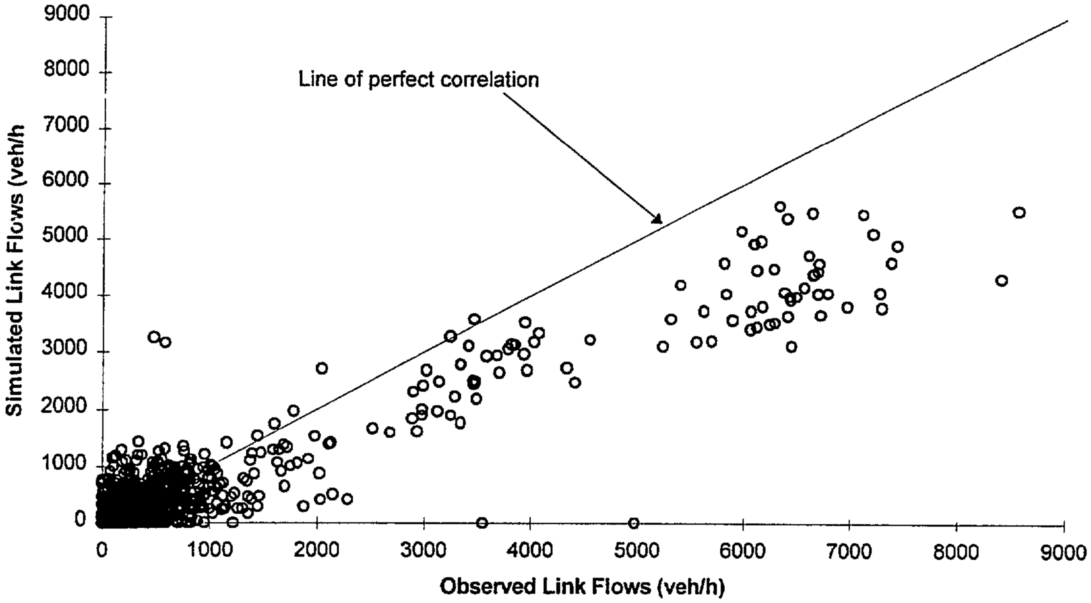


Figure 10. Observed versus simulated link flows

A further comparison was conducted in order to verify that the link flows along the primary and alternate routes of the O-D driving trials 13 and 14 were consistent with what was provided from the TRANPLAN model. These driving trials are described in further detail in the following section.

The first of these comparisons, compared the link flows provided from TRANPLAN (labeled observed) with those simulated by the INTEGRATION model (labeled simulation) along the northbound direction of I-35W from 90th street in the south to downtown Minneapolis in the north as illustrated in Figure 11. Figure demonstrates a similar spatial variation in the link flows, however, as was the case earlier, the link flows simulated by INTEGRATION are lower than those that were supplied by the TRANPLAN model. Again, the inability of TRANPLAN to capture capacity restraint impacts results in this inconsistency in the link flows.

Figure demonstrates a similar spatial variation in the link flows that were provided by the TRANPLAN model and those simulated by the INTEGRATION model for the southbound direction of the I-35W freeway. The same trends were also observed along the parallel arterial routes as illustrated in Figure and Figure .

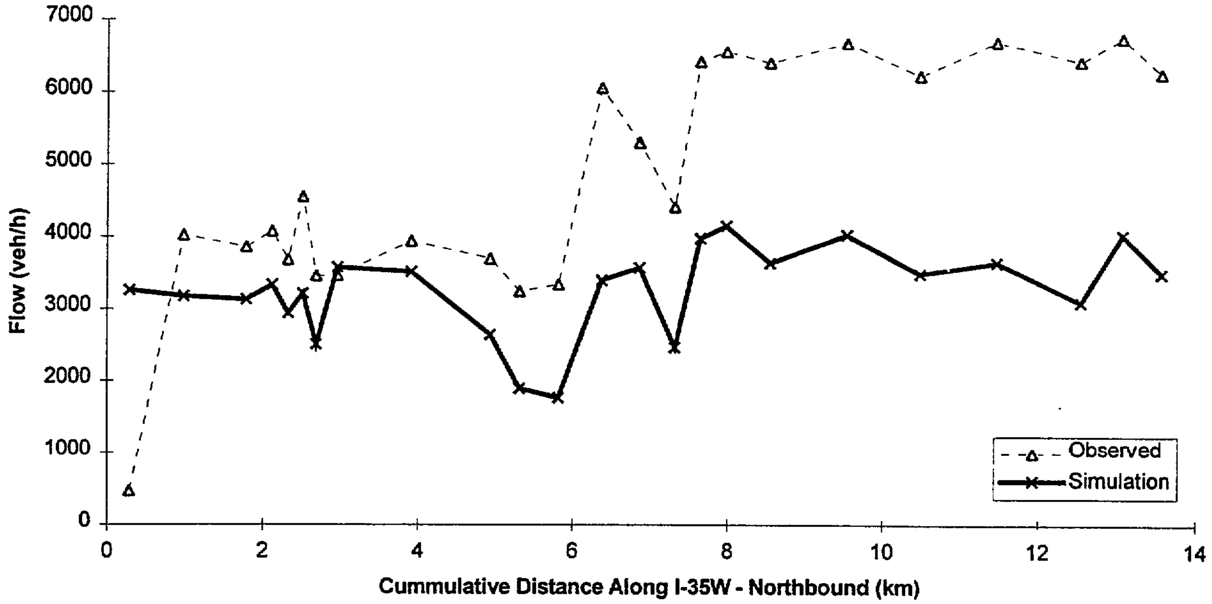


Figure 11. Spatial variation in observed and simulated link flows along the primary route for O-D driving trial 13

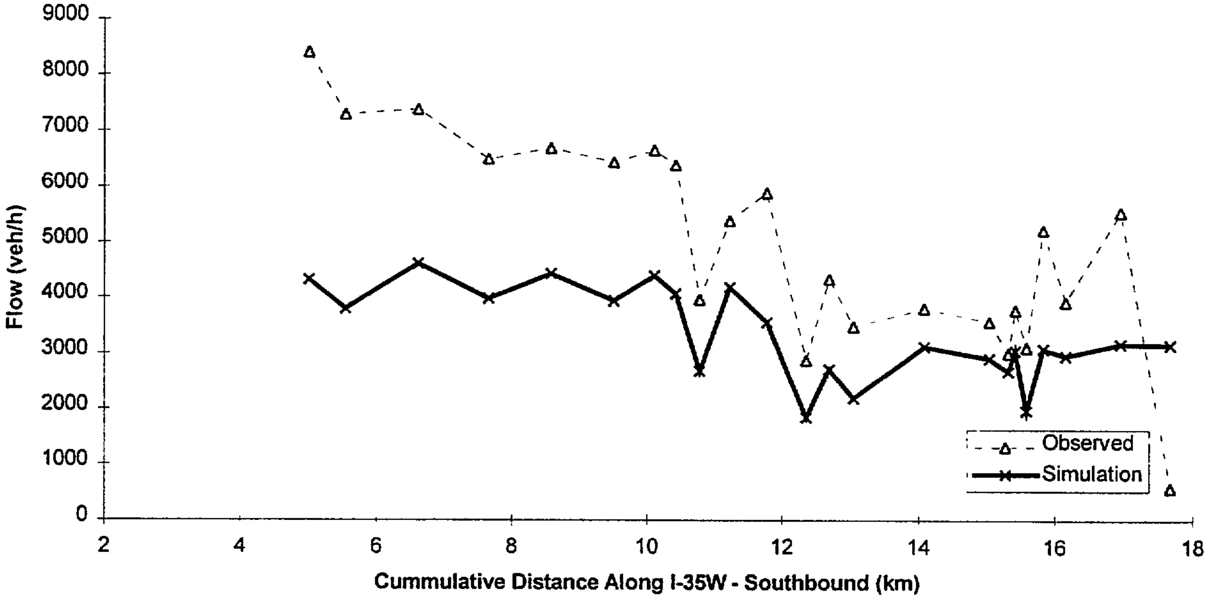


Figure 12. Spatial variation in observed and simulated link flows along the primary route for O-D driving trial 14

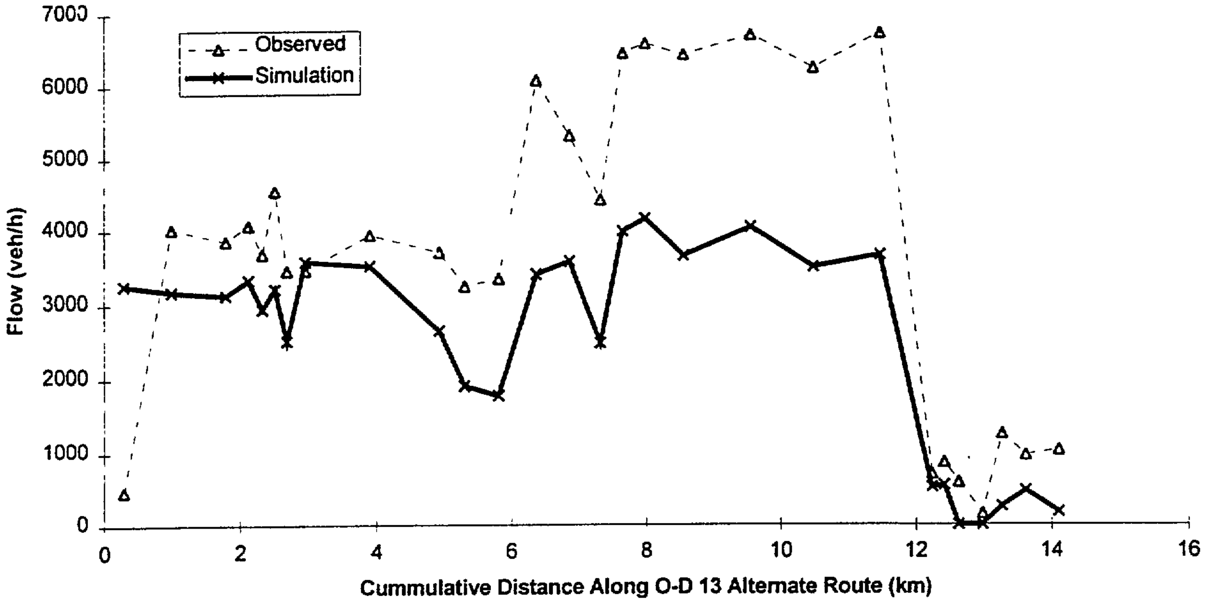


Figure 13. Spatial variation in observed and simulated link flows along the alternate route for O-D driving trial 13

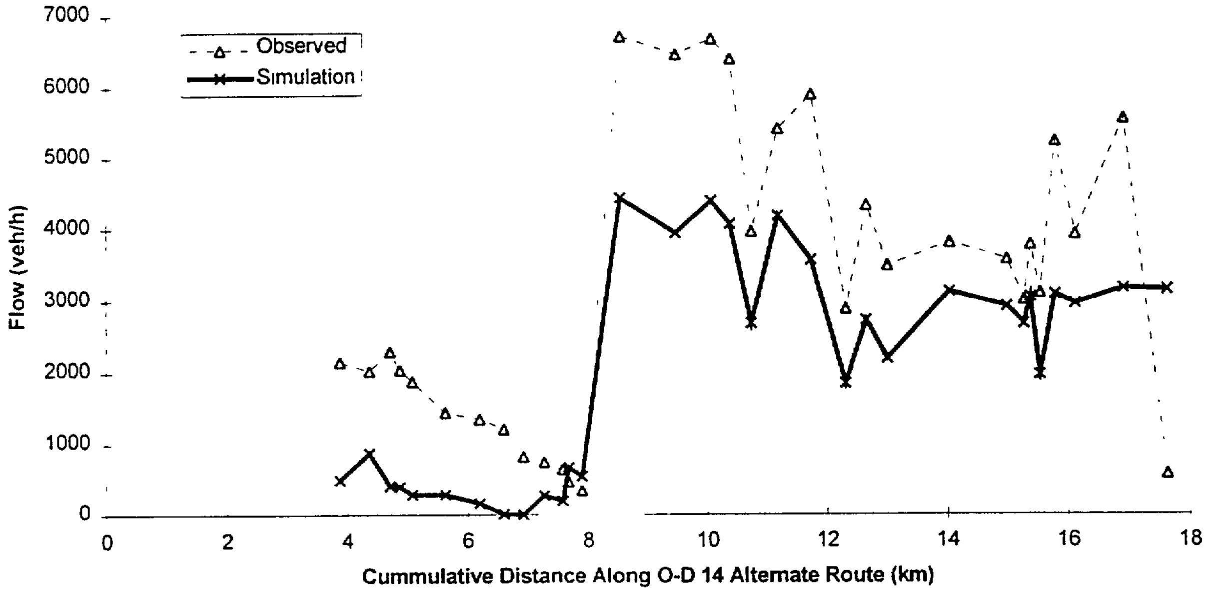


Figure 14. Spatial variation in observed and simulated link flows along the alternate route for O-D driving trial 14

3.3 CALIBRATION OF INTEGRATION TO O-D DRIVING TRIALS

The previous section described how the INTEGRATION simulation results were verified by comparing the simulated link flows to the TRANPLAN link flows that were provided by Mn/DOT. This initial comparison demonstrated that the INTEGRATION model captured the variation in link flows efficiently (coefficient of correlation of 92 percent). However, the INTEGRATION model tended to underestimate the link flows relative to those provided by the TRANPLAN model.

The next step in the verification process was to compare the simulation results for the base case to what was observed in the field during the field evaluation of the Genesis system. This field verification of the simulation results involved comparing the simulated and field travel times along the primary and alternate routes for the four O-D driving trials that occurred on the simulated network.

Initially, the trip lengths and trip composition, as identified on road maps, was compared to the simulated network as defined from the TRANPLAN input files. In addition, the similarity index for the different O-D driving trials was compared. These two comparisons verified that the node/link files that were generated for the modeling of Genesis were consistent with what was observed in the field.

A next step entailed the comparison of the travel times along the four O-D pairs in order to verify that traffic conditions in the field were consistent with the simulated traffic demands and conditions.

3.3.1 Trip Length and Composition

The difference between the field O-D driving trial trip lengths, that were computed from a road map, and the simulated lengths, computed from the simulation network, did not exceed 5 percent as demonstrated in Table 3. In addition, the O-D driving trial composition for the primary routes was very similar. It must be noted that the primary routes for O-D driving trials 13A and 14A are not presented separately in Table 3 because they were assumed to be identical to those of O-D's 13 and 14, respectively. It appears, that the composition of the alternate routes for O-D driving trials 13 and 14 are similar (within 10 percent). The same applies to O-D driving trial 14A, however, there appears to be a rather large discrepancy in the similarity index for O-D driving trial 13A (18 percent). It is not clear as to the reason behind this relatively large difference in the similarity index.

O-D	Route	Field (km)				Simulation (km)			
		UC	Arterial	Freeway	Total	L/C	Arterial	Freeway	Total
13	**Primary**	0.16	1.92	15.68	17.76	0.16	1.76	16.20	18.12
	Alternate	0.16	6.88	10.08	17.12	0.26	5.51	12.21	17.98
14	**Primary**	0.16	1.12	15.68	16.96	0.16	1.76	16.01	17.93
	Alternate	0.16	7.04	9.92	17.12	0.93	6.96	9.99	17.88
13A	**Alternate**	2.08	10.24	5.60	17.92	2.06	10.30	5.83	18.19
14A	**Alternate**	0.16	7.04	9.92	16.64	6.59	3.63	7.69	17.91

Table 3. O-D driving trial length and composition

O-D Driving Trial	Field	Simulation
13	57.7%	69.9%
14	59.8%	57.8%
13A	57.7%	40.3%
14A	59.8%	50.5%

Table 4. Similarity index of O-D driving trials

3.3.2 Trip Duration

The next step in verifying the simulation results was to compare the field and simulated travel times along the primary and alternate routes for the different O-D driving trials.

Figure illustrates a travel time of approximately 11 minutes along the primary route for the first 30 minutes for which the O-D demand was 50 percent the peak hour demand. The travel time increases for the next half hour (simulation time 30 to 60 minutes) as the full peak hour demand is introduced (100 percent peak hour demand). Finally, although the traffic demand is reduced to 50 percent the peak hour demand during the next half hour (simulation time 60 to 90 minutes), the travel time is much higher than experienced during the first half hour (23 versus 11 minutes) because of the oversaturation conditions that resulted during the full peak demand. It is interesting to note the following in Figure:

- The travel time along the alternate route for O-D driving trial 13 is always approximately 1 minute longer than the primary route which is consistent with the field study findings.
- The travel time along the alternate route for O-D driving trial 13A remains constant as traffic does not utilize this route. This route is not utilized because the routing of background traffic was set constant for the entire simulation period and thus would result in the routings for a 50 percent demand [(0.5+1.0+0.5+0.0)/4].

Figure illustrates the temporal variation in travel time along the primary and alternate routes forO-D driving trials 14 and 14A (Minneapolis to Bloomington). Figure demonstrates two findings. Firstly, it illustrates a peaking in travel time that replicates the O-D demand peaking. Secondly, Figure illustrates a higher travel time along the alternate routes relative to the primary route which demonstrates that the alternate routes that were selected during the field evaluation of Genesis do not represent the best routes for this O-D pair.

Figure compares the simulated travel time along the primary route of O-D 13 during the full peak demand (simulation time 30 to 60 minutes) to the field measurements that were computed from the O-D field test driving trials. Figure illustrates that the simulation travel times along the primary route of O-D 13 generally falls within the 95 percent confidence limits.

Figure and Figure demonstrate a lower correspondence, relative to Figure , between the simulated and field travel times along the alternate route for O-D 13, and primary route for O-D 14 driving trials, respectively.

Finally, Figure illustrates a high correspondence between the simulated and field travel times along the alternate route for O-D 14 driving trial.

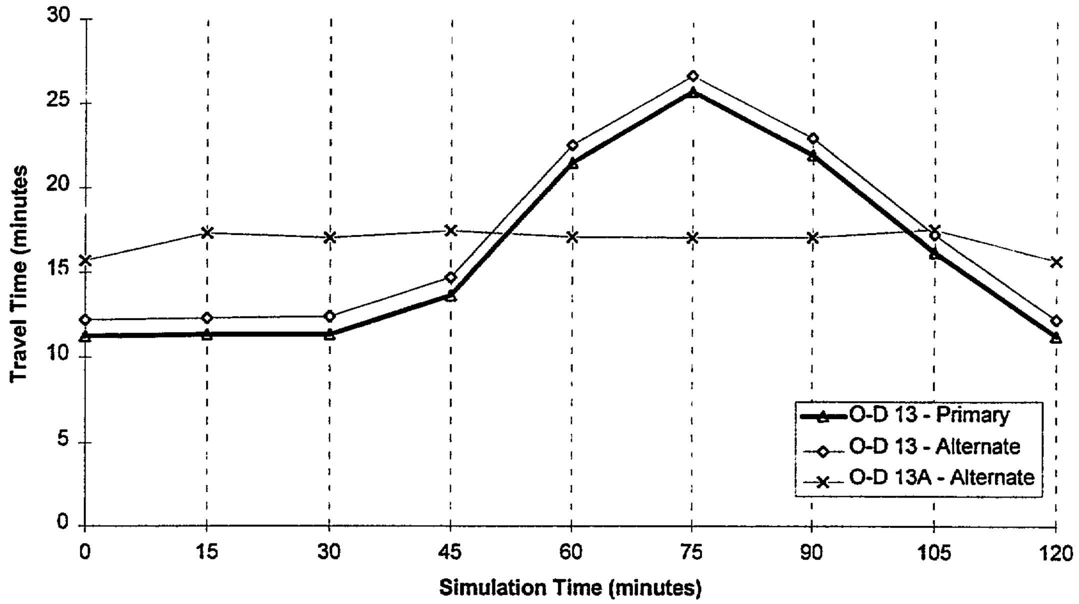


Figure15. Temporal variation in simulated travel time along primary and alternate routes for O-D driving trials 13 and 13A

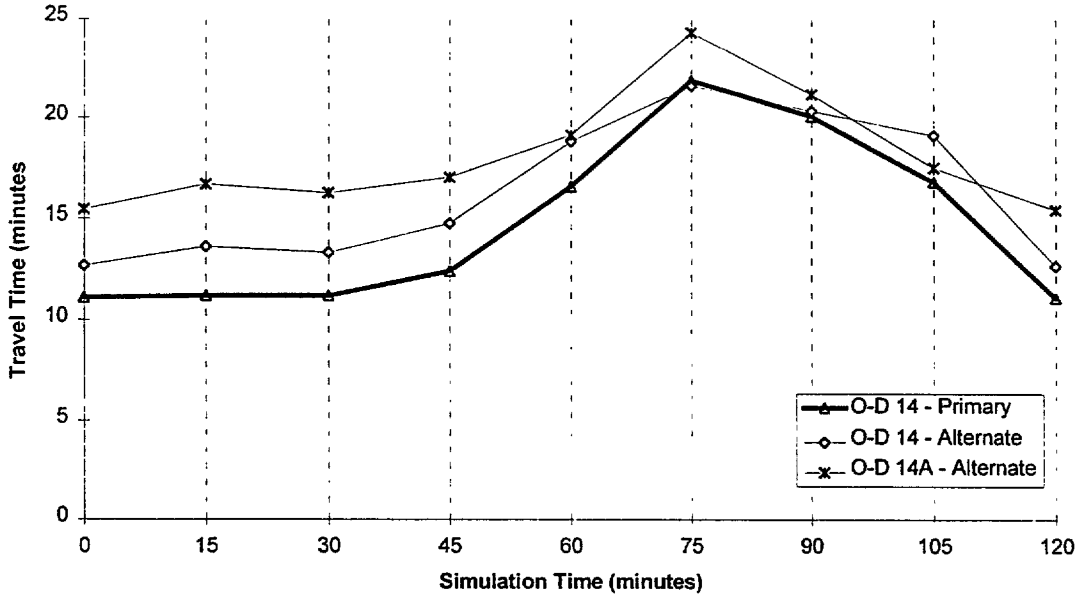


Figure 16. Temporal variation in simulated travel time along primary and alternate routes for O-D driving trials 14 and 14A

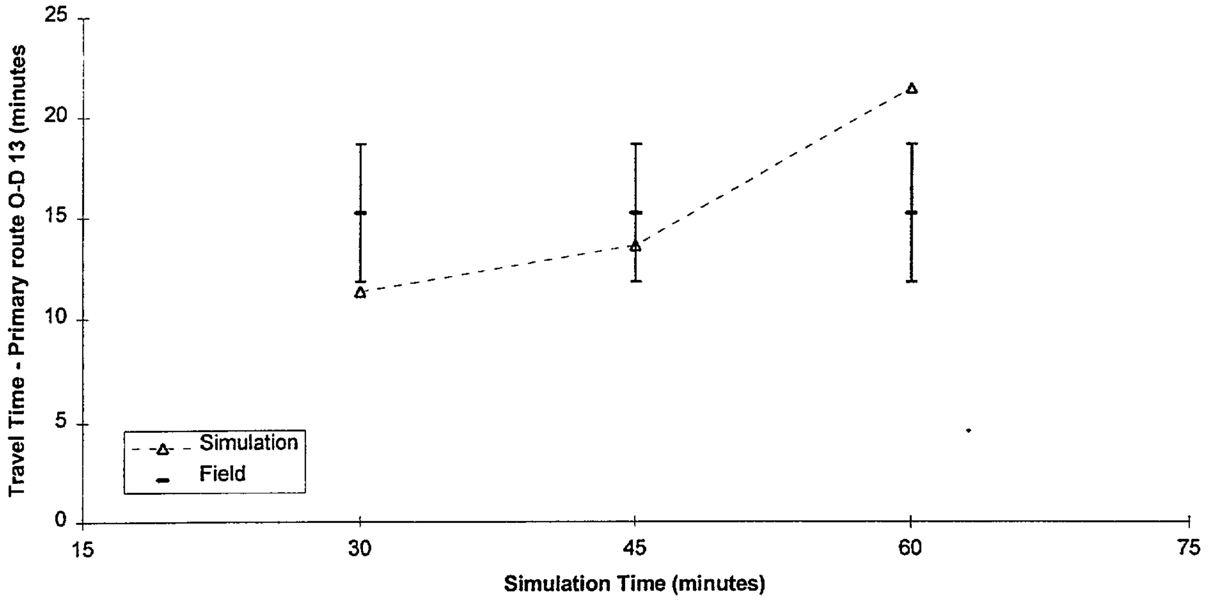


Figure 17. Comparison of simulated and field travel times along primary route for O-D driving trial 13

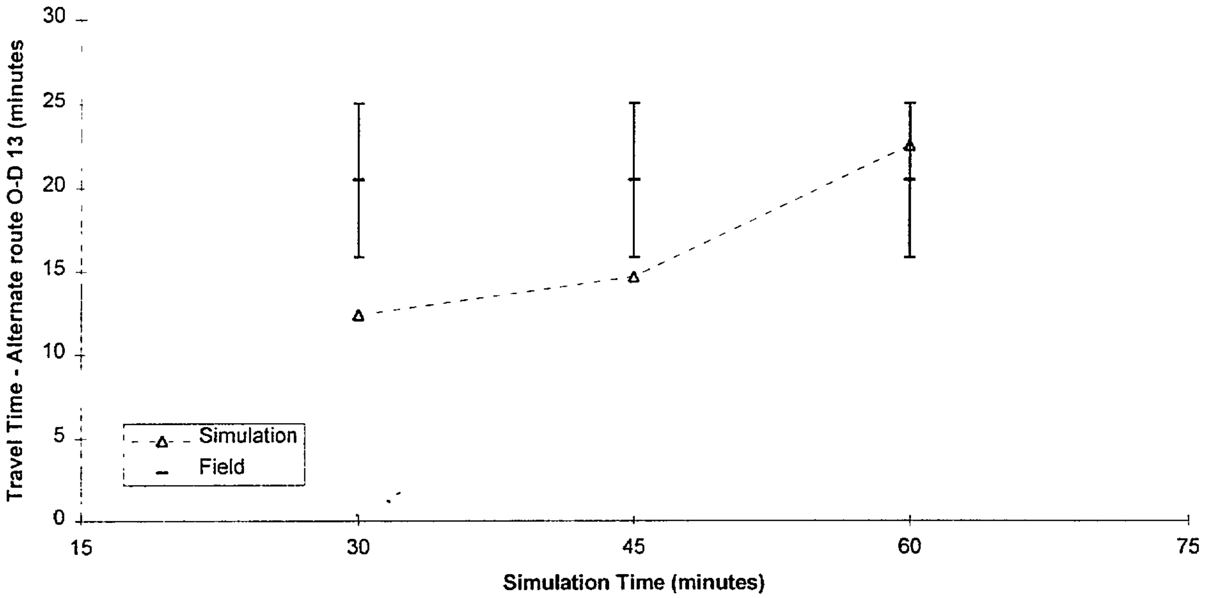


Figure 18. Comparison of simulated and field travel times along alternate route for O-D driving trial 13

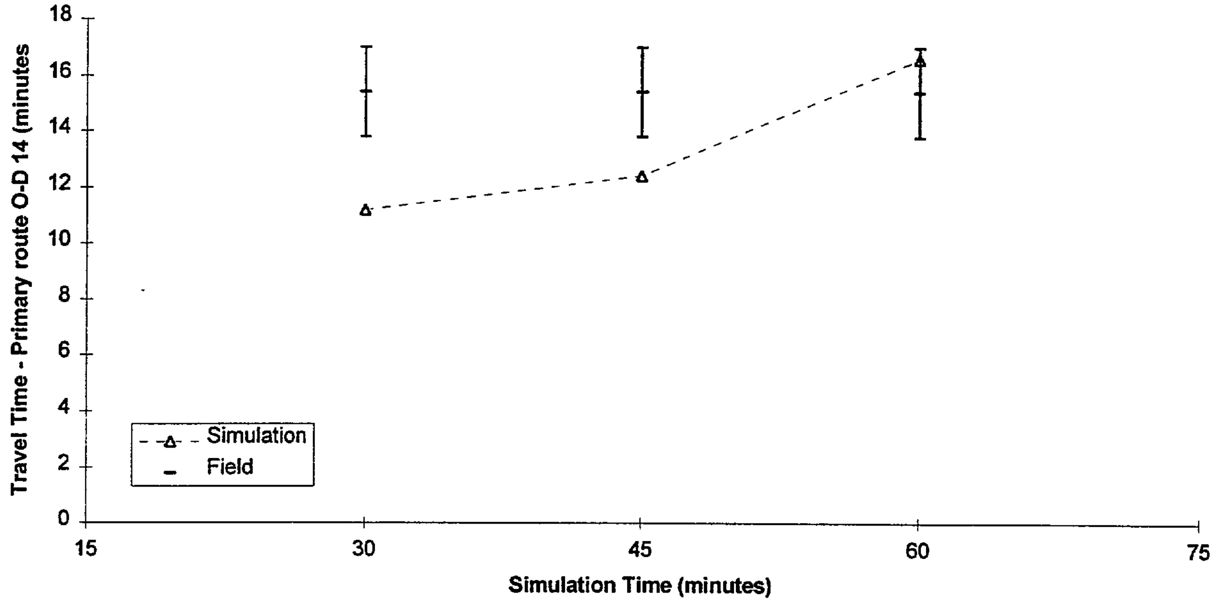


Figure 19. Comparison of simulated and field travel times along primary route for O-D driving trial 14

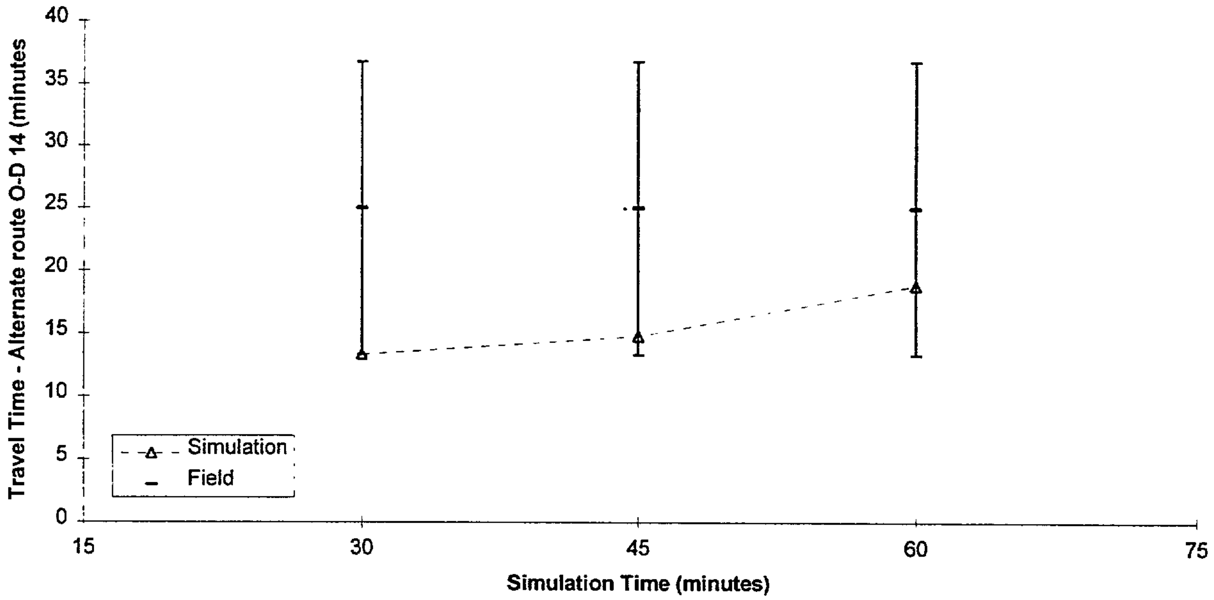


Figure 20. Comparison of simulated and field travel times along alternate route for O-D driving trial 14

3.4 INTEGRATION SUMMARY RESULTS FOR BASE CASE

The previous sections described the verification procedure that was utilized in order to ensure that the base case simulation reflected the existing network and traffic conditions on the I-35W network. This verification process demonstrated a high level of consistency between the simulated and input data (92 percent coefficient of correlation between link flows) in addition to a relatively high consistency with field travel time estimates (generally within the confidence limits). This section summarizes the base case results prior to modeling the impact of Genesis in the forthcoming section.

During a typical modeling run approximately 60,000 individual vehicles were traced, during the PM peak, through a total of 395,000 veh-km or 8,000 veh-h. For the base case, background traffic was routed using the rate-based deterministic macroscopic user traffic assignment technique within the INTEGRATION model.

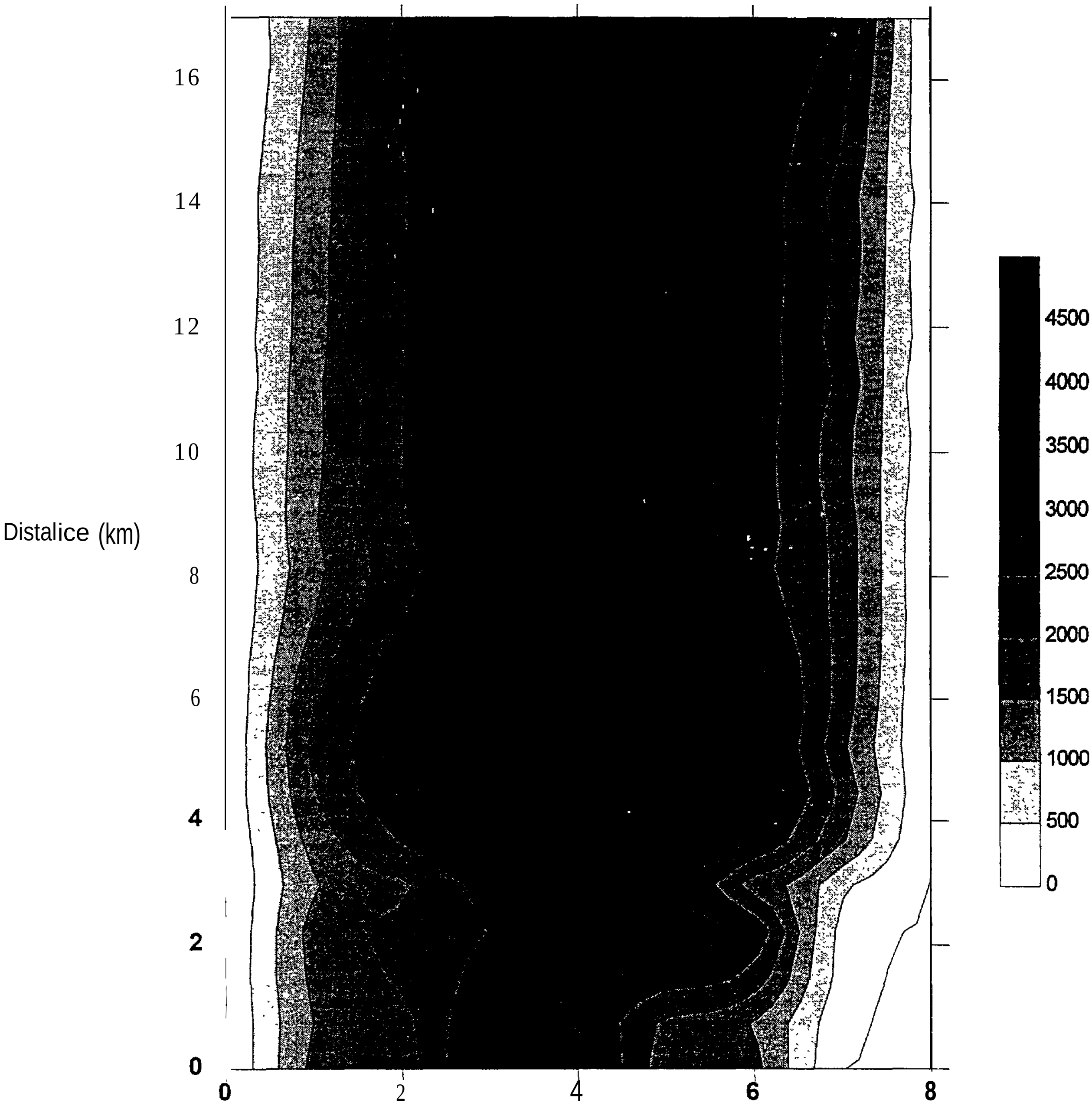
The base case resulted in an average trip duration of approximately 8 minutes, an average trip length of 6.6 kilometers and on average 2.75 stops/trip as demonstrated in Table 5. Vehicles consumed on average 1 litre of gasoline and emitted 10.9, 66.6 and 8.8 grams of HC, CO and NO, emissions, respectively. These vehicles on average experienced an accident risk of 2.2 accidents per million trips.

Figure 1 illustrates the temporal and spatial variation in flow along the northbound direction of I-35W from Bloomington to downtown Minneapolis. This figure demonstrates a temporal peaking of traffic flow at all locations after 45 minutes of simulation. Spatially, one can observe a drop in flow rate 3 kilometers along the network. This drop in flow could have resulted from a queue spillback from a downstream bottleneck or a reduction of demand.

Figure illustrates a similar temporal and spatial variation in flow along the southbound direction of I-35 W from downtown Minneapolis to Bloomington.

Description		**Value**
Average Trip Duration	(minutes)	8:05
Average Trip Length	(km)	6.61
Average Number of Stops		2.75
Average Fuel Consumption	(litres)	1.02
Average HC Emissions	(grams)	10.93
Average CO Emissions	(grams)	66.56
Average NO, Emissions	(grams)	8.78
Average Accident Risk		2.23

Table 5. Summary simulation results for base case



Simulation Time (15 minutes)

Figure 21. Temporal and spatial variation of flow along northbound direction of I-35W

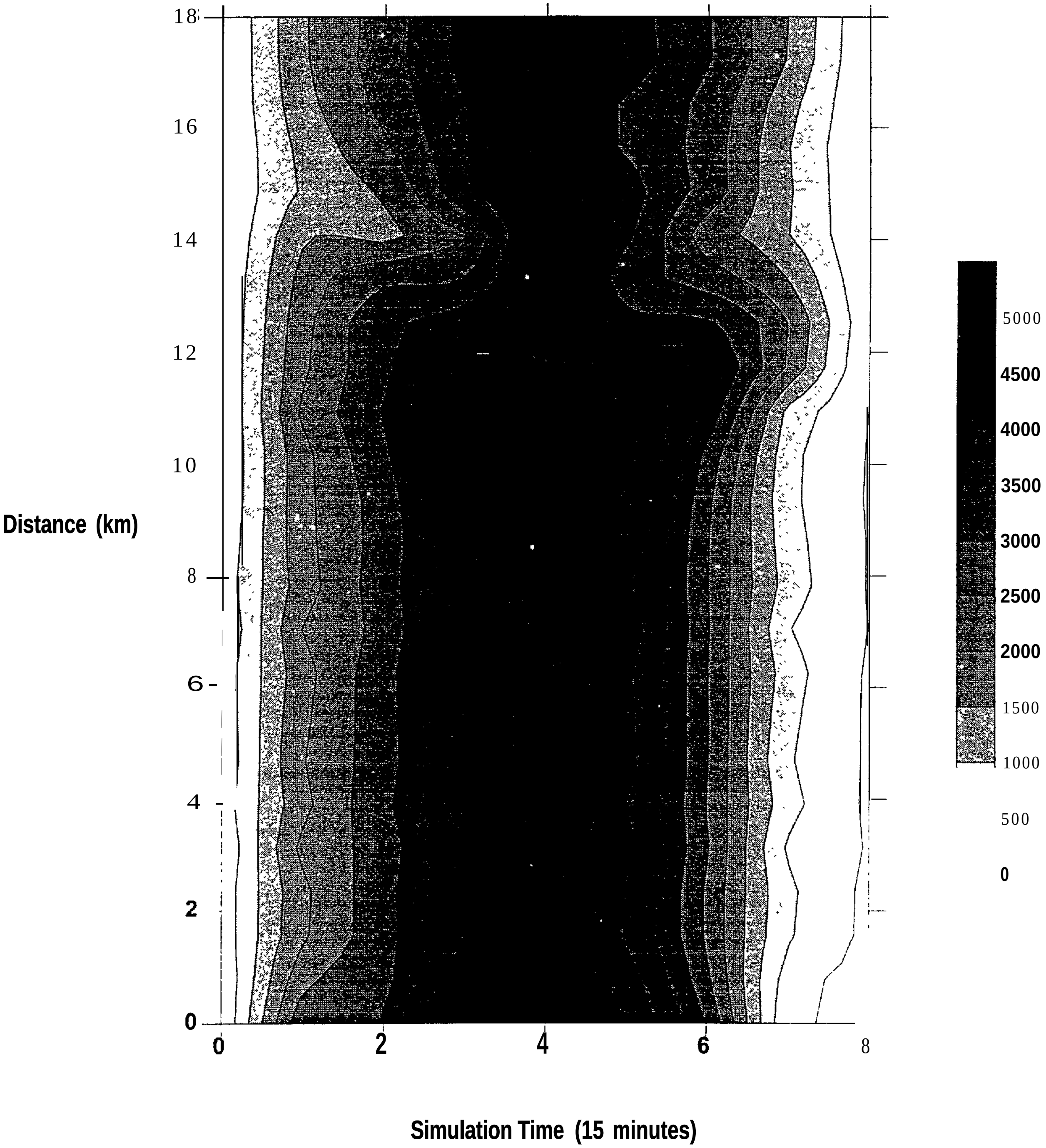


Figure 22. Temporal and spatial variation of flow along northbound direction of I-35W

4. EVALUATION OF IMPACT OF PERSONAL COMMUNICATION DEVICES ON TRAFFIC PERFORMANCE

In the previous section the derivation of the INTEGRATION input files was described in detail. In addition, the previous section described the calibration process that was conducted in order to ensure that the traffic conditions that were simulated prior to the introduction of the Genesis system replicated, within a small margin of error, the typical traffic conditions on the I-35W network.

This section describes the potential benefits of providing drivers with real-time information using Personal Communication Devices (PCD's). The experimental design of the modeling study is first presented followed by the results of the simulation for a number of Measures of Effectiveness (MOE's). The logic utilized within the INTEGRATION model to compute these MOE's was described earlier in this report and thus is not described in this section.

4.1 EXPERIMENTAL DESIGN OF GENESIS MODELING

Field experiments and surveys collected data and information on the performance of the Genesis test drivers. These data indicated how the system performed for the configuration that was tested and for the conditions that were encountered in Metropolitan Minneapolis/St. Paul by the vehicles during the time frame of the operational field test. It was not always possible to systematically collect all types of potential data on all test driver trips. It was also not possible to observe the system's performance for conditions that were not encountered in the field. Examples of the former data gaps are the fuel consumption, emissions and risk exposure of all of the test vehicles, whereas examples of the latter are the potential performance of the Genesis system for higher levels of market penetration.

The desire to examine these unobservable factors resulted in the inclusion of a modeling activity as part of the Genesis evaluation. This modeling activity was intended to permit an objective and systematic extension of the findings from the operational field test to generate performance estimates for a range of other conditions and configurations that would be of interest to those contemplating the deployment of similar systems on a wider scale.

The objectives of the simulation study were three-fold:

1. To assess the impact of PCD's on the network level of congestion (e.g. travel time).
2. To project the environmental impacts of PCD's.
3. To assess the safety impact of PCD's.

The modeling exercise assessed the impact of three variables, namely; the level of market penetration of PCD users, the demand level during the PM peak, and incident severity as demonstrated in Table . The 5 LMP's that were considered ranged from 1 to 99 percent in order to study the impact of higher levels of market penetration on the overall traffic performance. The 3 demand levels that were considered ranged from 80 to 100 percent in order to study the sensitivity of results to the level of congestion during peak traffic conditions. Finally, the four incident severities that were considered ranged from no incident to a 2-lane blockage on a 3-lane freeway section along the I-35W in order to analyze the impact of incident severities on the potential benefits of PCD’s. In total 60 runs were conducted (5x3x4) in order to systematically quantify the impacts of each of these parameters on the potential benefits of PCD’s.

Hypothesis:	PCD's reduce travel time, fuel consumption, vehicle emissions and accident risk of entire network with the benefits increasing with the increase in LMP							
Significance:	PCD’s are a viable means for reducing congestion, fuel consumption, emissions and accident risk							
CASE:	**Code**	**Total Levels**	**Unit**	**Level of Magnitude**				
				1	***2***	***3***	***4***	***5***
LMP	a	5	%	1	10	20	50	99
Demand Level	b	3	%	80	90	100		
Incident Severity	c	4	# lanes	0	0.5	1.0	2.0	
Total Combinations	60 runs							
Default Conditions:	load for first 30 minute interval at 50% demand, for second 30 minute interval at 100% demand, for third 30 minute interval at 50% demand; simulate for 120 minutes, incident starts after 30 minutes, incident lasts for 20 minutes, background traffic routed using deterministic macroscopic rate-based traffic assignment, PCD’s routed using deterministic microscopic feedback traffic assignment with an update frequency of 15 minutes.							
Network Configuration:	I-35W network from 90th street in the south to downtown Minneapolis							
Measure of Performance	Average travel time, average trip length, number of vehicle stops, average fuel consumption. average emissions of HC, CO and NOx, and accident risk							
Execution Time per run	3 hours							

Table 6. Experimental design of Genesis modeling study

4.2 ASSUMPTIONS AND CAVEATS OF THE MODELING STUDY

Because a simulation study is an attempt to replicate reality, the results of simulation must be interpreted within the margin of error, the assumptions of the study and the study caveats. This section lists some of the assumptions and caveats of the modeling study so that the results, that are presented in the next section, can be interpreted within context.

1. Background traffic was modeled using a static deterministic macroscopic rate-based traffic assignment.
2. PCD-equipped vehicle departure times were inelastic to the traffic demands on the network.
3. PCD-equipped vehicles were provided real-time information every 15 minutes. These vehicles were routed using a deterministic microscopic feedback traffic assignment procedure.
4. The study assumed that both the background traffic and vehicles equipped with PCD’s could estimate the travel times along routes perfectly (i.e. link travel time error was zero).
5. The study also assumed that the only source for providing drivers with real-time information was the Genesis system.

4.3 IMPACT OF PERSONAL COMMUNICATION DEVICES ON TRAVEL TIME

This section assesses the impact of LMP of PCD equipped vehicles and the peak demand level on the average trip duration of the entire system, on the average trip duration of PCD equipped vehicles and the trip duration of background traffic (non-PCD equipped vehicles). This analysis is conducted for recurring and non-recurring traffic conditions.

4.3.1 Impact of PCD's During Recurring Congestion

As illustrated in Figure the average trip duration for the entire system decreased as the LMP of PCD equipped vehicles increased. This rate of decrease, in average trip duration, decreased as the LMP increased (reduction of average trip time of 15 percent at an LMP of 50 and 100 percent).

Figure demonstrates that if, by providing drivers with real-time information, drivers elect to change their time of departure and thus reduce the traffic demand during the peak period, considerable benefits can be attained. For example, if the peak demand is reduced by 10 percent as a result of departure time shifts, the average trip duration is decreased by approximately 20 percent (100% line versus 90% line). However, the benefits of traffic re-routing decrease as the level of congestion decreases as illustrated by the steeper slope of the 100 percent demand level line versus the 80 percent demand level line in Figure .

Figure 4 illustrates that the average trip duration for the background traffic (non-PCD equipped) was reduced as the LMP of PCD-equipped vehicles increased. The decrease in average trip duration of background traffic resulted because PCD-equipped vehicles diverted from the I-35W freeway, thus reducing the level of congestion experienced by the background traffic. It is interesting to note a small increase in the average travel time of background vehicles at an LMP of 99 percent versus 50 percent (2 percent increase). For lower levels of congestion, the impact of PCD vehicle re-routing was minimal as demonstrated from the 80 percent demand level in Figure 4.

Figure illustrates how the average travel time for the PCD-equipped vehicles varied as a function of the LMP. It is evident from Figure that the average travel time remained approximately constant for the different LMP's. Comparing Figure to Figure demonstrates that PCD-equipped vehicles selected routes that were 15 percent faster than the routes utilized by the background traffic even when no incident occurred.

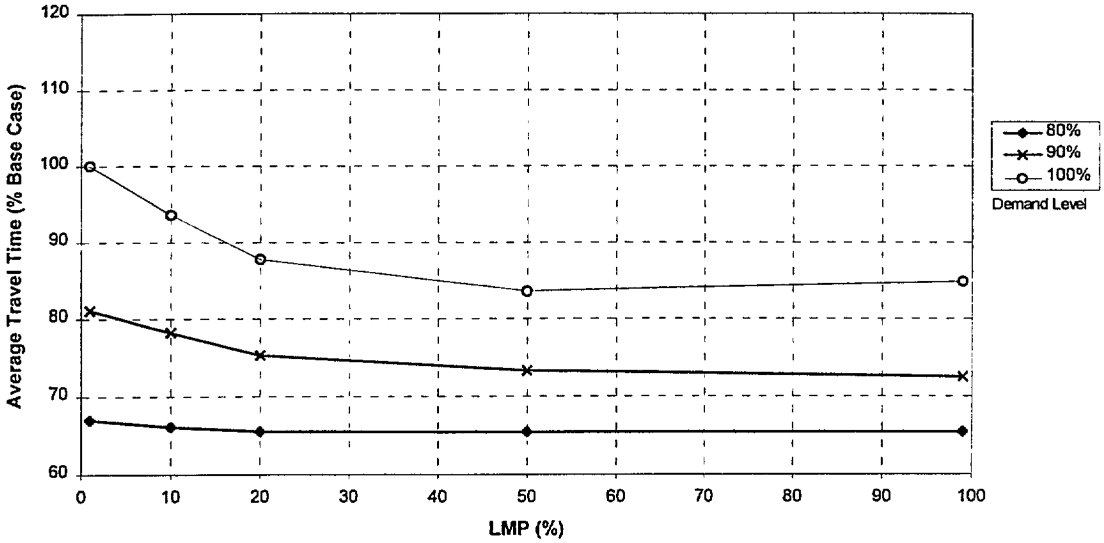


Figure 23. Variation in average trip time of entire vehicle population as a function of LMP and demand level (No incident)

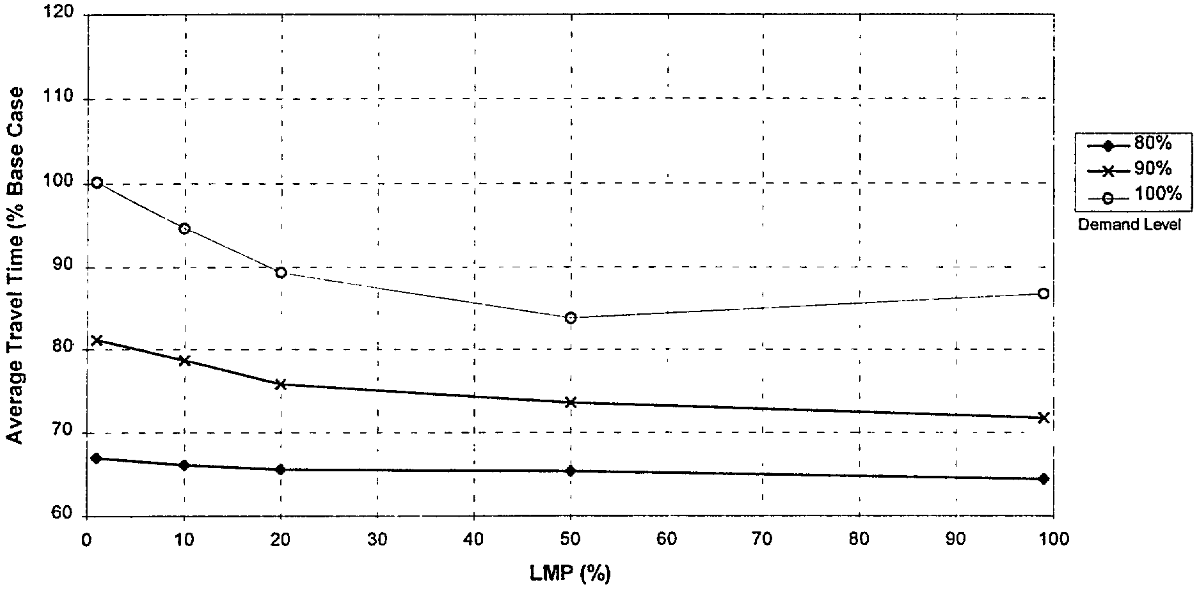


Figure 24. Variation in average trip time of background traffic as a function of LMP and demand level (No incident)

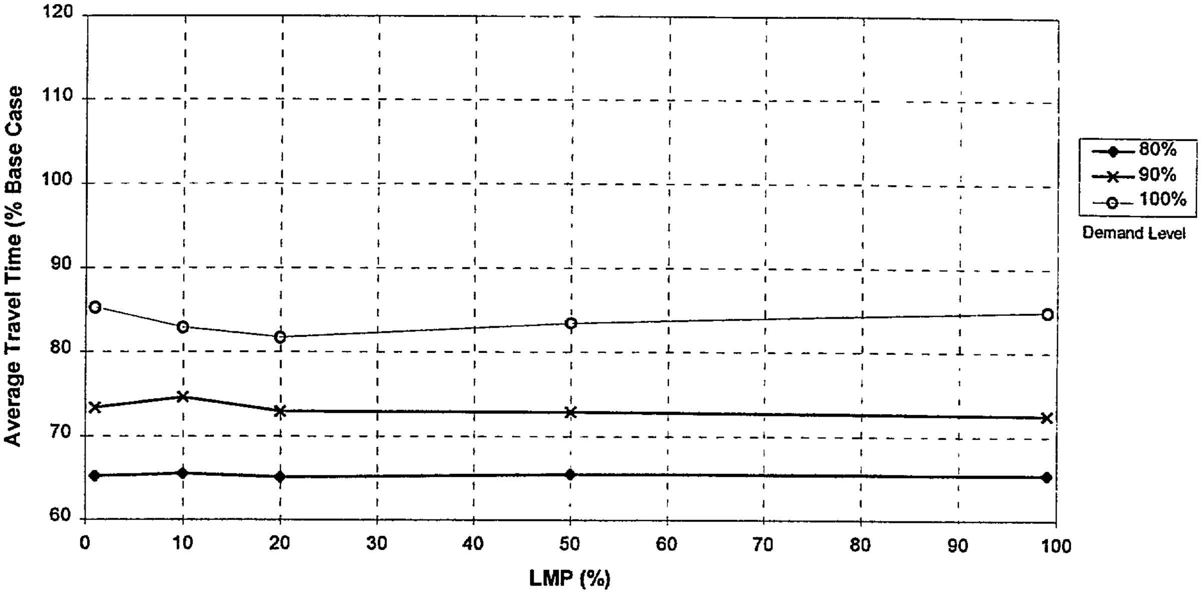


Figure 25. Variation in average trip time of PCD equipped vehicles as a function of LMP and demand level (No incident)

4.3.2 Impact of PCD's During Non-Recurring Congestion

An introduction of a 0.5-lane blockage (equivalent to a stalled vehicle on the shoulder lane) on the I-35W freeway did not result in any major change in the overall results as demonstrated by comparing Figure to Figure . A 1-lane blockage also did not result in any major increase in the average travel time as illustrated in Figure .

A 2-lane blockage incident resulted in a 10 percent increase in the average travel time as illustrated in Figure (100% demand level). The introduction of a 10 percent LMP reduced the average travel time to the non-incident travel time. At 50 percent LMP the average travel time was equivalent to the average travel time at a 50 percent LMP for the non-incident condition.

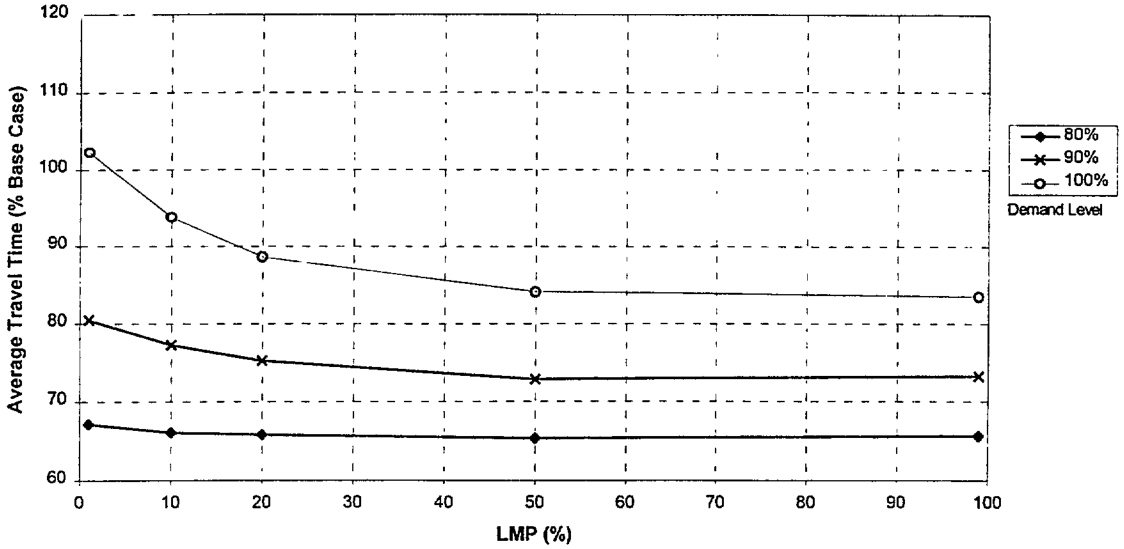


Figure 26. Variation in average trip time of entire vehicle population as a function of LMP and demand level (0.5-lane blockage)

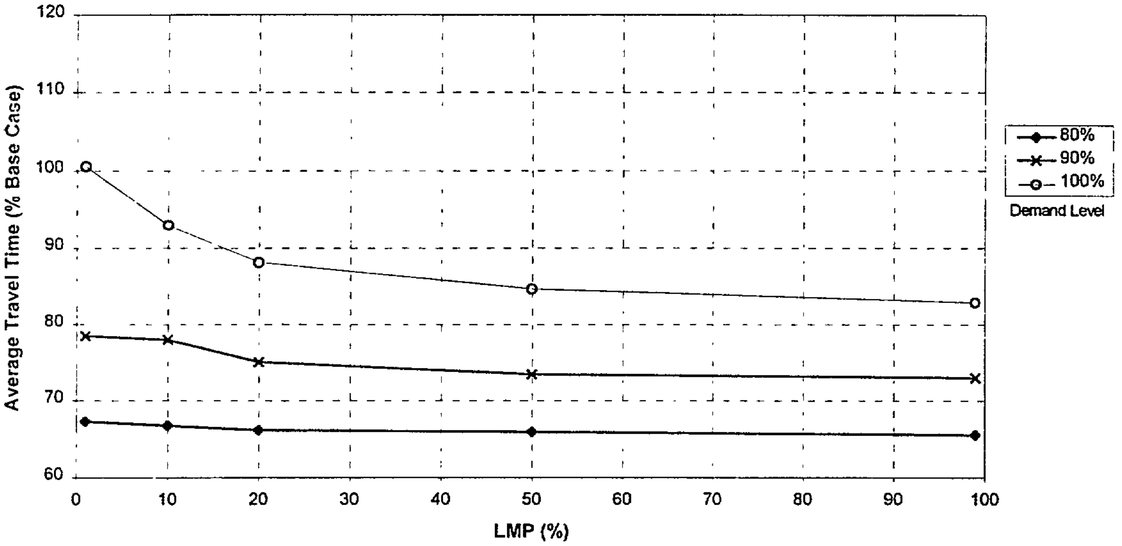


Figure 27. Variation in average trip time of entire vehicle population as a function of LMP and demand level (1-lane blockage)

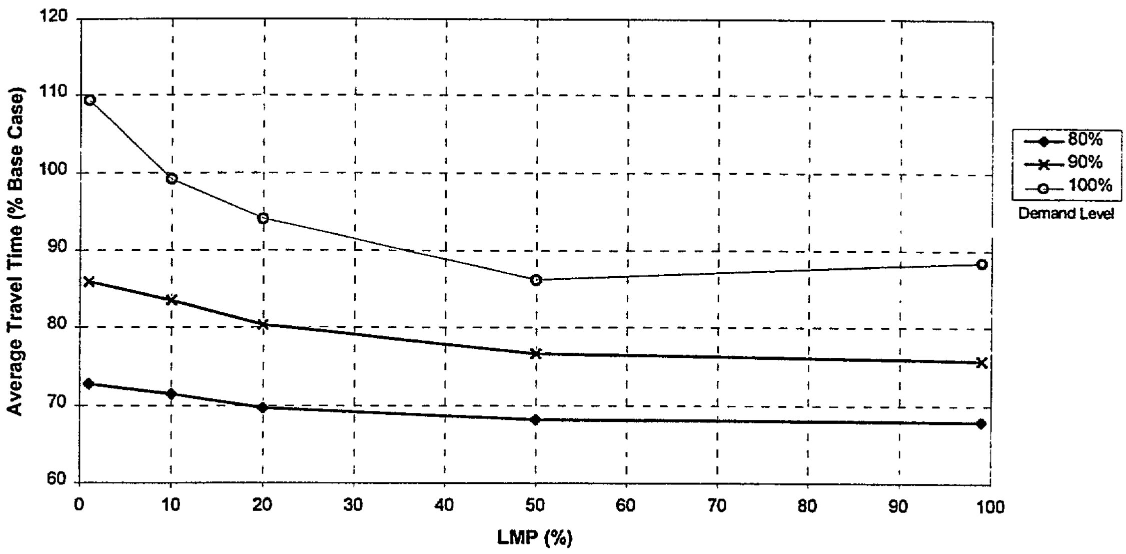


Figure 28. Variation in average trip time of entire vehicle population as a function of LMP and demand level (2-lane blockage)

4.4 IMPACT OF PERSONAL COMMUNICATION DEVICES ON TRAVEL DISTANCE

The average trip length was found to decrease very slightly as the LMP of PCD-equipped vehicles increased as illustrated in Figure . The maximum reduction in the average trip length was approximately 0.3 percent for a LMP of 99 percent. Consequently, it appears that the real-time information that was provided to the drivers enabled them to select routes that were of equal distance but faster.

A further analysis of the variation in average trip length for the different driver classes (background versus PCD-equipped) revealed that the average trip length increased for the background and PCD-equipped vehicles as the LMP increased as illustrated in Figure and Figure , respectively. However, because the average trip length for the PCD-equipped vehicles was lower than that for the background vehicles the average trip length for the entire population decreased slightly as the LMP increased.

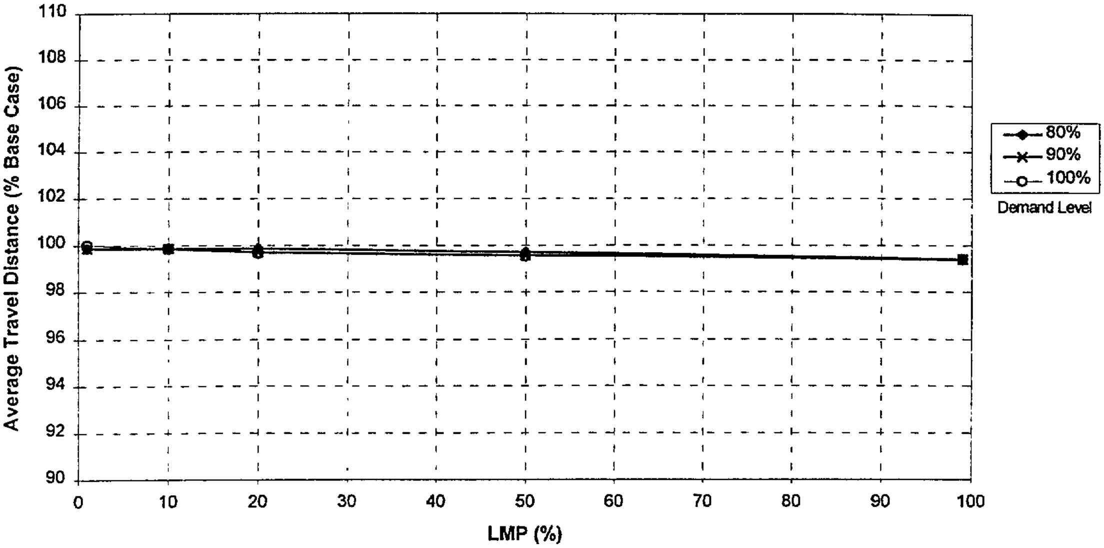


Figure 29. Variation in average trip length of entire vehicle population as a function of LMP and demand level (No incident)

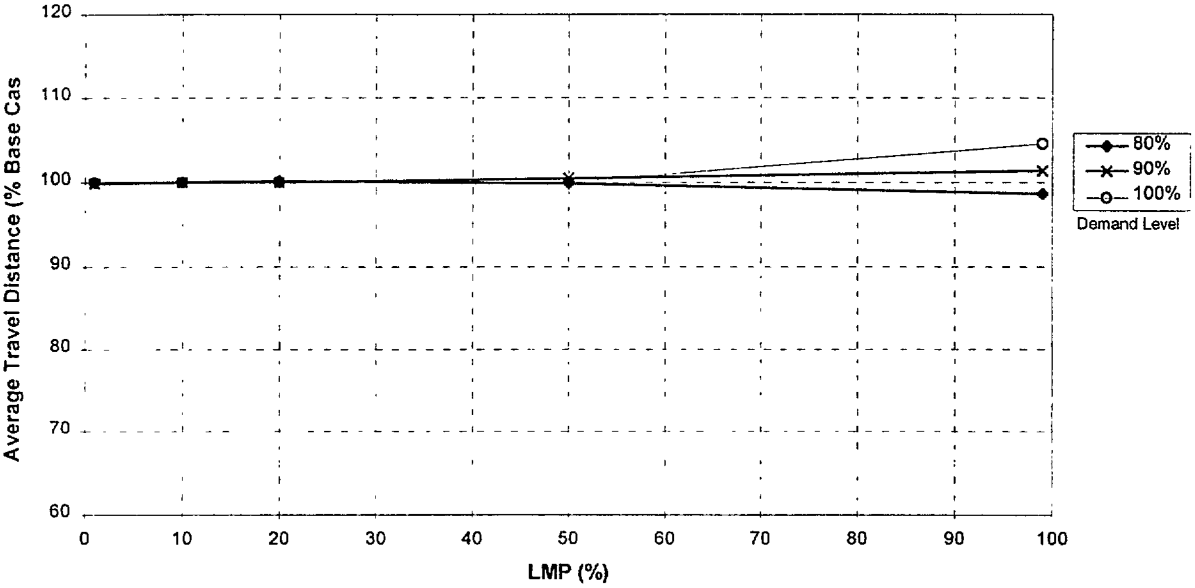


Figure 30. Variation in average trip length of background traffic as a function of LMP and demand level (No incident)

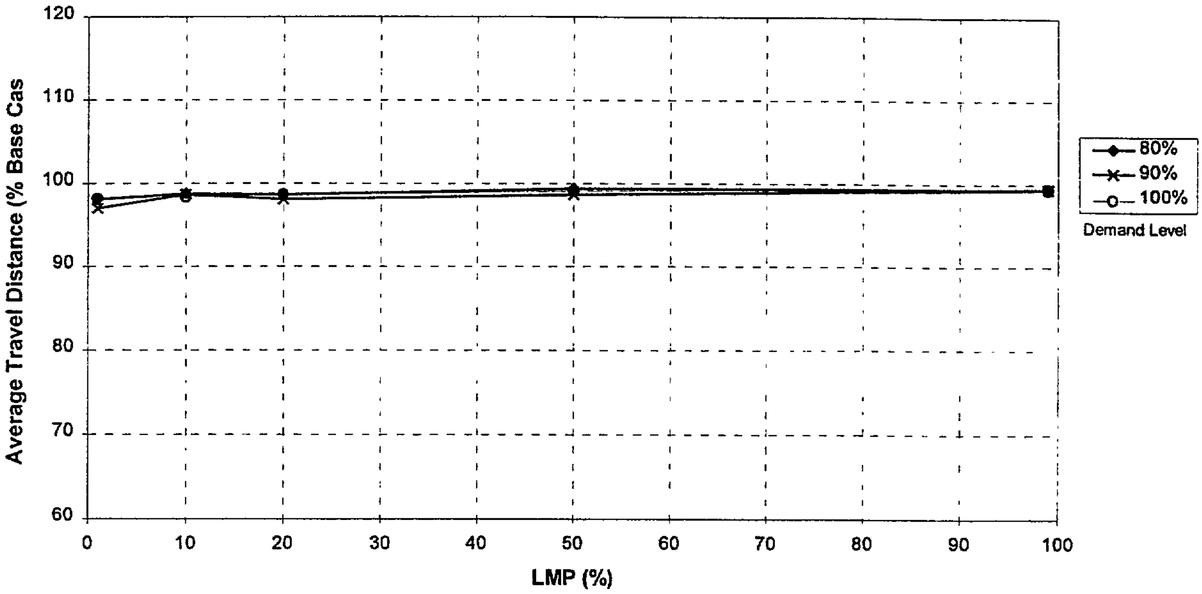


Figure 31. Variation in average trip length of PCD equipped vehicles as a function of LMP and demand level (No incident)

4.5 IMPACT OF PERSONAL COMMUNICATION DEVICES ON VEHICLE STOPS

The simulation results demonstrated an initial decrease in the number of vehicle stops as the LMP increased followed by an increase in the number of vehicle stops as illustrated in Figure . The maximum reduction in the number of vehicle stops was 5 percent at an LMP of 50 percent. The impact of LMP on the average number of vehicle stops was less as the level of congestion decreased (100% versus 80%).

The same trend of variation in vehicle stops as a function of LMP was found for the background traffic as illustrated in Figure . The average number of vehicle stops for the PCD-equipped vehicles was found to remain constant up to an LMP of 50 percent and then increase as the LMP increased from 50 to 99 percent as illustrated in Figure .

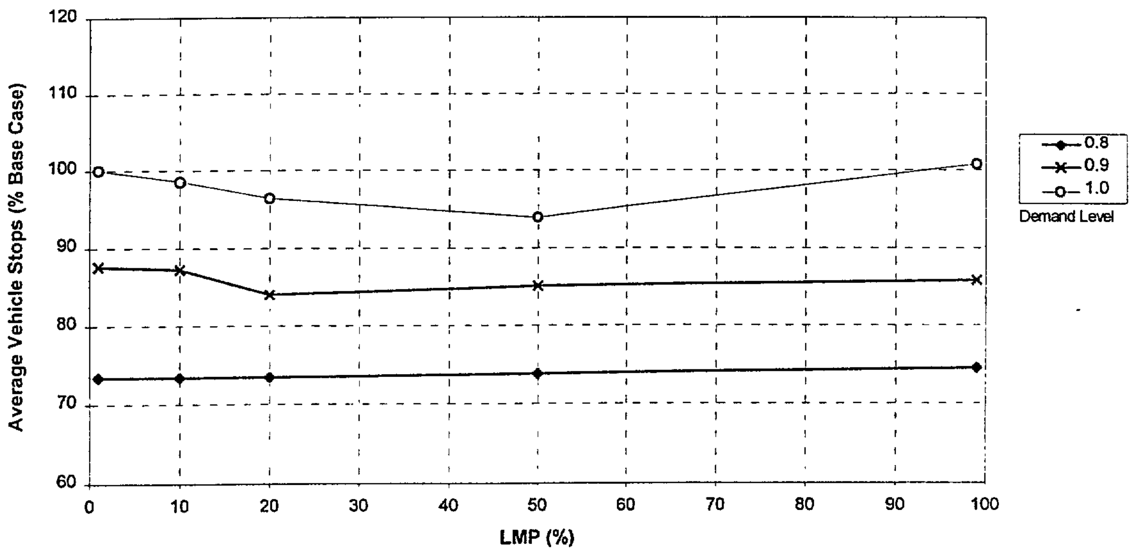


Figure 32. Variation in average number of vehicle stops of entire vehicle population as a function of LMP and demand level (No incident)

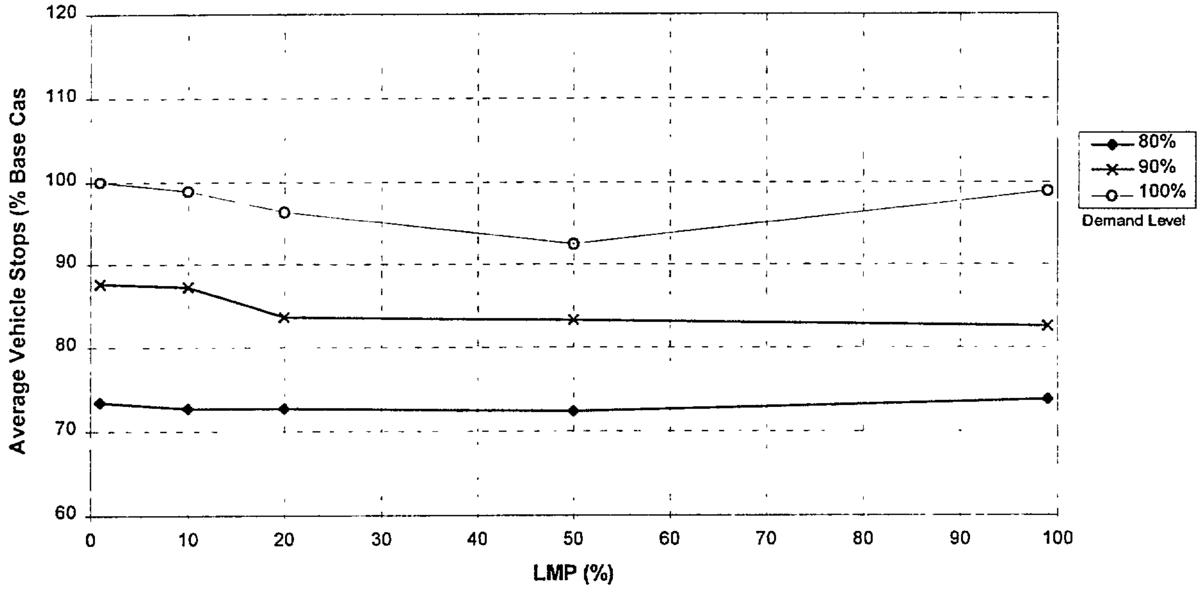


Figure 33. Variation in average number of vehicle stops of background traffic as a function of LMP and demand level (No incident)

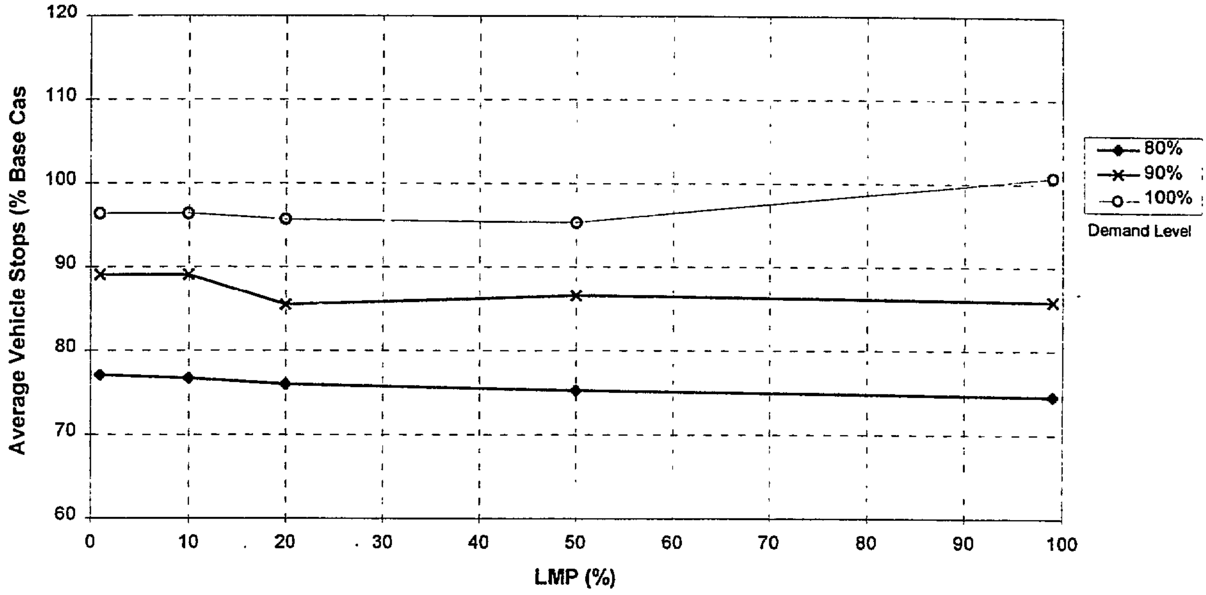


Figure 34. Variation in average number of PCD equipped vehicles as a function of LMP and demand level (No incident)

4.6 IMPACT OF PERSONAL COMMUNICATION DEVICES ON FUEL CONSUMPTION

The average fuel consumption was found to decrease as the LMP of PCD-equipped vehicles increased as illustrated in Figure . The rate at which the fuel consumption was reduced decreased as the LMP increased. The maximum reduction in fuel consumption was found to be in the range of approximately 5 percent. Furthermore, the benefits of traffic re-routing were found to decrease as the level of congestion in the network decreased (comparing the slope of the 100% and 80% demand lines).

The background (non-PCD equipped vehicles) experienced an initial reduction in fuel consumption as the LMP of PCD-equipped vehicles increased as illustrated in Figure . This initial reduction in the average fuel consumption of the background traffic was a result of the diversion of the PCD-equipped vehicles to less congested routes and thus reducing the level of congestion experienced by the background traffic. However, at an LMP of 99 percent the fuel consumption of the background traffic increased to its original value (prior to introduction of PCD-equipped vehicles). It is not clear as to why the average fuel consumption of the background traffic increased at an LMP of 99 percent.

The average fuel consumption of the PCD-equipped vehicles was not impacted by the LMP of these vehicles as illustrated in Figure . Noteworthy, is the fact that the average fuel consumption for the PCD-equipped vehicles was approximately 8 percent lower than the background traffic because the PCD-equipped vehicles were provided with real-time information and thus were able to select less congested routes.

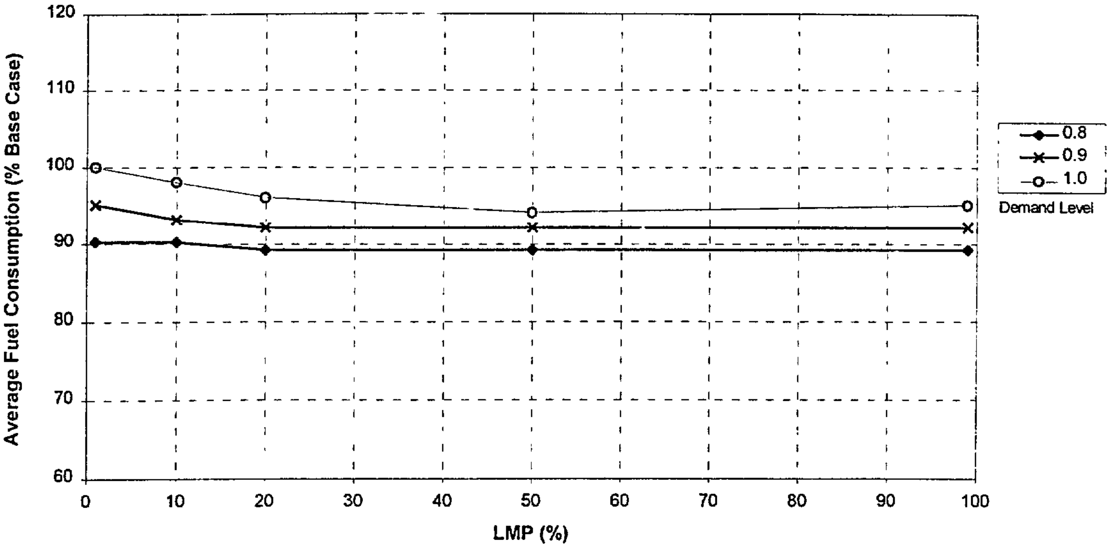


Figure 35. Variation in average fuel consumption of entire vehicle population as a function of LMP and demand level (No incident)

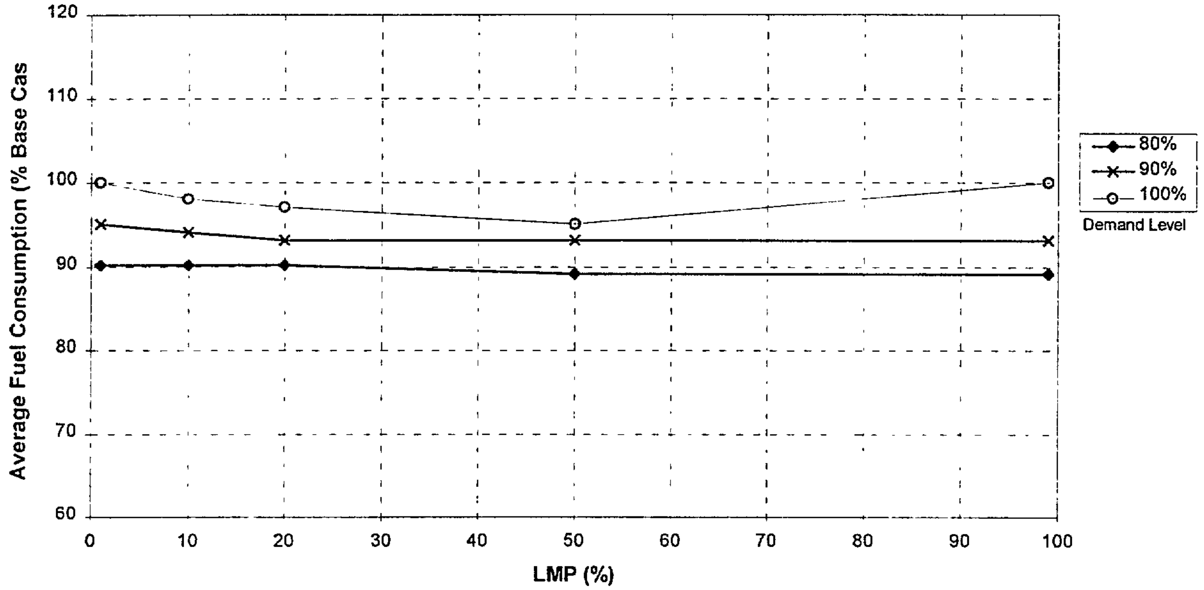


Figure 36. Variation in average fuel consumption of background traffic as a function of LMP and demand level (No incident)

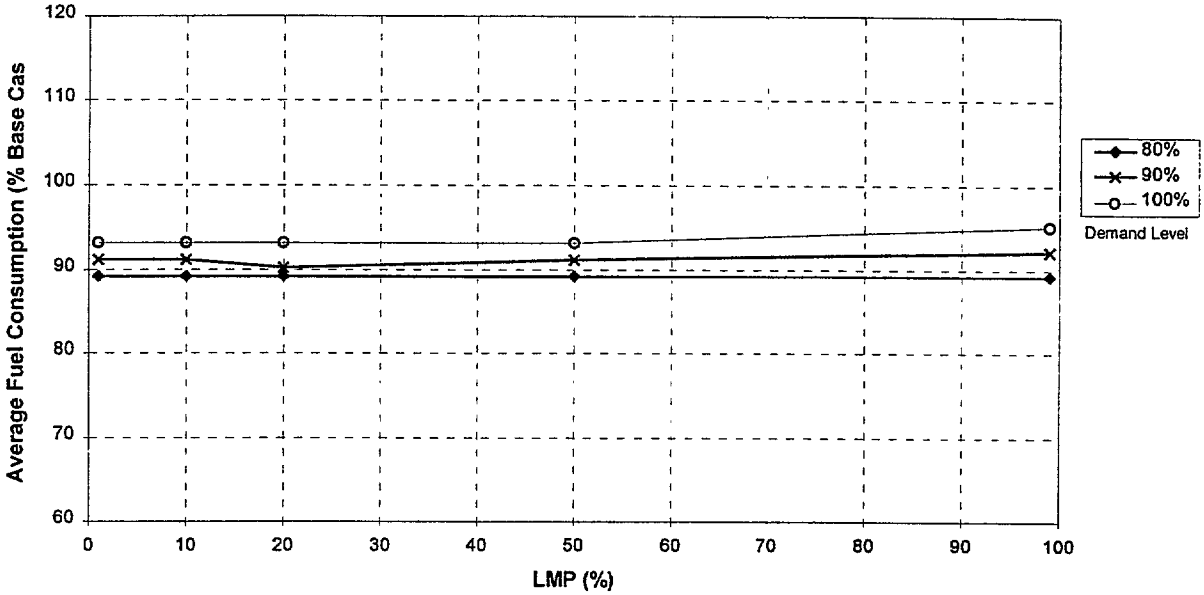


Figure 37. Variation in average fuel consumption of PCD equipped vehicles as a function of LMP and demand level (No incident)

4.7 IMPACT OF PERSONAL COMMUNICATION DEVICES ON HC EMISSIONS

The average HC emissions were found to decrease as the LMP of PCD-equipped vehicles increased as illustrated in Figure . The rate at which the HC emissions were reduced decreased as the LMP increased. The maximum reduction in HC emissions was found to be in the range of 7 percent. Furthermore, the benefits of traffic re-routing were found to decrease as the level of congestion in the network decreased (comparing the slope of the 100% and 80% demand lines).

The background (non-PCD equipped vehicles) experienced an initial reduction in HC emissions as the LMP of PCD-equipped vehicles increased as illustrated in Figure . This initial reduction in the average HC emissions of the background traffic was a result of the diversion of the PCD-equipped vehicles to less congested routes and thus reducing the level of congestion experienced by the background traffic. However, at an LMP of 99 percent the HC emissions of the background traffic increased slightly (3 percent).

The average HC emissions of the PCD-equipped vehicles was not impacted by the LMP of these vehicles as illustrated in Figure . Noteworthy, is the fact that the average HC emissions for the PCD-equipped vehicles was approximately 6 percent lower than the background traffic because the PCD-equipped vehicles were provided with real-time information and thus were able to select less congested routes.

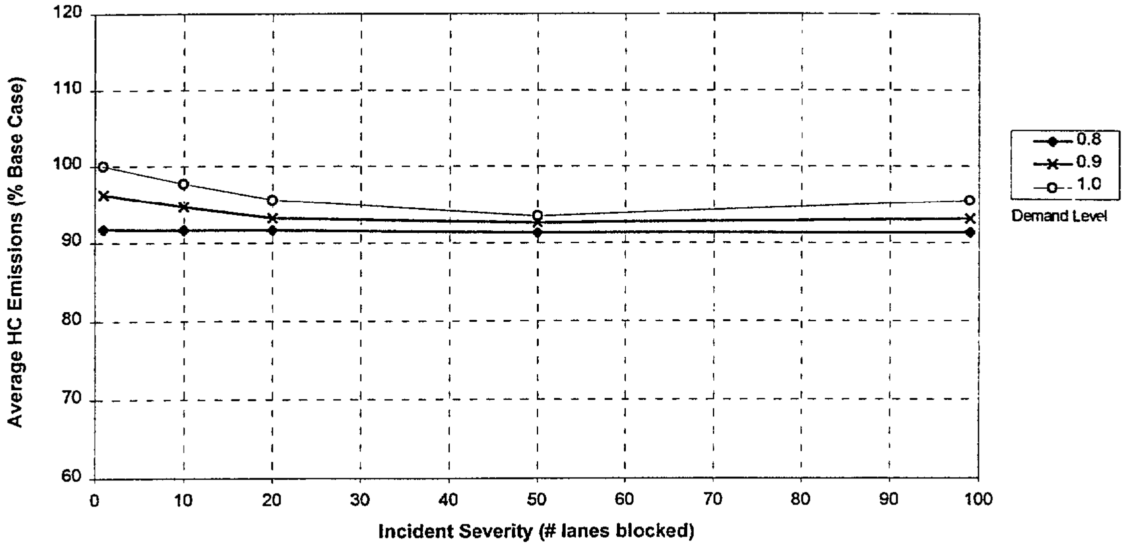


Figure 38. Variation in average HC emissions of entire vehicle population as a function of LMP and demand level (No incident)

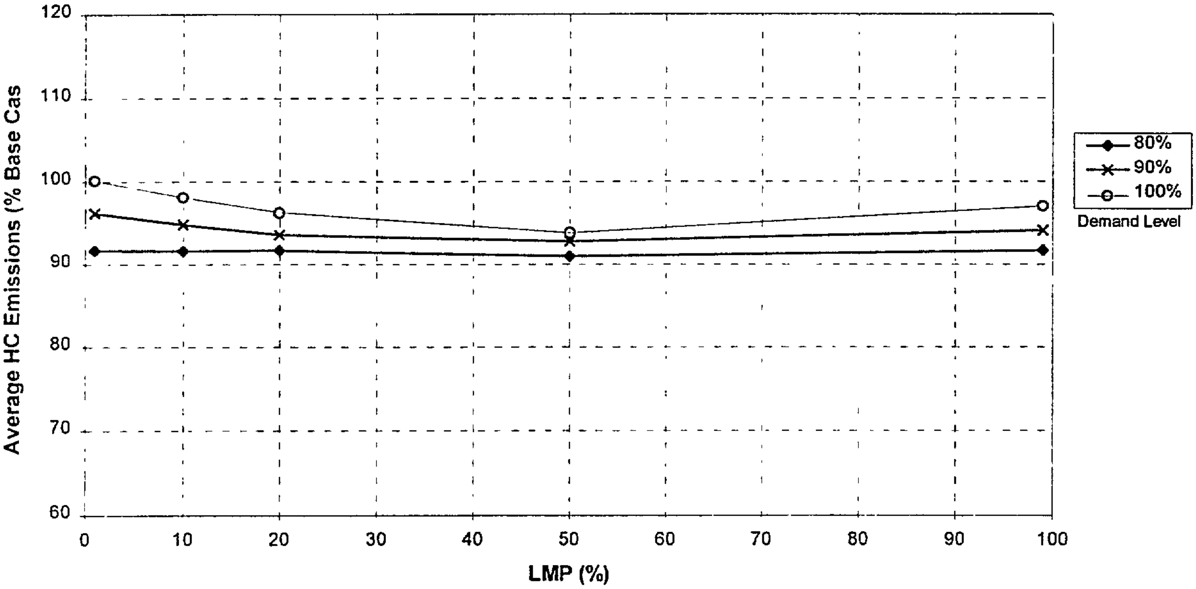


Figure 39 Variation in average HC emissions of background traffic as a function of LMP and demand level (No incident)

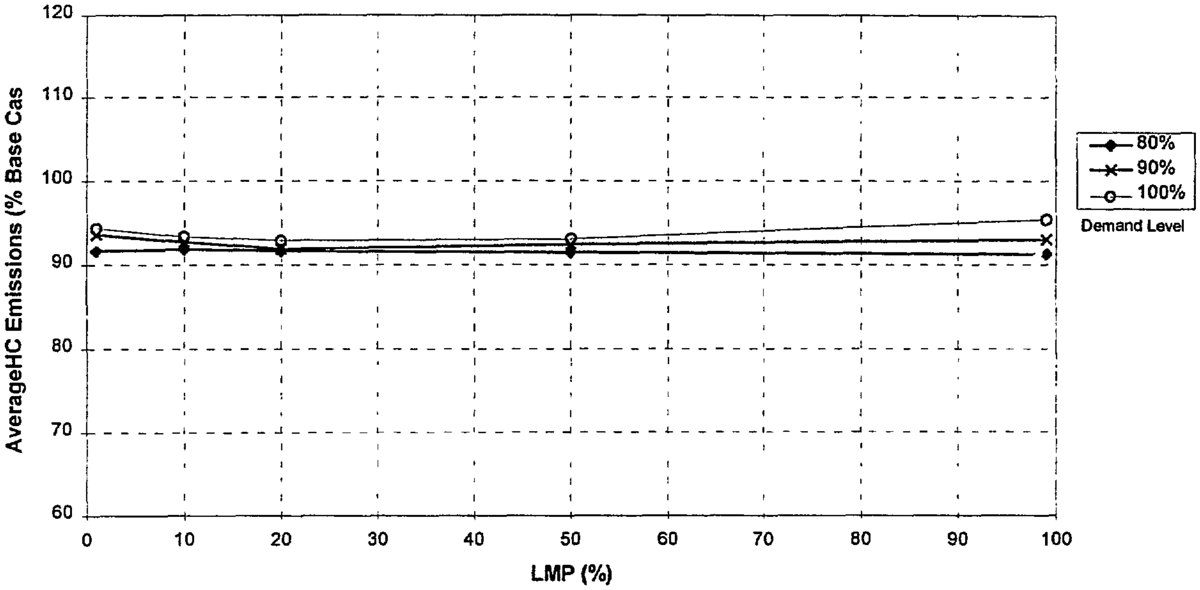


Figure 40. Variation in average HC emissions of PCD equipped vehicles as a function of LMP and demand level (No incident)

4.8 IMPACT OF PERSONAL COMMUNICATION DEVICES ON CO EMISSIONS

The impact of different percentages of PCD-equipped vehicles on CO emissions appeared to be marginal as illustrated in Figure . Interestingly, as the level of congestion within the network decreased, the average CO emissions increased (100% demand versus 80% demand).

The same trend of variation in CO emissions as a function of the LMP appeared to occur for both the background and PCD-equipped vehicles as illustrated in Figure and Figure , respectively. These results are consistent with the findings of the TravTek evaluation study (Van Aerde and Rakha, 1995).

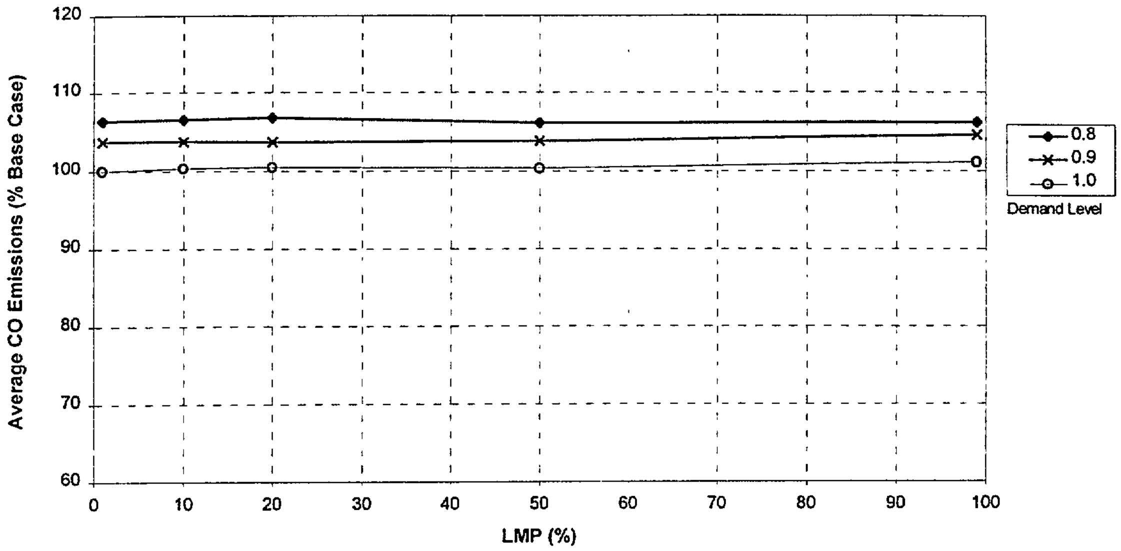


Figure 41. Variation in average CO emissions of entire vehicle population as a function of LMP and demand level (No incident)

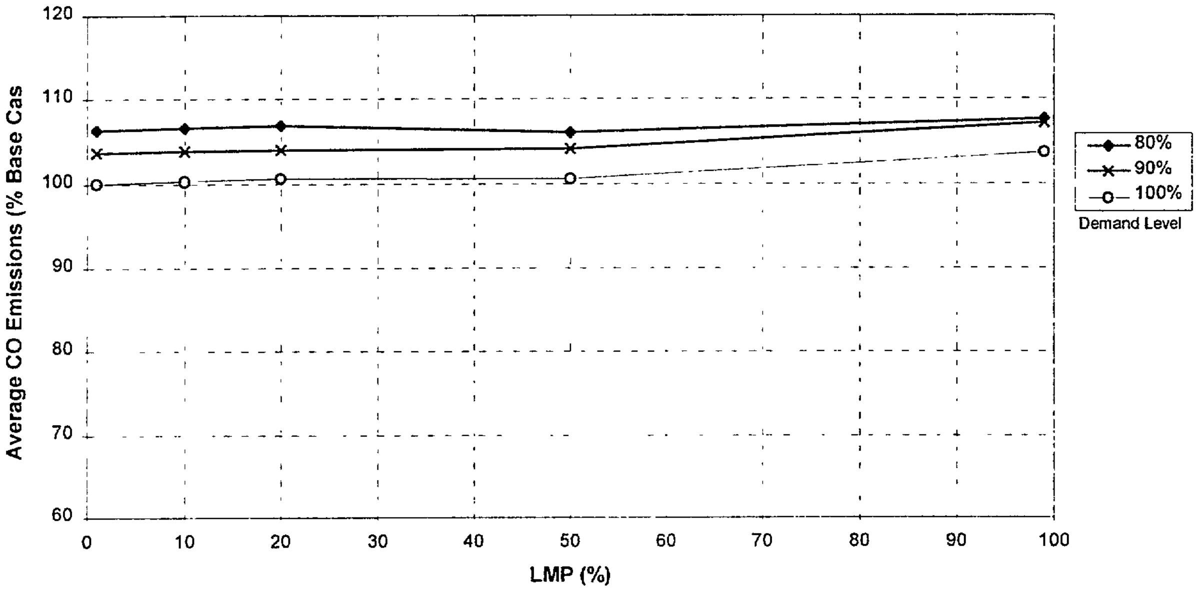


Figure 42. Variation in average CO emissions of background traffic as a function of LMP and demand level (No incident)

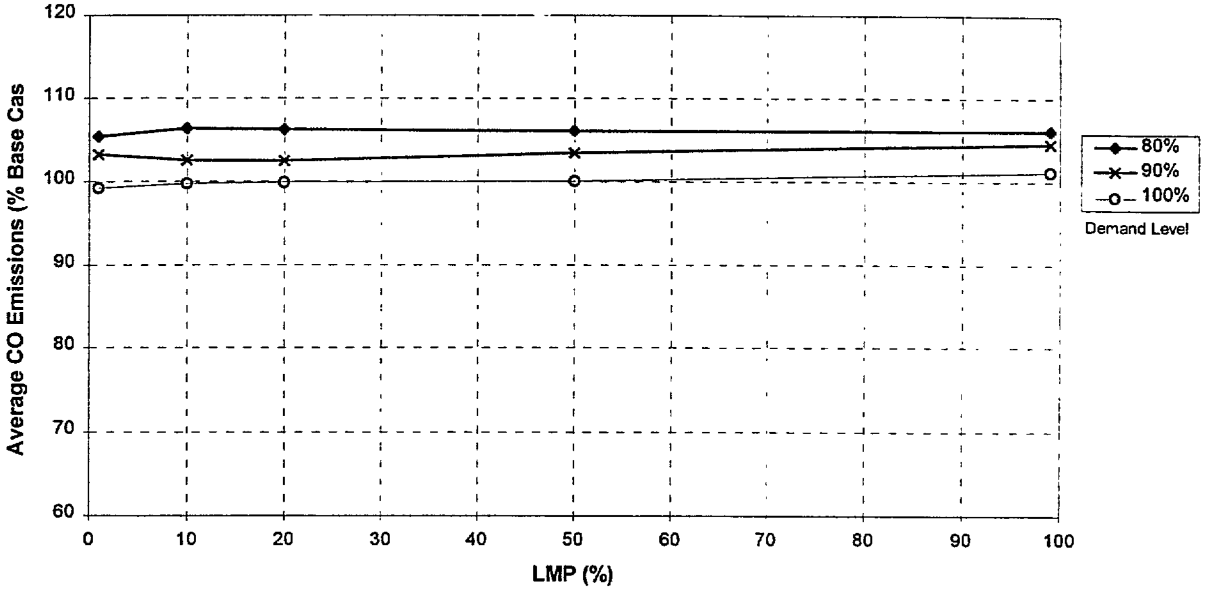


Figure 43. Variation in average CO emissions of PCD equipped vehicles as a function of LMP and demand level (No incident)

4.9 IMPACT OF PERSONAL COMMUNICATION DEVICES ON NO_X EMISSIONS

As the percentage of PCD-equipped vehicles increased, the average NO_x emissions appeared to increase at a decreasing rate as illustrated in Figure . The maximum increase in NO_x emissions was 5 percent. Furthermore, as the level of congestion within the network decreased, the average NO_x emissions increased (100% demand versus 80% demand).

The same trend of variation in NO_x emissions as a function of the LMP appeared to occur for both the background and PCD-equipped vehicles as illustrated in Figure and Figure , respectively. These results are consistent with the findings of the TravTek evaluation study (Van Aerde and Rakha, 1995) and other studies that have shown that NO_x emissions increase as the average travel speed increases.

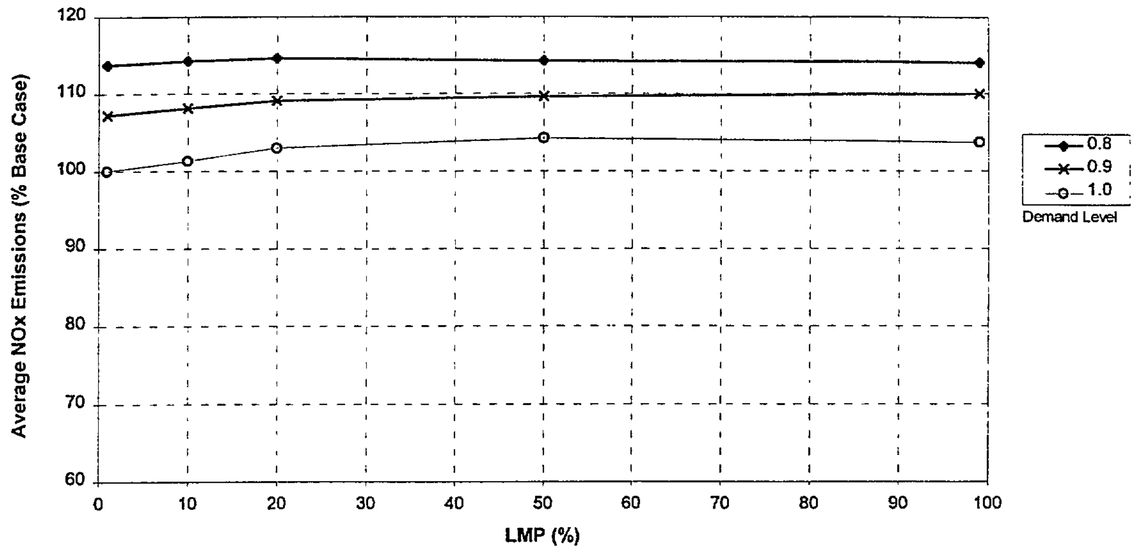


Figure 44. Variation in average NO_x emissions of entire vehicle population as a function of LMP and demand level (No incident)

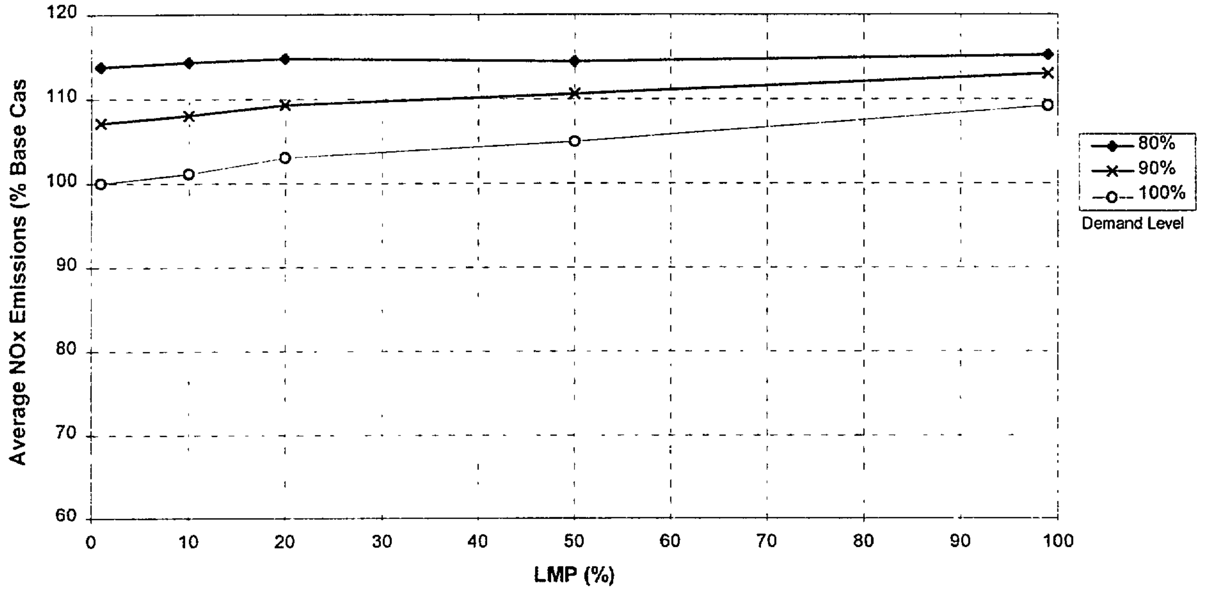


Figure 45. Variation in average NO_x emissions of background traffic as a function of LMP and demand level (No incident)

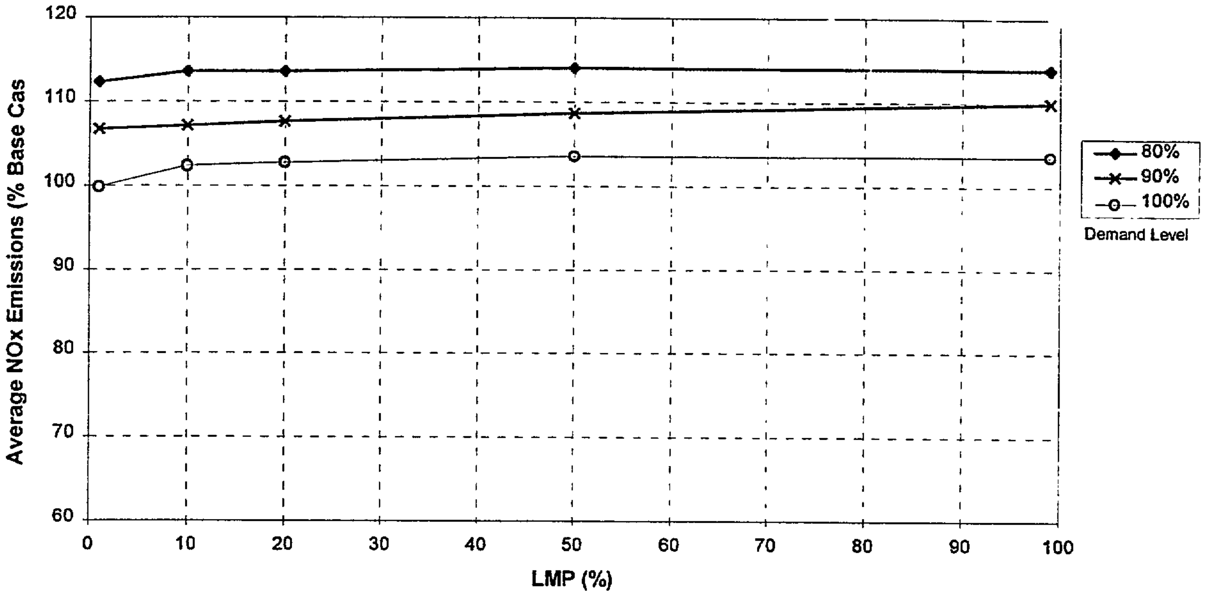


Figure 46. Variation in average NO_x emissions of PCD equipped vehicles as a function of LMP and demand level (No incident)

4.10 IMPACT OF PERSONAL COMMUNICATION DEVICES ON ACCIDENT RISK

The impact of both the percentage of PCD-equipped vehicles and the level of congestion within the network appeared to be marginal on the average accident risk as illustrated in Figure .

The same trend of variation in accident risk as a function of the LMP appeared to occur for both the background and PCD-equipped vehicles as illustrated in Figure and Figure , respectively.

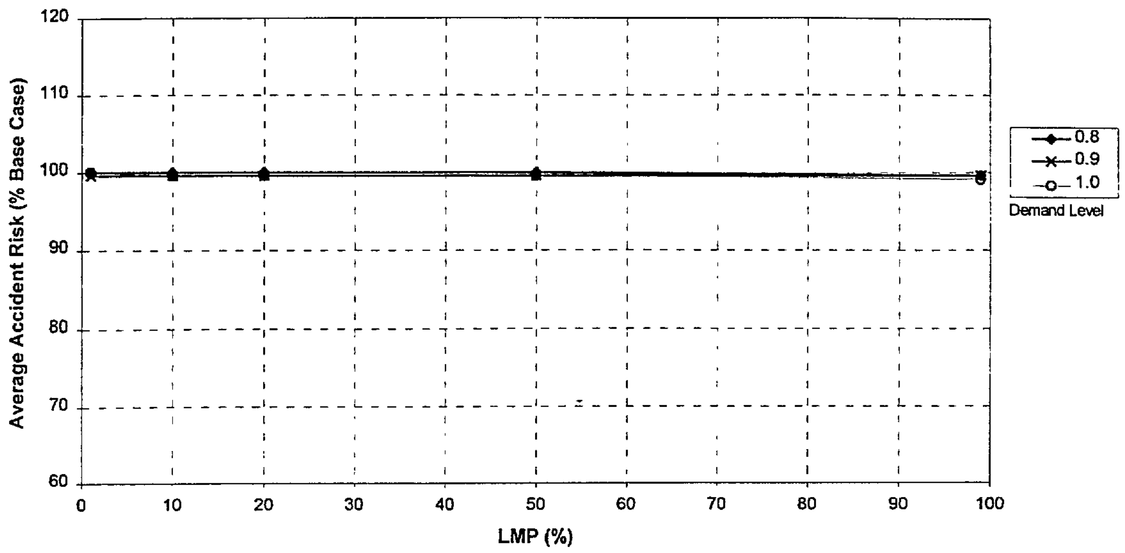


Figure 47. Variation in average accident risk of entire vehicle population as a function of LMP and demand level (No incident)

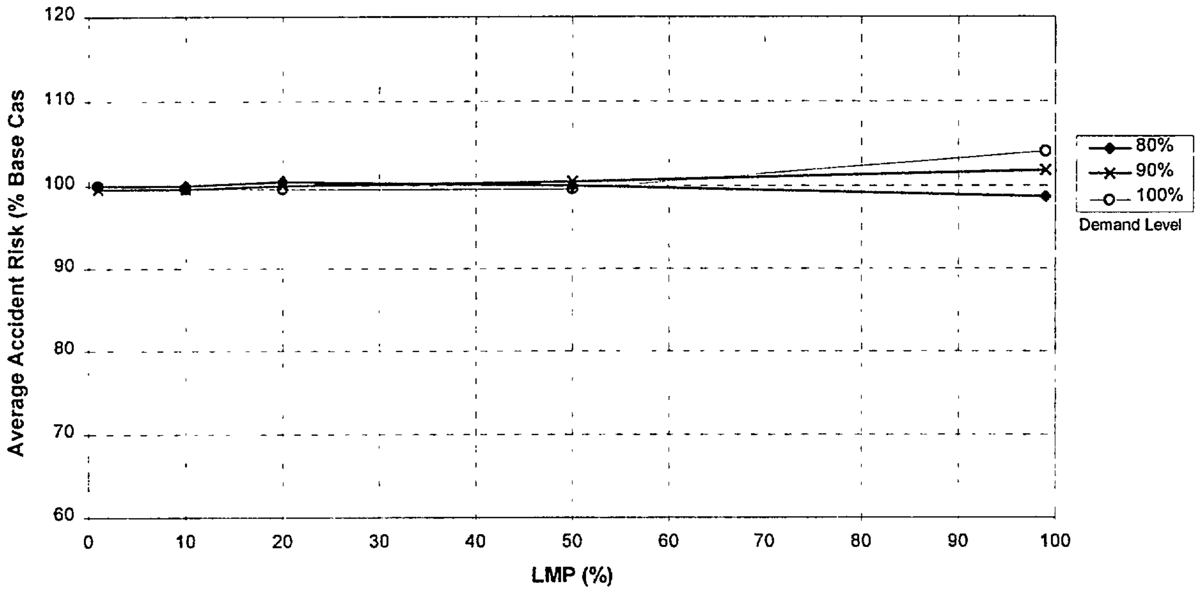


Figure 48. Variation in average accident risk of background traffic as a function of LMP and demand level (No incident)

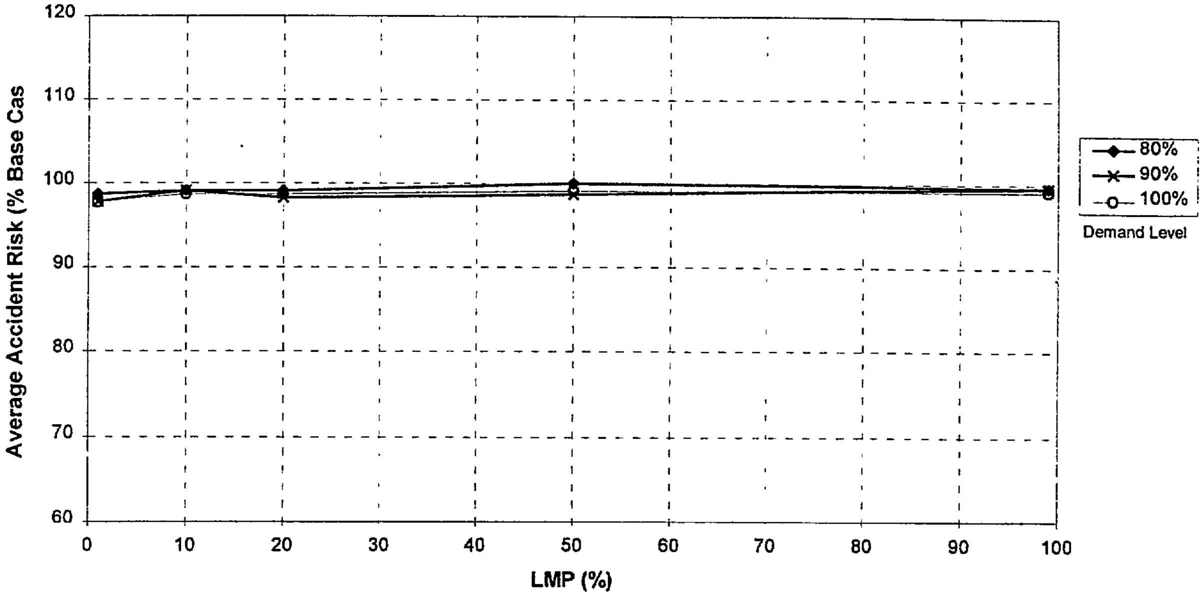


Figure 49. Variation in average accident risk of PCD equipped vehicles as a function of LMP and demand level (No incident)

4.11 SUMMARY AND CONCLUSIONS

The modeling study, presented in this report, was undertaken as part of the Genesis evaluation in order to extrapolate the benefits of PCD's for higher levels of market penetration and to estimate the benefits in terms of fuel consumption, vehicle emissions and accident risk.

Because a simulation study is an attempt to replicate reality, the results of simulation must be interpreted within the margin of error, the assumptions of the study and the study caveats. Furthermore, the results of this study were defined for the traffic and network conditions within the I-35W network, discretion is required in extrapolating these results for other network and traffic conditions.

The modeling study that was undertaken as part of the Genesis evaluation demonstrated that Personal Communication Devices (PCD's) can achieve benefits within the following ranges:

1. PCD's can reduce the average travel time of the entire system by up to 15 percent. Most of these benefits are achieved through a 20 percent utilization of these devices. Further benefits can be achieved during non-recurring congestion depending on the severity of the incident.
2. The benefits of PCD's, in terms of savings in average travel time, increase as the level of congestion in the network increases.
3. PCD's provide little benefits in average travel distance, CO emissions and accident risk (benefits less than 1 percent).
4. PCD's can reduce vehicle stops, fuel consumption, HC emissions by up to 5 percent. Most of these benefits are achieved through a 20 percent utilization of these devices.
5. PCD's can increase NO_x emissions by up to 5 percent.

5. SUMMARY AND CONCLUSIONS OF MODELING REPORT

This section summarizes the findings and presents the conclusions of the Genesis Modeling Study. Initially, the logic behind selecting the INTEGRATION model as the evaluation tool is summarized followed by the calibration procedure of the INTEGRATION model to the traffic and network characteristics of the I-35W network. Next, the results for the base case, prior to the introduction of the Genesis system, are summarized. Finally, the impact of the PCD's on traffic congestion, fuel consumption, vehicle emissions and accident risk are summarized.

5.1 INTEGRATION: MODELING TOOL

1. INTEGRATION models traffic microscopically and thus information is available on an individual vehicle basis. This microscopic nature allows for modeling of real-time traffic information that is provided to a specific class of vehicles.
2. INTEGRATION can simulate five different vehicle classes. These vehicle classes allow for the modeling of Genesis and non-Genesis users.
3. INTEGRATION models routing and assignment, thus allowing for the modeling of traffic re-routing in response to real-time traffic information.
4. INTEGRATION allows for the integrated modeling of freeway and arterial systems. This capability allows for modeling of traffic diversion between the freeway/arterial facilities.
5. INTEGRATION models a number of routing capabilities including a macroscopic rate-based assignment and a microscopic feedback based assignment. These assignment techniques can range from static to dynamic assignment or from deterministic to stochastic.
6. INTEGRATION has been utilized in the evaluation of the TravTek route guidance system (Van Aerde and Rakha, 1995) and the Intelligent Transportation Systems (ITS) architecture study.

5.2 CALIBRATION OF THE INTEGRATION MODEL TO THE I-35W NETWORK

1. The calibration process demonstrated a high level of consistency between the simulated and input flows (92 percent coefficient of correlation).
2. The calibration process demonstrated a high consistency with field travel time estimates (generally within the confidence limits).
3. The background traffic (non-Genesis users) were modeled using the deterministic macroscopic rate based traffic assignment.
4. The Genesis vehicles were modeled using a deterministic microscopic feedback traffic assignment logic using a routing update frequency of fifteen minutes.

5.3 RESULTS FOR BASE CASE

1. During a typical modeling run approximately 60,000 individual vehicles were traced, during the PM peak, through a total of 395,000 veh-km or 8,000 veh-h.
2. The base case resulted in an average trip duration of approximately 8 minutes, an average trip length of 6.6 kilometers and on average 2.75 stops/trip. Vehicles consumed on average 1 litre of gasoline and emitted 10.9, 66.6 and 8.8 grams of HC, CO and NO, emissions, respectively. These vehicles on average experienced an accident risk of 2.2 accidents per million trips.

5.4 IMPACT OF PERSONAL COMMUNICATION DEVICES

The modeling study that was undertaken as part of the Genesis evaluation demonstrated that Personal Communication Devices (PCD's) can achieve benefits within the following ranges:

1. PCD's can reduce the average travel time of the entire system by upto 15 percent. Most of these benefits are achieved through a 20 percent utilization of these devices. Further benefits can be achieved during non-recurring congestion depending on the severity of the incident.
2. The benefits of PCD's, in terms of savings in average travel time, increase as the level of congestion in the network increases.
3. PCD's provide little benefits in average travel distance, CO emissions and accident risk (benefits less than 1 percent).
4. PCD's can reduce vehicle stops, fuel consumption, HC emissions by upto 5 percent. Most of these benefits are achieved through a 20 percent utilization of these devices.
5. PCD's can increase NO, emissions by upto 5 percent.

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APPENDIX (A)
INTEGRATION INPUT MASTER FILES

135W-111.INT

```
Genesis Modeling (LMP= 1% - Demand= 80% - No
incident)
 7200    3600    900     1      0
-7200     900      0     0      0
 0.00    0.00   0.00   0.00  0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4  ll.dat
i35w5-l.dat
none -
none
none
none
i35w-lll.rlO
none
i35w  111.r.12
none-
none
none
none
none
none
none
none
none
none
```

135W_112.INT

```
Genesis Modeling   (LMP= 1%- Demand= 80% - 0.5 lane
blockage)
 7200   3600    900      1      0
-7200    900      0      0      0
 0.00   0.00   0.00   0.00   0.00


i35wl .dat
i35w2.dat
i35w3.dat
i35w4  ll.dat
i35w5_2.dat
none
none
none
none
i35w_112.rl0
none
i35w_112.112
none
none
none
none
none
none
none
none
none
none
```

I35W_113.INT

```
Genesis  Modeling  (LMP= 1% -Demand=80%- 1 lane
blockage)
 7200   3600    900      1      0
-7200    900      0      0      0
 0.00   0.00   0.00   0.00   0.00
i35wl.dat
i35w2.dat
i35w3.dat
i35w4  ll.dat
i35w5_3.dat
none
none
none
none
i35w_113.r10
none
i35w_113.r12
none
none
none
none
none
none
none
none
none
none
```

I35W_114.INT

```
Genesis Modeling (LMP= 1%  -  Demand=  80%  -  2  lane
blockage)
 7200    3600     900     1      0
-7200
 0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4ll.dat
i35w5_4.dat
none
none
none
none
i35w-114.rlO
none
i35w_114.rl2
none
none
none
none
none
none
none
none
none
none
```

135W_121.INT

```
Genesis Modeling  (LMP  1%  -  Demand=  90% - No
incident)
 7200   3600    900       1      0
-7200    900      0       0      0
 0.00   0.00   0.00    0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4 12.dat
i35w5_l.dat
none
none
none
none
i35w_121.r10
none
i35w_121.r12
```

```
none
none
none
none
none
none
none
none
none
none
```

I35W_ 122.INT

```
Genesis Modeling (LMP= 1% - Demand= 90% - 0.5 lane
blockage)
 7200   3600   900     1     0
-7200    900     0     0     0
 0.00   0.00  0.00  0.00  0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4 12.dat
i35w5_2.dat
none
none
none
none
i35w_122.rlO
none
i35w_122.r12
none
none
none
none
none
none
none
none
none
none
```

I35W_123.INT

```
Genesis Modeling (L.MP= 1% - Demand= 90% - 1 lane
blockage
 7200   3600   900     1     0
-7200    900     0     0     0
 0.00   0.00  0.00  0.00  0.00


i35wl.dat
i35w2.dat
i35w3.dat
135w4 12.dat
135w5_3.dat
none
none
none
none
i35w_123.rlO
none
i35w_123.r12
none
none
none
none
none
none
none
none
none
none
```

I35W-124.INT

```
Geneses Modeling (LMP= 1% - Demand= 90% - 2 lane
blockage)
 7200   3600   900     1     0
-7200    900     0     0     0
 0.00   0.00  0.00  0.00  0.00
i35wl.dat
i35w2.dat
i35w3.dat
i35w4 12.dat
i35w5_4.dat
none
none
none
none
i35w_124.r10
none
i35w_124.r12
none
none
none
none
none
none
none
none
none
none
```

I35W_131 .INT

```
Genesis Modeling  (LMP= 1% - Demand=lOO% -  No
incident)
 7200   3600   900     1     0
-7200    900     0     0     0
 0.00   0.00  0.00  0.00  0.00


i35wl.dat
i35w2.dat
135w3.dat
i35w4 13.dat
i35w5_1.dat
none
none
none
none
i35w 131.rlO
none-
i35w_131.r12
none
none
none
none
none
none
none
none
none
none
```

135W_132.INT

```
Genesis Modeling (LMP= 1% – Demand=100% - 0.5 lane
blockage)
 7200   3600   900     1     0
-7200    900     0     0     0
 0.00   0.00  0.00  0.00  0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4 13.dat
i35w5_2.dat
none
none
none
none
i35w_132.rlO
none
i35w_132.r12
none
none
none
none
none
none
none
none
none
```

```
none
```

135W_133.INT

```
Genesis Modeling (LMP 1% - Demand=lOO%
blockage
 7200 3600    900     1     0
-7200  900      0     0     0
 0.00 0.00   0.00  0.00  0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4  13.dat
i35w5_3.dat
none
none
none
none
i35w-133.r10
none
i35w-133.r12
none
none
none
none
none
none
none
none
none
none
```

135W_134.INT

```
Genesis Modeling (LMP= 1% - Demand=lOO% - 2 lane
blockage
 7200   3600    900     1     0
-7200    900      0     0     0
 0.00   0.00   0.00  0.00  0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4  13.dat
i35w5_4.dat
none
none
none
none
i35w-134.r10
none
i35w_134.r12
none
none
none
none
none
none
none
none
none
none
```

I35W_211INT

```
Genesis Modeling  [LMP=lO%   - Demand=  80%  - No
incident)
 7200   3600    900       1   0
-7200    900      0     0     0
 0.00   0.00   0.00  0.00  0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4  2l.dat
i35w5-l.dat
none -
none
none
none
i35w-211.rlO
none
i35w-211.r12
none
none
none
none
none
none
none
none
none
none
```

I35W_212.INT

```
Genesis Modeling (LMP=lO%   Demand= 80% - 0.5 lane
blockage)
 7200   3600    900     1
-7200    900      0     0     0
 0.00   0.00   0.00  0.00  0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4  2l.dat
i35w5_2.dat
none
none
none
none
i35w_212.r10
none
i35w_212.r12
none
none
none
none
none
none
none
none
none
none
```

I35W_213.INT

```
Genesis yodeling (LMP=lO% -- Demand= 80% - 1 lane
blockage)
 7200 3600    900     1     0
-7200  900      0     0     0
 0.00 0.00   0.00  0.00  0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4  2l.dat
i35w5_3.dat
none
none
none
none
i35w-213.rlO
none
i35w-213.r12
none
none
none
none
none
none
none
none
none
none
```

I35W_214.INT

```
Genesis Modeling (LMP=lO%  - Demand=  80%  - 2  lane
blockage)
 7200   3600    900    1      0
-7200    900      0    0      0
```

```
 0.00   0.00   0.00   0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4 2l.dat
i35w5_4.dat
none
none
none
none
i35w_214.rlO
none
i35w_214.r12
none
none
none
none
none
none
none
none
none
none
```

l35W_221 INT

```
Genesis  Modeling  (LMP=lO%  -  Demand= 90% - No
incident
 7200   3600    900      1      0
-7200    900      0      0      0
 0.00   0.00   0.00   0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
135w4 22.dat
i35w5_l.dat
none
none
none
none
i35w 221.r10
none
i35w 221.r12
none-
none
none
none
none
none
none
none
none
none
```

135W_222.INT

```
Genesis  Modeling  (LMP=10%  -  Demand= 90%  -  0.5  lane
blockage1
 7200   3600    900    1      0
-7200    900      0    0      0
 0.00   0.00   0.00 0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4 22.dat
i35w5_2.dat
none
none
none
none
i35w_222.rlO
none
i35w_222.r12
none
none
none
none
none
none
```

```
none
none
none
none
```

135W_223.INT

```
Genesis Modeling (LMP=lO% - Demand= 90% - 1 lane
blockage
 7200   3600    900      1      0
-7200    900   0.00      0      0
 0.00   0.00          0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4 22.dat
i35w5_3.dat
none
none
none
none
i35w 223.rlO
none-
i35w_223.r12
none
none
none
none
none
none
none
none
none
none
```

135W_224.INT

```
Genesis Modeling (LMP=lO% - Demand= 90% - 2 lane
blockage
 7200   3600    900      1      0
-7200    900      0      0      0
 0.00   0.00   0.00   0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4 22.dat
i35w5_4.dat
none
none
none
none
i35w 224.r10
none
i35w 224.r12
none-
none
none
none
none
none
none
none
none
none
```

135W_231.INT

```
Genesis  Modeling  (LMP=lO%  -  Demand=lOO%  -  No
incident
 7200      3600
-7200    900     0      0      0
 0.00   0.00  0.00   0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4 23.dat
i35w5_l.dat
none
```

```
none
none
none
i35w-231.rlO
none
i35w 231.r12
none-
none
none
none
none
none
none
none
none
none
```

I35W_232.INT

```
Genesis Modeling (LMP=l0% - Demand=lOO% - 0.5 lane
blockage)
 7200   3600    900      1      0
-7200    900      0      0      0
 0.00   0.00   0.00   0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4 23.dat
i35w5_2.dat
none
none
none
none
i35w 232.rlO
none
i35w_232.r12
none
none
none
none
none
none
none
none
none
none
```

I35W_233.INT

```
Genesis Modeling (LMP=l0% – Demand=l00% - 1 lane
blockage
 7200   3600    900      1      0
-7200    900      0      0      0
 0.00   0.00   0.00   0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4 23.dat
i35w5_3.dat
none
none
none
none
i35w-233.rlO
none
i35w 233.r12
none
none
none
none
none
none
none
none
none
none
```

I35W_234.INT

```
Genesis yodeling (LMP=l0% - Demand=lOO% - 2 lane
blockage
 7200   3600    900      1      0
-7200    900      0      o      0
 0.00   0.00   0.00   0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4 23.dat
i35w5_4.dat
none
none
none
none
i35w_234.r10
none
i35w_234.r12
none
none
none
none
none
none
none
none
none
none
```

I35W_311.INT

```
Genesis Modeling (LMP=20% - Demand= 80% - No
incident
 7200   3600    900      1      0
-7200    900      0      0      0
 0.00   0.00   0.00   0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4 3l.dat
i35w5_l.dat
none
none
none
none
i35w_311.r10
none-
i35w 311.r12
none-
none
none
none
none
none
none
none
none
none
```

I35W_312.INT

```
Genessis Modeling [LMP=20% · Demand= 80% - 0.5 lane
blockage)
 7200   3600    900      1      0
-7200    900      0      0      0
 0.00   0.00   0.00   0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4 3l.dat
i35w5-2.dat
none -
none
none
none
i35w 312.r10
none
i35w_312.r12
```

```
none
none
none
none
none
none
none
none
none
none
```

135W_313.INT

```
Genesis Modeling (LMP=20% - Demand= 80% - 1 lane
blockage )
 7200   3600     900      1      0
-7200    900       0      0      0
 0.00   0.00   0.00   0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4 31.dat
i35w5_3.dat
none
none
none
none
i35w 313.r10
none-
i35w_313.r12
none
none
none
none
none
none
none
none
none
none
```

135W_314.INT

```
Genesis Medeling (LMP=20% - Demand= 80% - 2 lane
blockage
 7200   3600    900      1      0
-72CO    900      0      0      0
 0.00   0.00   0.00   0.00   0.00


i35wl.dat
i35w:.dat
i35w3.dat
-35w4 3l.dat
135w5-4.dat
none -
none
none
none
135w-314.r10
none-
i35w 314.r12
none-
none
none
none
none
none
none
none
none
```

I35W_321.INT

```
Genesis Modeling (LMP=20% - Demand= 90% - No
Incident
 7200   3600    900      1      0
-7200    900      0      0      0
 0.00   0.00   0.00   0.00   0.00
i35wl.dat
i35w2.dat
i35w3.dat
i35w4 32.dat
i35w5_l.dat
none
none
none
none
i35w-321.rlO
none
i35w 321.r12
none-
none
none
none
none
none
none
none
none
none
```

135W-322.INT

```
Genesis Modeling (LMP=20% - Demand= 90% - 0.5 lane
blockage)
 7200 · 3600    900      1      0
-7200    900      0      0      0
 0.00   0.00   0.00   0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4 32.dat
i35w5-2.dat
none
none
none
none
i35w_322.r10
none
i35w 322.r12
none-
none
none
none
none
none
none
none
none
none
```

I35W 323.INT

```
Genesis Modeling (LMP=20% – Demand= 90% - 1 lane
blockage
 7200   3600    900      1      0
-7200    900      0      0      0
 0.00   0.00   0.00   0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4 32.dat
i35w5-3.dat
none
none
none
none
i35w-323.rlO
none
135w_323.r12
none
none
none
none
none
none
none
none
none
```

```
none
```

135W_324.INT

```
Genesis  Modeling  (LMP=20%    Demand= 90% - 2 lane
blockage)
 7200   3600    900      1      0
-7200    900      0      0      0
 0.00   0.00   0.00   0.00   0.00


i35wl.dat
135w2.dat
i35w3 .dat
i35w432.dat
i35w5-4.dat
none -
none
none
none
i35w 324.r10
none-
i35w-324.r12
none
none
none
none
none
none
none
none
none
none
```

I35W_331.INT

```
Genesis Modeling  (LMP=20%  -    Demand=l00%  -  No
incident
 7200   3600    900      1      0
-7200    900      0      0      0
 0.00   0.00   0.00   0.00   0.00


i35w1 .dat
i35w2.dat
i35w3.dat
i35w4  33.dat
i35w5-1.dat
none  -
none
none
none
i35w-331.rl0
none
i35w  331.r12
none-
none
none
none
none
none
none
none
none
none
```

135W-332.INT

```
Genesis  Modeling  (LMP=20%  - Demand=lOO%- 0.5 lane
blockage)
 7200   3600    900      1      0
-7200    900      0      0      0
 0.00   0.00   0.00   0.00   0.00


i35wl .dat
i35w2.dat
i35w3.dat
i35w4  33.dat
i35w5_2.dat
none
none
none
none
i35w_332.r10
none
i35w  332.r12
none
none
none
none
none
none
none
none
none
none
```

135W_333.INT

```
Genesis  Modeling  (LMP=20%  -  Demand=lOO%  -  1  lane
blockage
 7200   3600    900      1      0
-7200    900      0      0      0
 0.00   0.00   0.00   0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4  33.dat
i35w5_3.dat
none
none
none
none
i35w  333.r10
none-
i35w-333.r12
none
none
none
none
none
none
none
none
none
none
```

I35W_334.INT

```
Genesis  Modeling  (LMP=20%  –  Demand=100%  -  2  lane
blockage
 7200   3600    900      1      0
-7200    900      0      0      0
 0.00   0.00   0.00   0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4  33.dat
i35w5_4.dat
none
none
none
none
i35w_334.r10
none
i35w 334.r12
none-
none
none
none
none
none
none
none
none
none
```

I35W_411 .INT

```
Genesis   Modelinq   (LMP=50%   -  Demand=   80%   -   No
Incident
 7200   3600    900      1      0
-7200    900      0      0      0
```

```
 0.00   0.00   0.00   0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4  4l.dat
i35w5_l.dat
none
none
none
none
i35w-4_1.rlO
none
i35w_411.r12
none
none
none
none
none
none
none
none
none
none
```

l35W_412.INT

```
Genesis Modeling  (LMP=50%  -  Demand=  80%  -  0.5  lane
blockage)
 7200   3600     900      1      0
-7200    900       0      0      0
 0.00   0.00   0.00   0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4  4l.dat
i35w5_l.dat
none
none
none
none
i35w-4_2.rlO
none
i35w_4_2.r12
none
none
none
none
none
none
none
none
none
```

135W_413.INT

```
Genesis Modeling  (LMP=50%  -  Demand  80%  -  1  lane
blockage
 7200   3600     900      1      0
-7200    900       0      0      0
 0.00   0.00   0.00   0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4  4l.dat
i35w5_3.dat
none
none
none
none
i35w-4_3.rlO
none
i35w413.r12
none-
none
none
none
none
none
none
none
none
none
```

135W_414.1NT

```
Genesis  Modeling  (LMP=50%  -  Demand=  80%  -  2  lane
blockage
 7200   3600     900      1      0
-7200    900       0      0      0
 0.00   0.00   0.00   0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4  4l.dat
i35w5_4.dat
none
none
none
none
i35w_414.r10
none
i35w_414.r12
none
none
none
no*e
none
none
none
none
none
none
```

135W_421.INT

```
Genesis  Modeling  (LMP=50%  -  Demand=  90%  -  No
incident
 7200   3600     900      1      0
-7200    900       0      0      0
 0.00   0.00   0.00   0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4  42.dat
i35w5_l.dat
none
no78
none
none
i35w 421.rlO
none-
i35w_421.r12
none
none
none
none
none
none
none
none
none
none
```

135W_422.INT

```
Genesis  Modeling  (LMP=50%  ·  Demand=  90%  -  0.5  lane
blockage)
 7200   3600     900      1      0
-7200    900       0      0      0
 0.00   0.00   0.00   0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4  42.dat
i35w5_2.dat
none
```

```
none
none
none
i35w-422.r10
none-
i35w_422.r12            0
none          0              0     2
none
none
none
none
none
none
none
none
none
```

135W_423.INT

```
Genesis  Modeling  (LMP=50%  -  Demand=  90%  -  1  lane
blockage
 7200    3600     900     1      0
-7200     900       0     0      0
 0.00    0.00    0.00    0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w_ 42.dat
i35w5-3.dat
none
none
none
none
i35w 423.rl0
none-
i35w 423.r12
none-
none
none
none
none
none
none
none
none
none
```

I35W-424.INT

```
Genesis  Modeling  (LMP=50%    Demand= 90% - 2 lane
blockage
 7200    3600     900        1   0
-7200     900       0        0   0
 0.00    0.00    0.00    0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4 42.dat
i35w5-4.dat
none
none
none
none
i35w 424.rl0
none-
i35w_424.r12
none
none
none
none
none
none
none
none
none
none
```

I35W_431.INT

```
Genesis   Modeling   (LAMP=50%   -   Demand=l00%  -N o
incident
 7200    3600     900       1         0
0                              2                       -  7
 7      0     7                          0


i35wl.dat
i35w2.dat
i35w3.dat
i35w4 43.dat
i35w5_l.dat
none
none
none
none
i35w-431.r10
none
i35w_431.r12
none
none
none
none
none
none
none
none
none
none
```

I35W-432.INT

```
Genesis  Modelinq  (LMP=50%  -  Demand=100%  -  0.5  lane
blockage)
 7200    3600     900        1   0
-7200     900       0        0
 0.00    0.00    0.00    0.00   0.00


i35wl .dat
i35w2.dat
i35w3.dat
i35w4 43.dat
i35w5-2.dat
none -
none
none
none
i35w 432.rl0
none-
i35w 432.r12
none-
none
none
none
none
none
none
none
none
```

135W-433.INT

```
Genesis Modeling (LMP=50%   –  Demand=lOO%   -  1 lane
blockage
 7200    3600       900       1         0
-7200     900        0        0          0
 0.00    0.00    0 .00      0.00       0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4 43.dat
i35w5_3.dat
none
none
none
none
i135w4 33.r10
none-
i35w_433.r12
```

```
none
none
none
none
none
none
none
none
none
none
```

135W 434.INT

```
Genesis Modeling (LMP=50%    Demand=l00%  -  2  lane
blockage
 7200   3600    900      1      0
-7200    900      0      0      0
 0.00   0.00   0.00   0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4 43.dat
i35w5_4.dat
none
none
none
none
i35w-434. r10
none
i35w_434.r12
none
none
none
none
none
none
none
none
none
none
```

135W-511 .INT

```
Genesis  Modeling  (LMP=99%  -  Demand=  80%  -  No
Incident
 7200   3600    900      1
-7200    900      0      0      0
 0.00   0.00   0.00   0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4 5l.dat
135w5-l.dat
none
none
none
none
i35w_511.r10
none
i35w_511.r12
none
none
none
none
none
none
none
none
none
none
```

135W-512.INT

```
Genesls Modeling (LMP=99% - Demand= 80% - 0.5 lane
blockage)
 7200   3600    900      1      0
-7200    900      0      0      0
 0.00   0.00   0.00   0.00   0.00
i35wl.dat
i35w2.dat
i35w3.dat
i35w4 5l.dat
i35w5_2.dat
none
none
none
none
i35w 512.rlO
none-
i35w 512.r12
none-
none
none
none
none
none
none
none
none
none
```

135W 513.INT

```
Genesis Modeling (LMP=99% - Demand= 80% - 1
blockage
 7200   3600    900      1      0
-7200    900      0      0      0
 0.00   0.00   0.00   0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4 5l.dat
i35w5_3.dat
none
none
none
none
i35w 513.r10
none-
i35w 513.r12
none-
none
none
none
none
none
none
none
none
none
```

I35W-514.INT

```
Genesis Modeling (LMP=99% – Demand= 80% - 2
blockage
 7200   3600    900      1      0
-7200    900      0      0      0
 0.00   0.00   0.00   0.00   0.00


i35wl.dat

i35w3.dat
i35w4 5l.dat
i35w5-4.dat
none -
none
none
none
i35w 514.rlO
none-
i35w 514.r12
none-
none
none
none
none
none
none
none
none
```

```
none
```

I35W_521 .INT

```
Genesis  Modeling  (LMP=99%  -  Demand=  90%  -  No
incident
 7200   3600    900      1      0
-7200    900      0      0      0
 0.00   0.00   0.00   0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4  52.dat
i35w5_l.dat
none
none
none
none
i35w  521.rlO
none-
i35w_521.r12
none
none
none
none
none
none
none
none
none
none
```

135W_522.INT

```
Genesls  Modeling  lLMP=99%  -  Demand=  90%  -  0.5  lane
blockage)
 7200   3600    900      1      0
-7200    900      0      0      0
 0.00   0.00   0.00   0.00   0.00


135wl.dat
135w2.dat
i35w3.dat
i35w4  52.dat
i35w5_2.dat
none
none
none
none
i35w  522.rlO
none-
i35w_522.r12
none-
none
none
none
none
none
none
none
none
none
```

135W_523.INT

```
Genesis  Modeling  (LMP=99%  -  Demand=  90%  -  1  lane
blockage
 7200   3600    900      1      0
-7200    900      0      0      0
 0.00   0.00   0.00   0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4  52.dat
i35w5_3.dat
none
none
none
none
i35w_523.r10
none
i35w_523.r12
none
none
none
none
none
none
none
none
none
none
```

I35W_524.INT

```
Genesis  Modeling  (LMP=99%  -  Demand=  90%  -  2  lane
blockage
 7200   3600    900      1      0
-7200    900      0      0      0
 0.00   0.00   0.00   0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4  52.dat
i35w5_4.dat
none
none
none
none
i35w  524.rlO
none-
i35w_524.r12
none
none
none
none
none
none
none
none
none
none
```

I35W_531.INT

```
Genesis  Modeling  (LMP=99%-  Demand=100%  -  No
incident
 7200   3600    900      1      0
-7200    900      0      0      0
 0.00   0.00   0.00   0.00   0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4  53.dat
i35wS-l.dat
none -
none
none
none
i35w-531.rl0
none
i35wb531.r12
none
none
none
none
none
none
none
none
none
none
```

I35W_532.INT

```
Genesis Modeling  (LMP=99%  -  Demand=lOO%  -  0.5  lane
blockage)
 7200   3600    900      1      0
-7200    900      0      0      0
```

```
 0.00    0.00    0.00    0.00    0.00                                  none
                                                                       none
                                                                       none
i35wl .dat                                                             none
i35w2 .dat
i35w3.dat
i35w4  53.dat
i35w512.dat
none
none
none
none
i35wb532.r30
none
i35we532.r12
none
none
none
none
none
none
none
none
none
none
```

I35W 533.INT

```
Genesis Modeling  (LMP=99%  -  Demand=lOO%  -  1  lane
blockage   )
 7200    3600      900      1       0
-7200     900       0       0       0
 0.00    0.00    0.00    0.00    0.00


i35wl.dat
135w2.dat
i35w3.dat
135W4  53.dat
i35w5-3.dat
none  -
none
none
none
135w-533.rlO
none
i35w  533.  r12
none-
none
none
none
none
none
none
none
none
none
```

I35W-534.INT

```
Genesis  Modeling  (LMP=99%  -  D emand=lOO%  -  2  lane
blockage
 7200    3600     900      0       0
-7200     900       0      0       0
 0.00    0.00    0.00    0.00    0.00


i35wl.dat
i35w2.dat
i35w3.dat
i35w4  53.dat
i35w5_4.dat
none
none
none
none
i35w  534.rlO
none-
i35w  534.r12
none-
none
none
none
none
none
```

APPENDIX (B)
SIMULATION OVERALL RESULTS

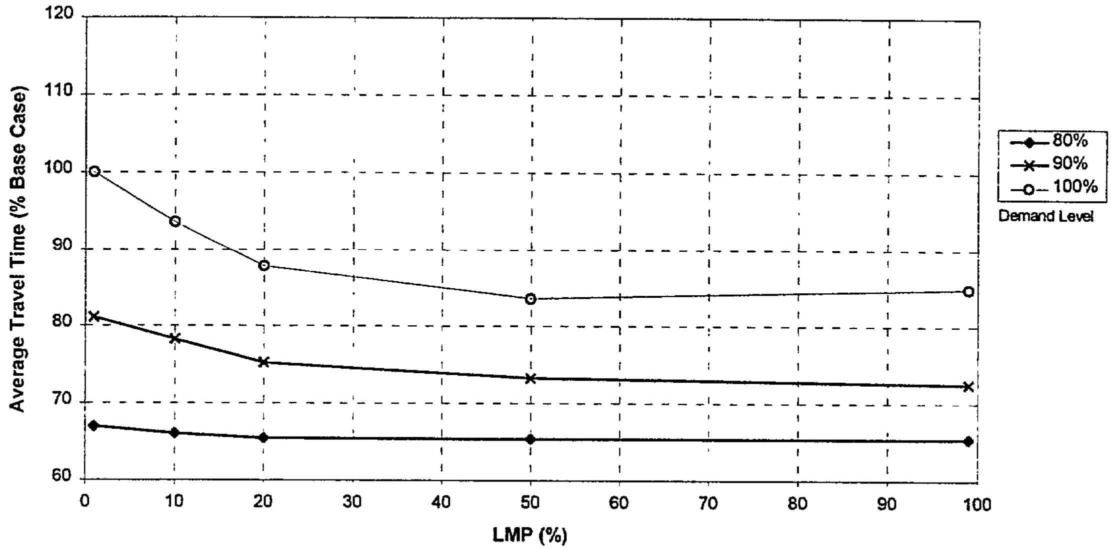

Figure B-1. Variation in average trip time as a function of LMP and demand level (No incident)

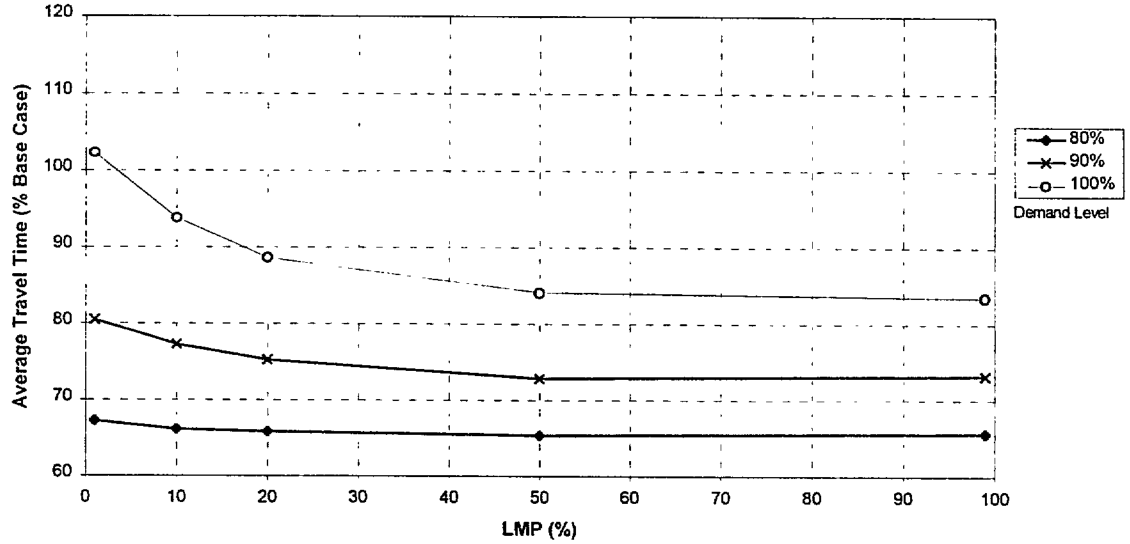

Figure B-2. Variation in average trip time as a function of LMP and demand level (0.5-lane blockage)

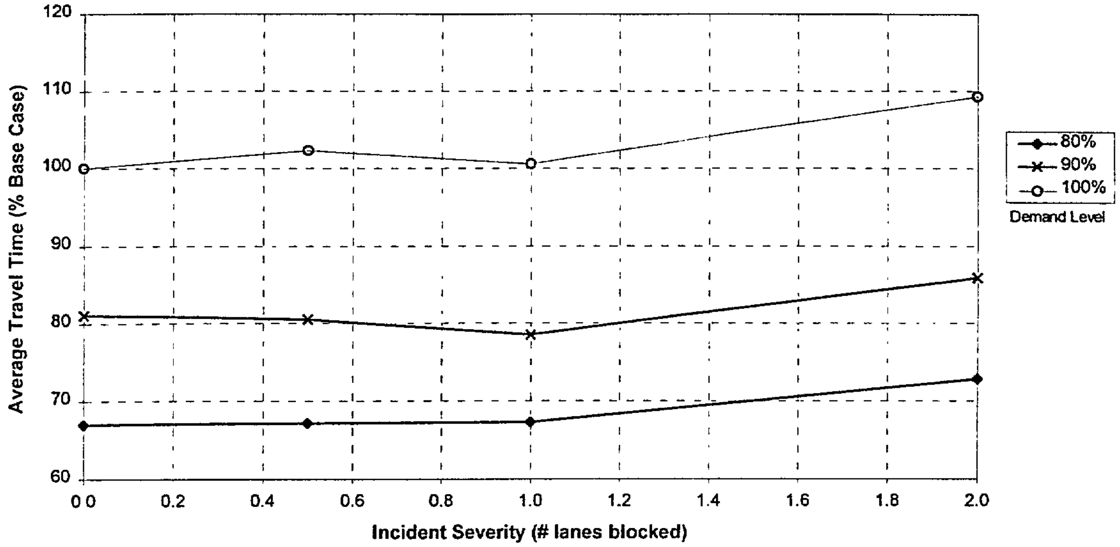

Figure B-5. Variation in average trip time as a function of incident severity and demand level (1% LMP)

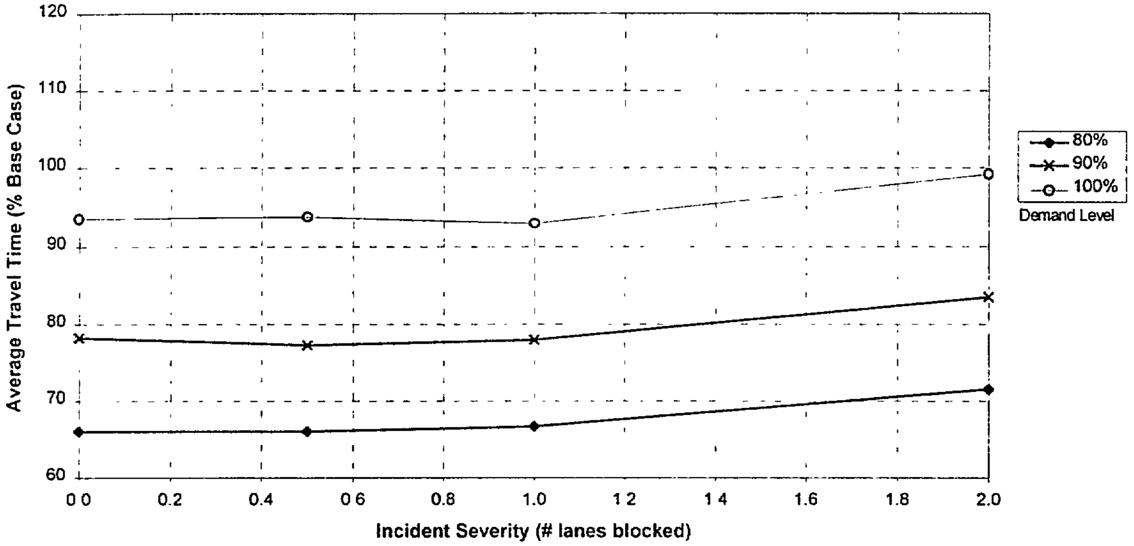

Figure B-6. Variation in average trip time as a function of incident severity and demand level (10% LMP)

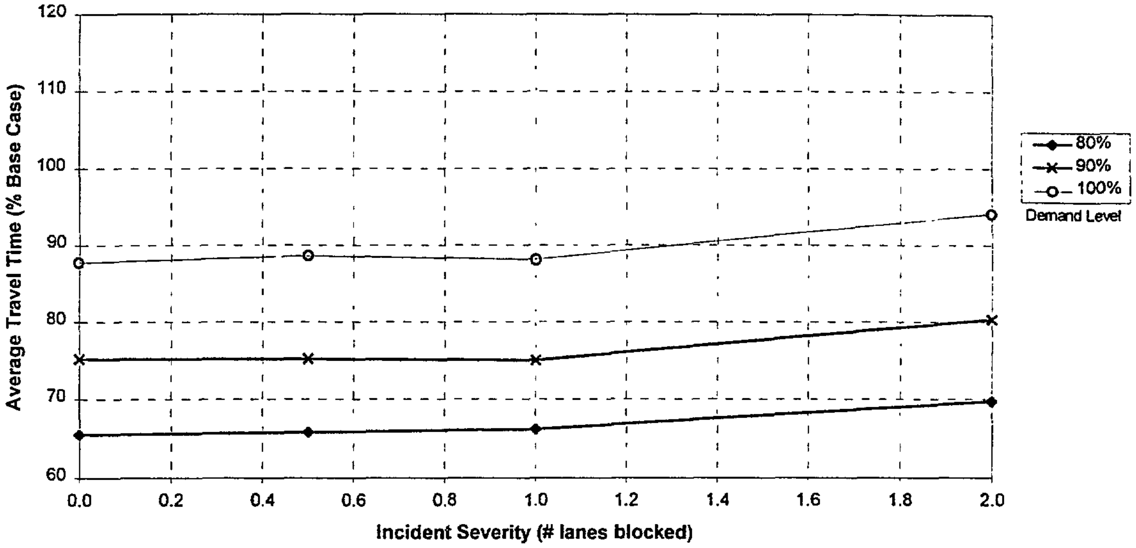

Figure B-7. Variation in average trip time as a function of incident severity and demand level (20% LMP)

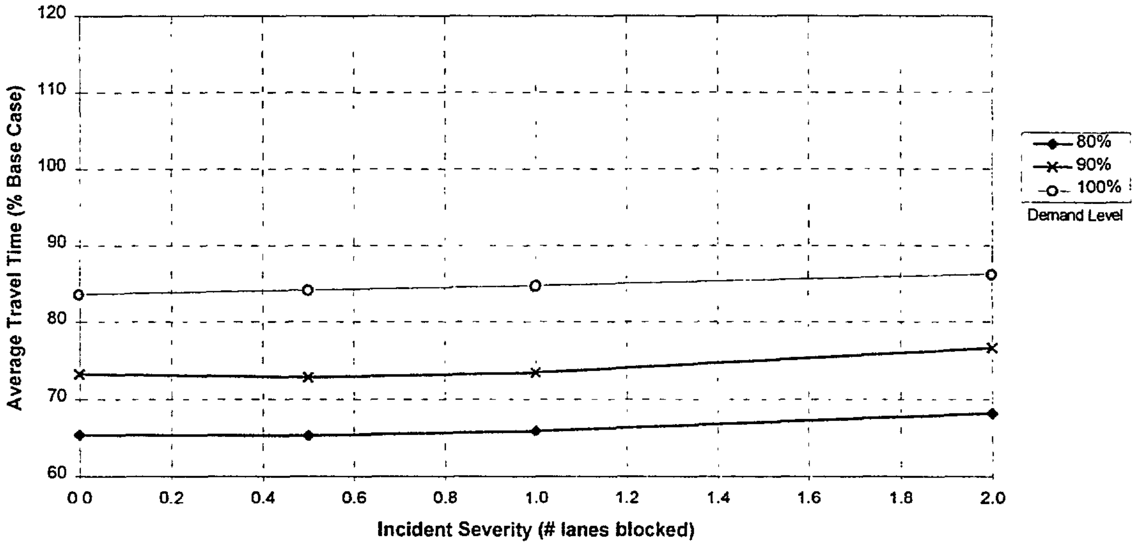

Figure B-8. Variation in average trip time as a function of incident severity and demand level (50% LMP)

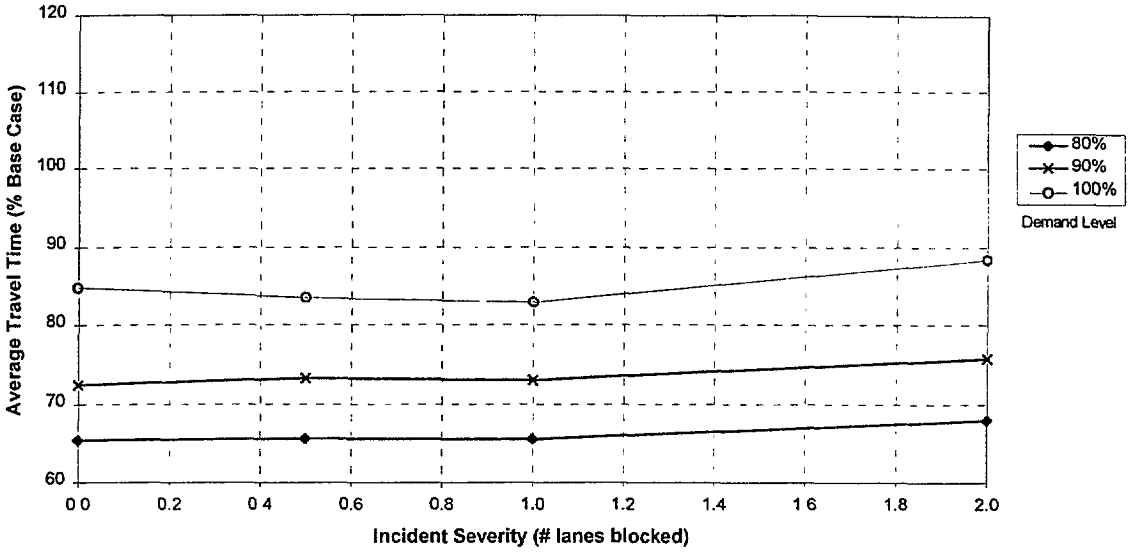

Figure B-9. Variation in average trip time as a function of incident severity and demand level (99% LMP)

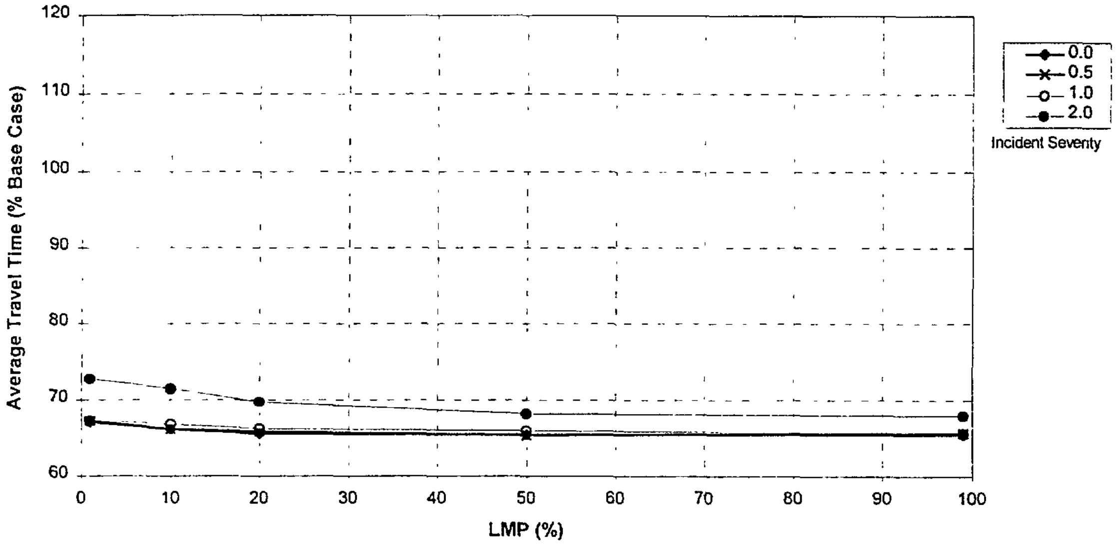

Figure B-10. Variation in average trip time as a function of LMP and incident severity (80% demand)

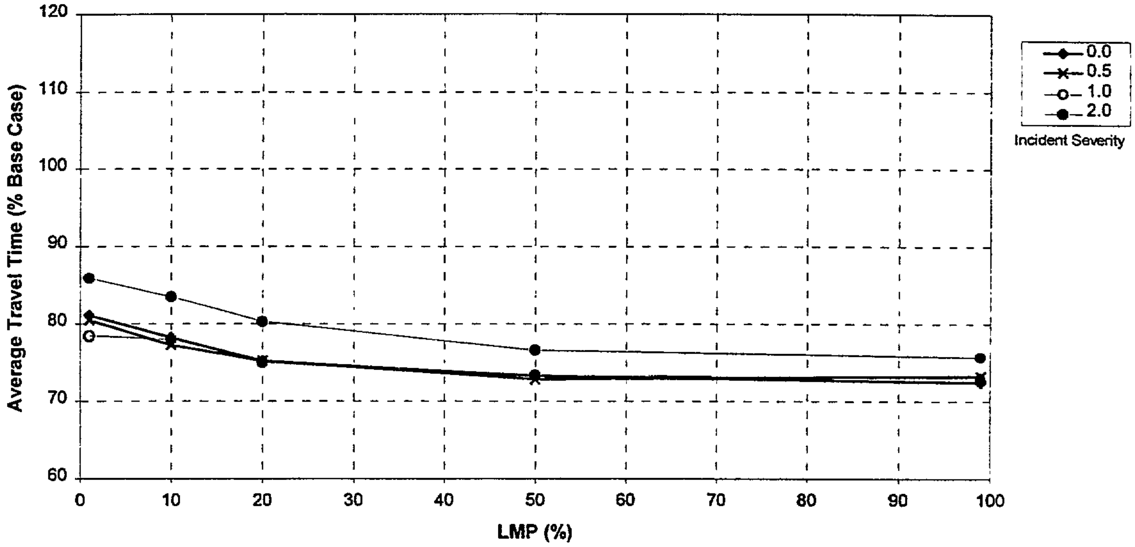

Figure B-11. Variation in average trip time as a function of LMP and incident severity (90% demand)

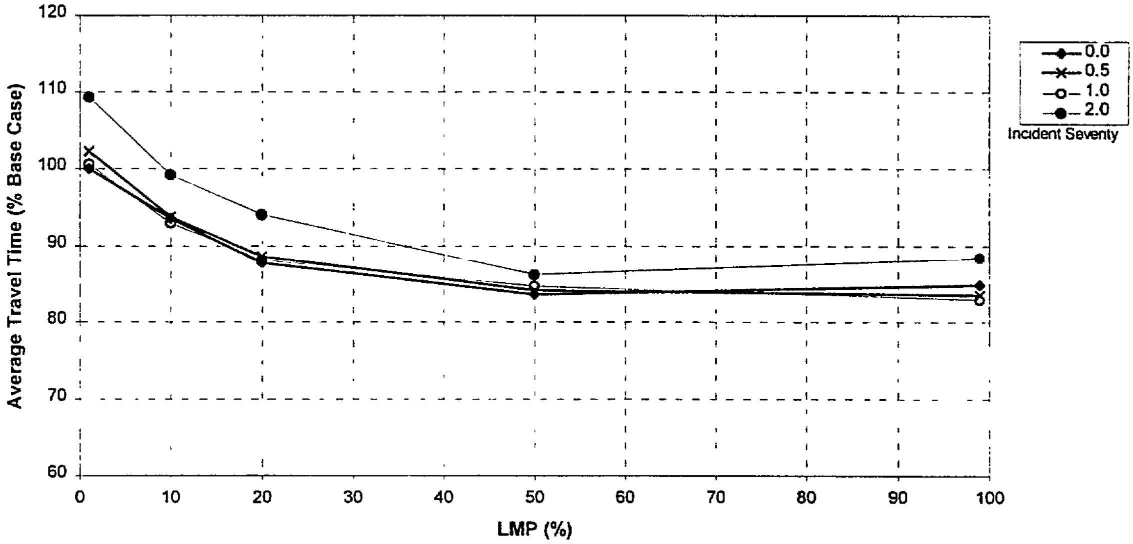

Figure B-12. Variation in average trip time as a function of LMP and incident severity (100% demand)

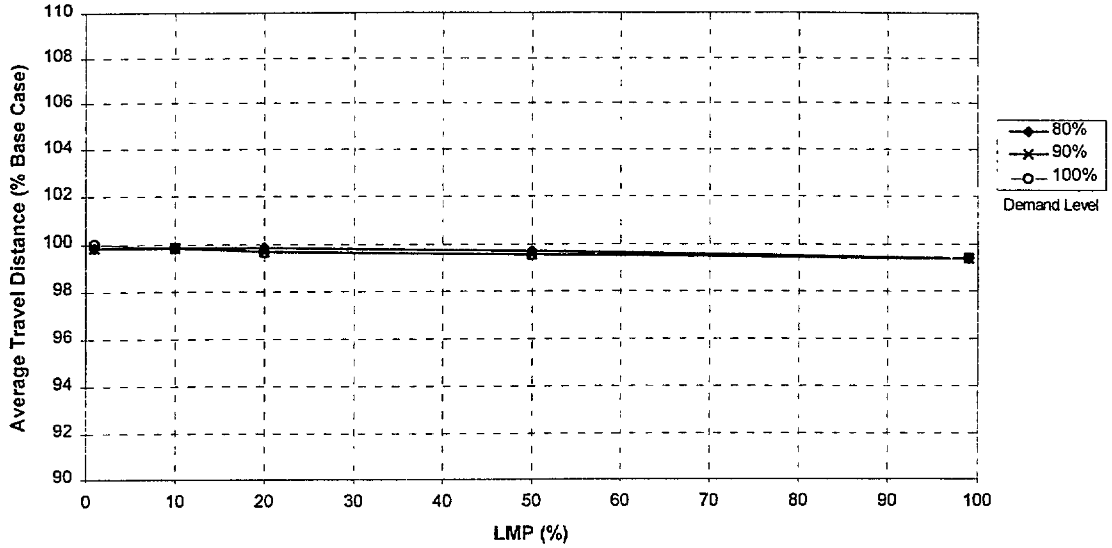

Figure B-13. Variation in average trip length as a function of LMP and demand level (No incident)

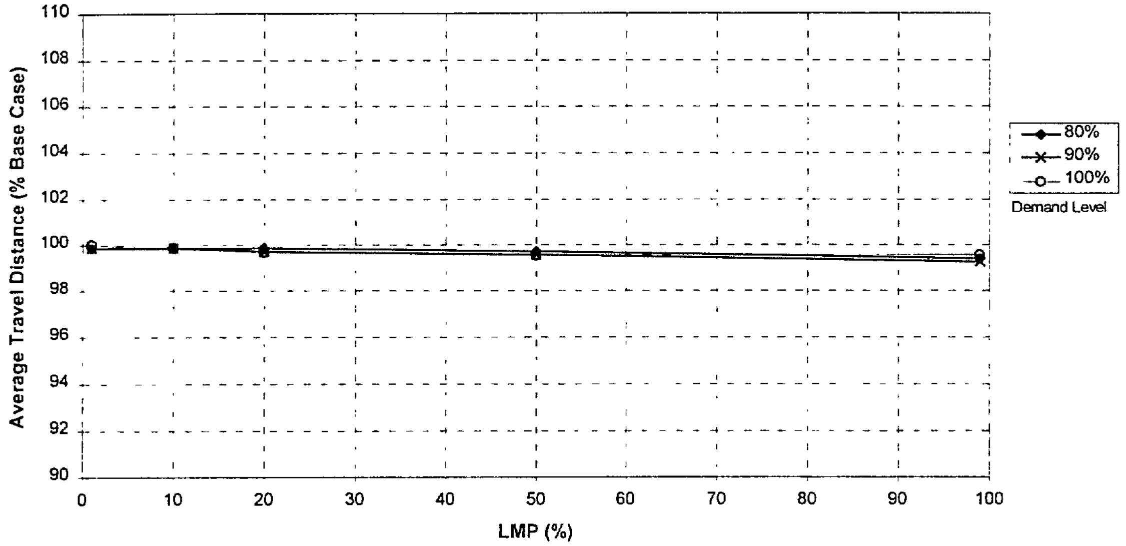

Figure B-14. Variation in average trip length as a function of LMP and demand level (0.5-lane blockage)

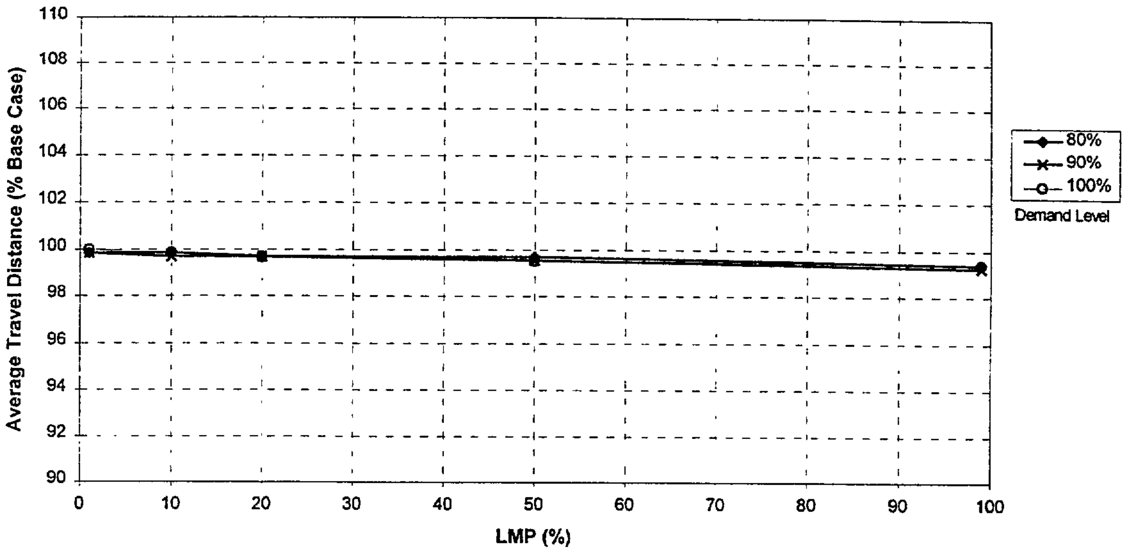

Figure B-15. Variation in average trip length as a function of LMP and demand level (1-lane blockage)

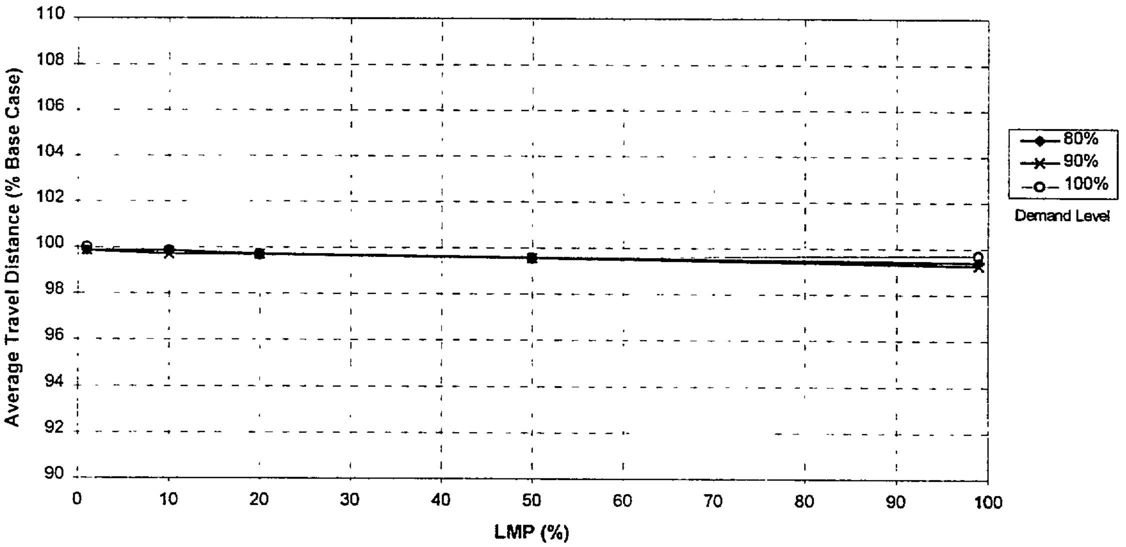

Figure B-16. Variation in average trip length as a function of LMP and demand level (2-lane blockage)

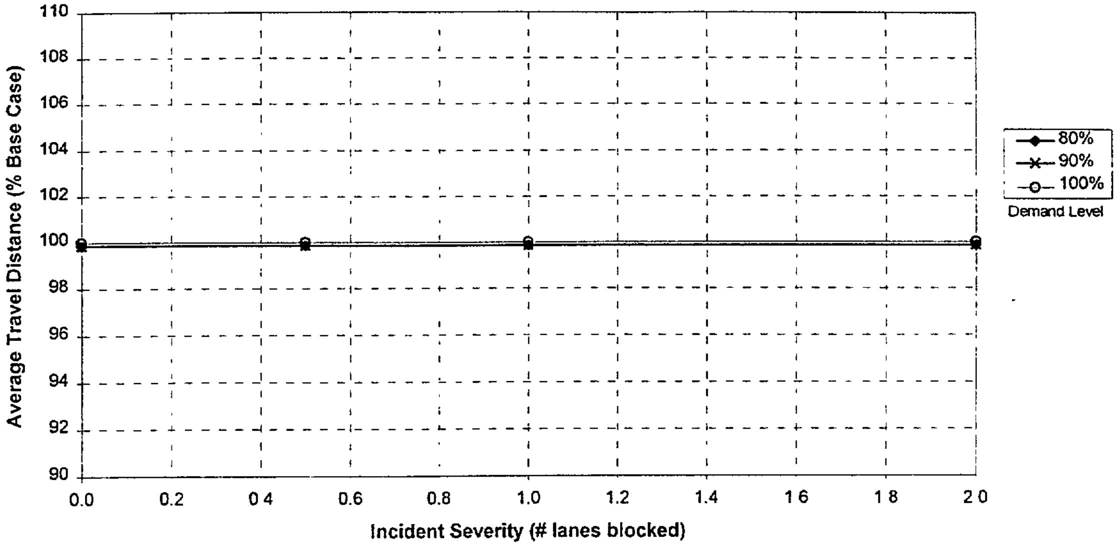

Figure B-17. Variation in average trip length as a function of incident severity and demand level (1% LMP)

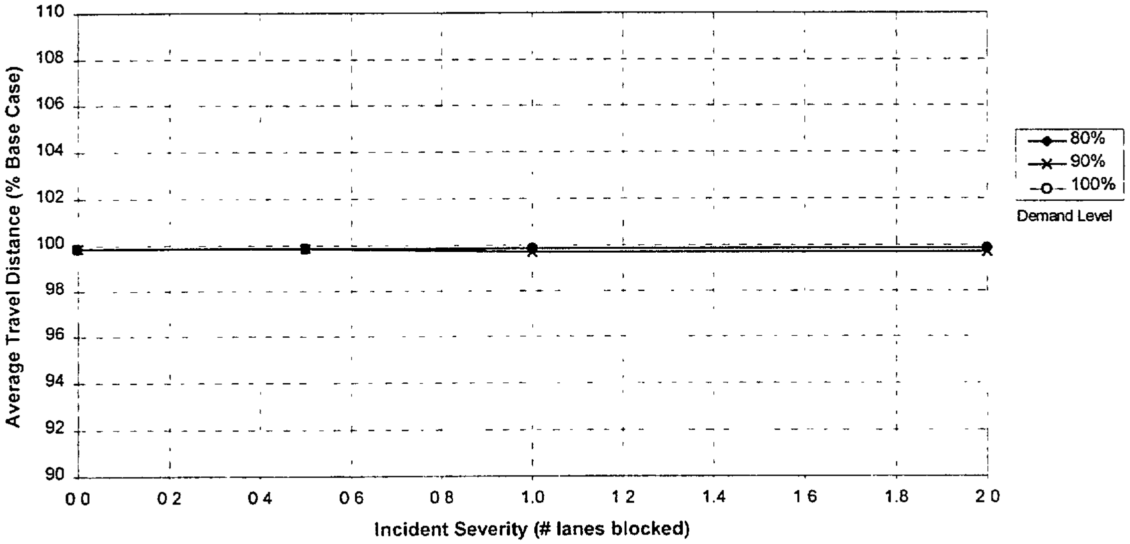

Figure B-18. Variation in average trip length as a function of incident severity and demand level (10% LMP)

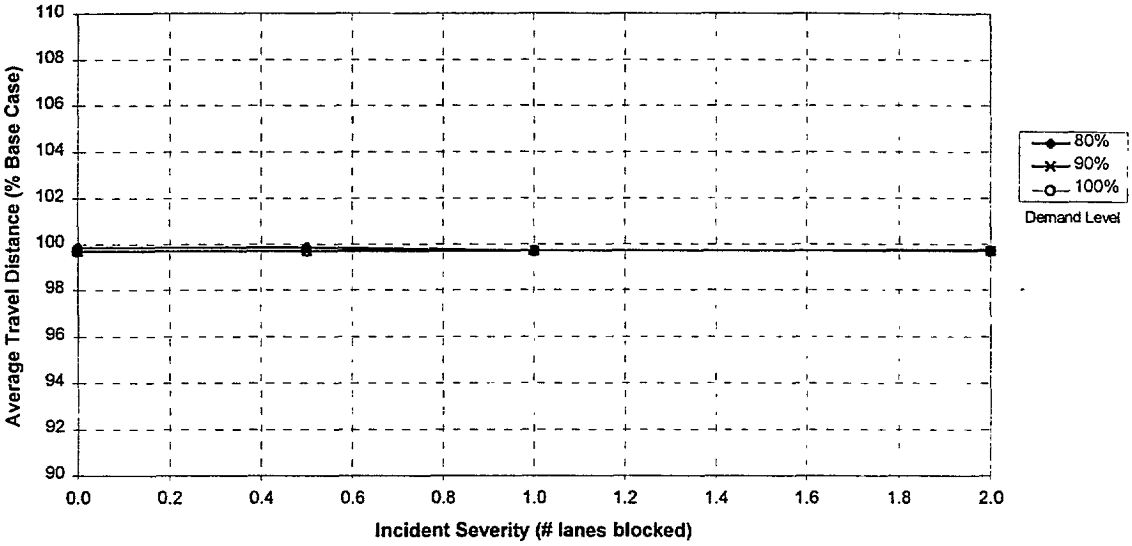

Figure B-19. Variation in average trip length as a function of incident severity and demand level (20% LMP)

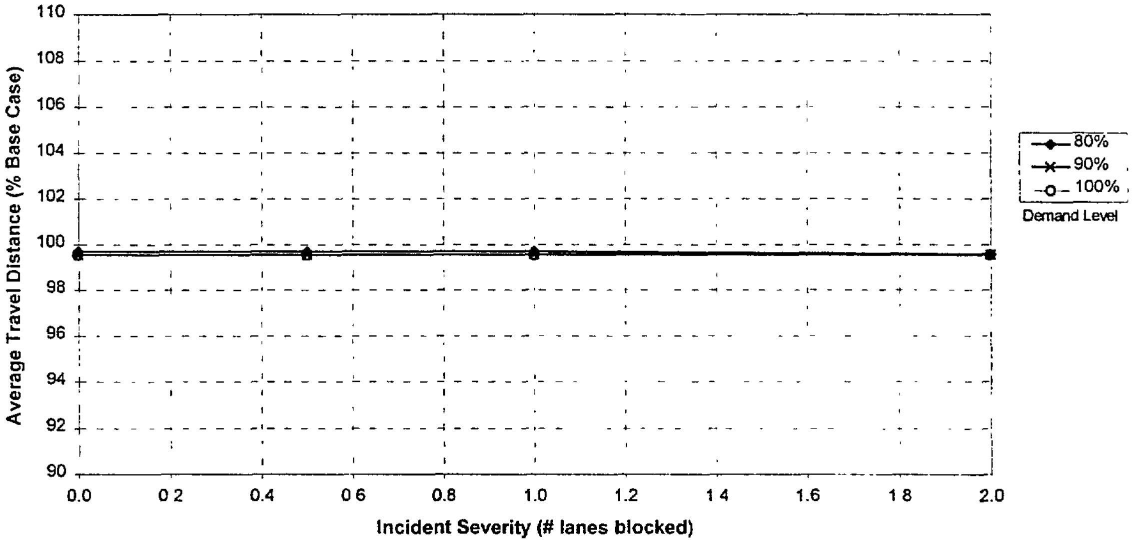

Figure B-20. Variation in average trip length as a function of incident severity and demand level (50% LMP)

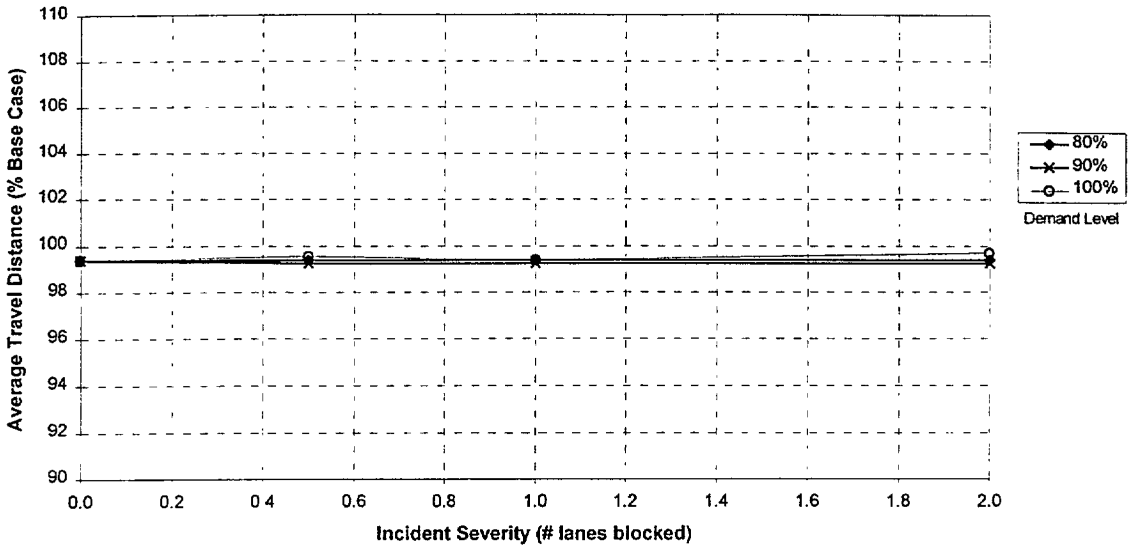

Figure B-21. Variation in average trip length as a function of incident severity and demand level (99% LMP)

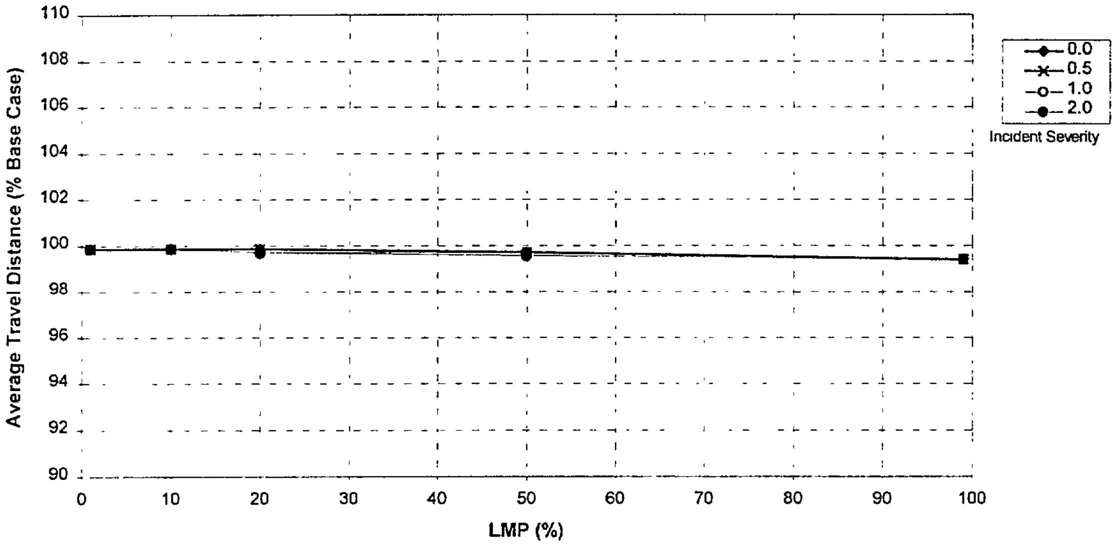

Figure B-22. Variation in average trip length as a function of LMP and incident severity (80% demand)

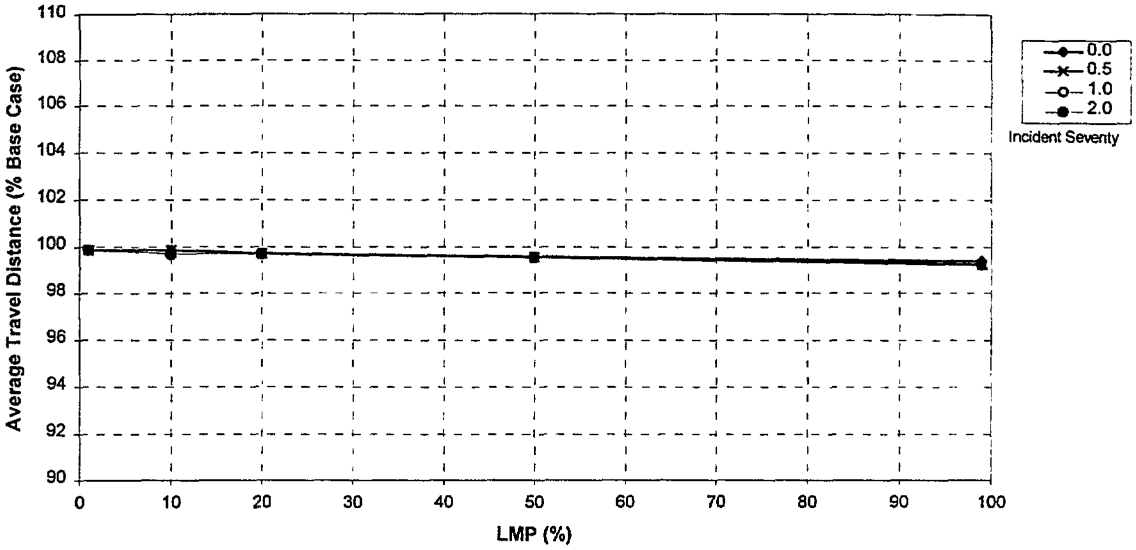

Figure B-23. Variation in average trip length as a function of LMP and incident severity (90% demand)

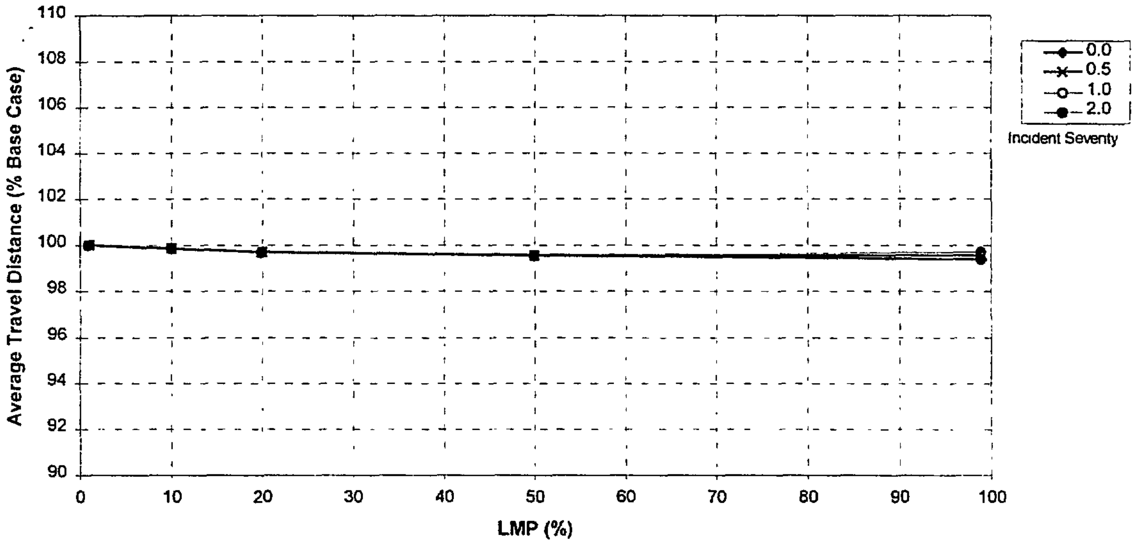

Figure B-24. Variation in average trip length as a function of LMP and incident severity (100% demand)

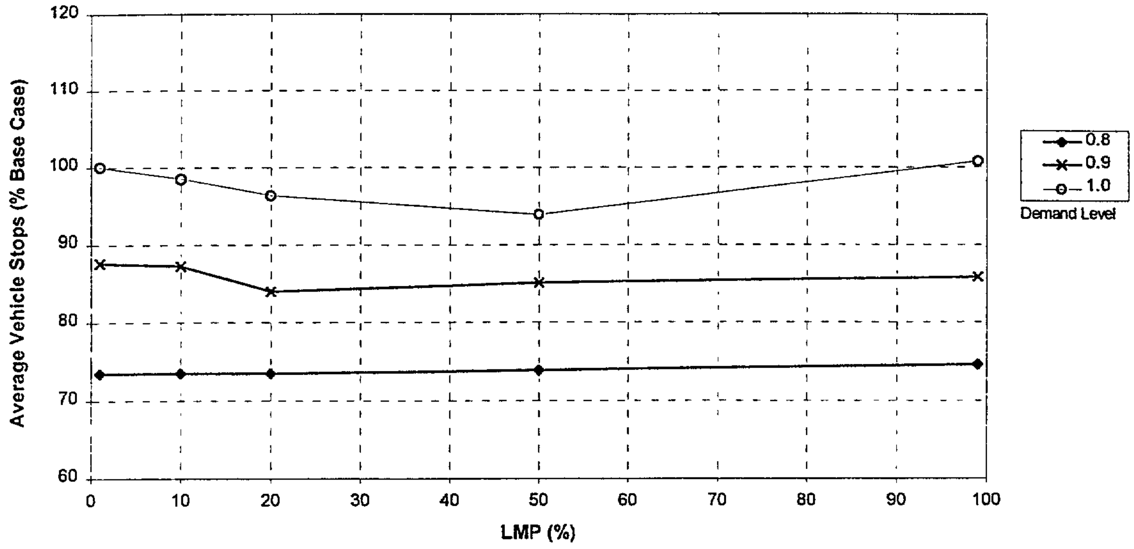

Figure B-25. Variation in average number of vehicle stops as a function of LMP and demand level (No incident)

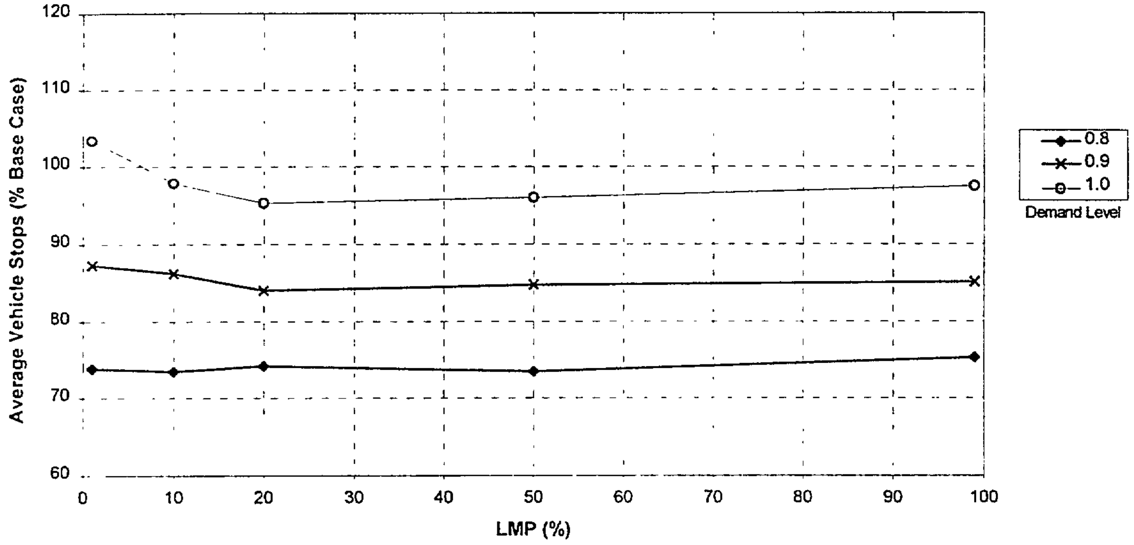

Figure B-26. Variation in average number of vehicle stops as a function of LMP and demand level (0.5-lane blockage)

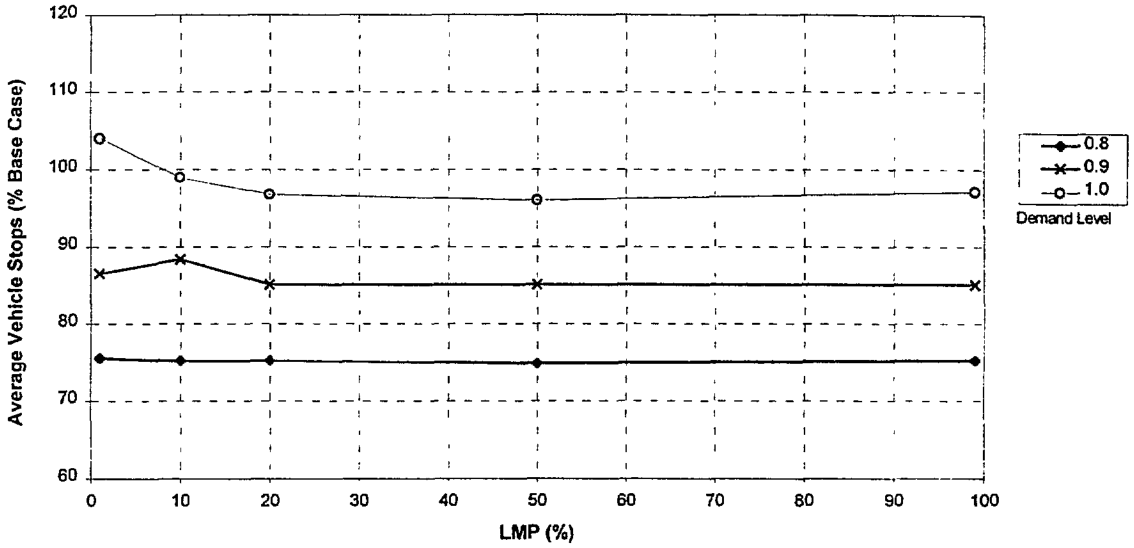

Figure B-27. Variation in average nmuber of vehicle stops as a function of LMP and demand level (1-lane blockage)

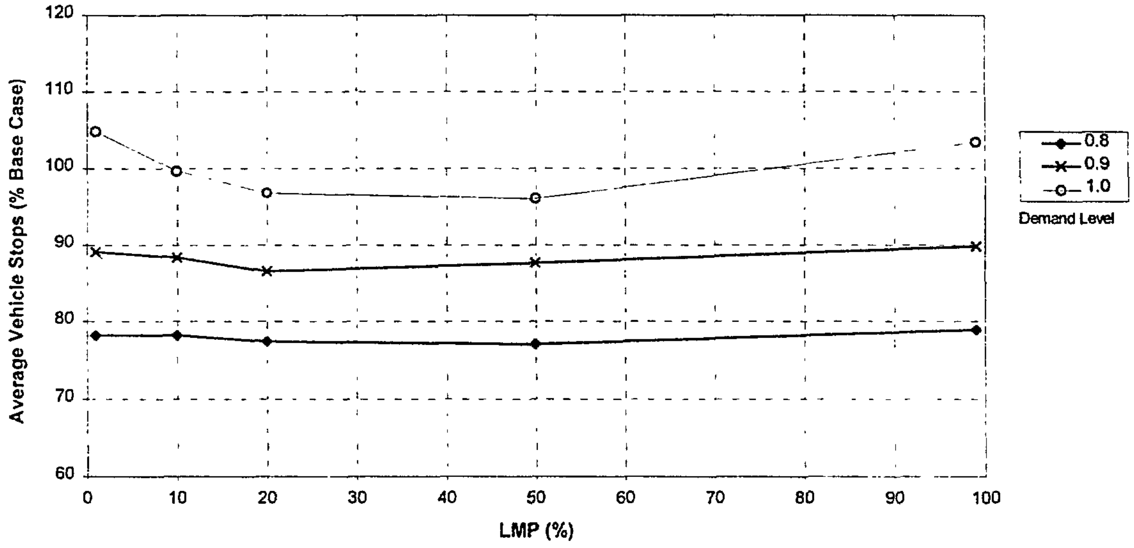

Figure B-28. Variation in average number of vehicle stops as a function of LMP and demand level (2-lane blockage)

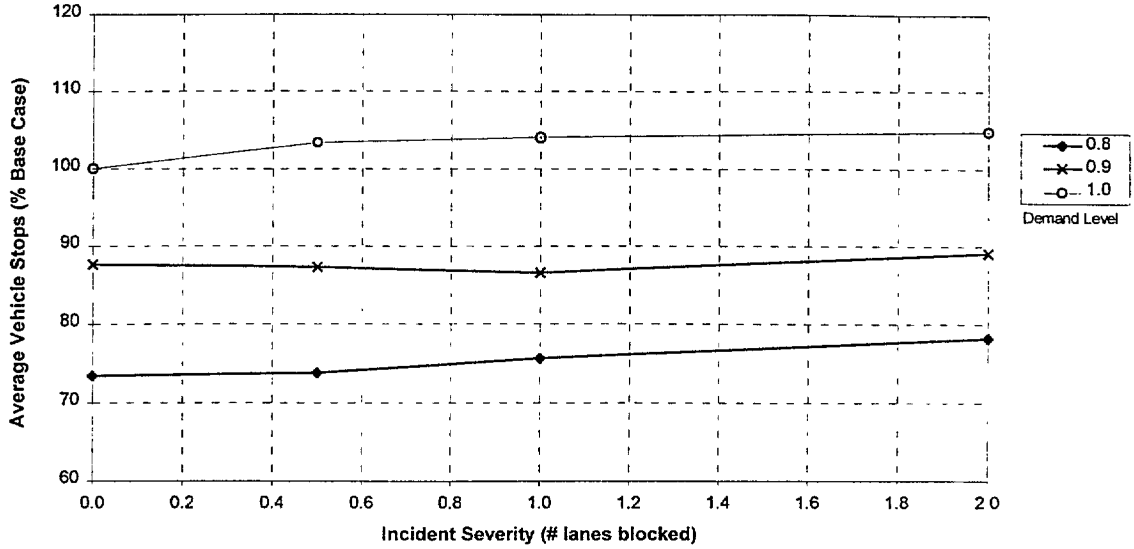

Figure B-29. Variation in average number of vehicle stops as a function of incident severity and demand level (1% LMP)

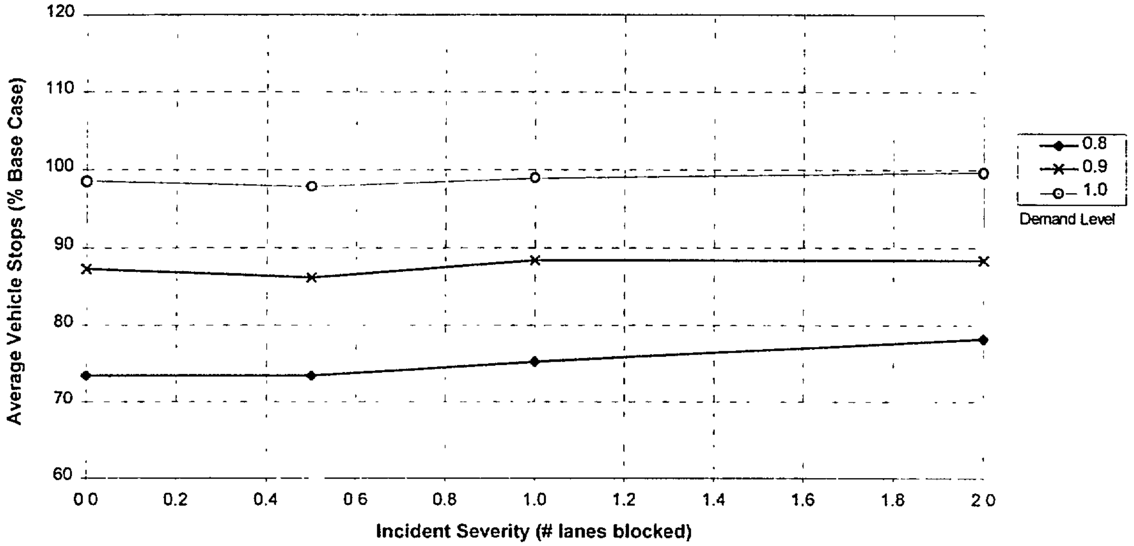

Figure B-30. Variation in average number of vehicle stops as a function of incident severity and demand level (10% LMP)

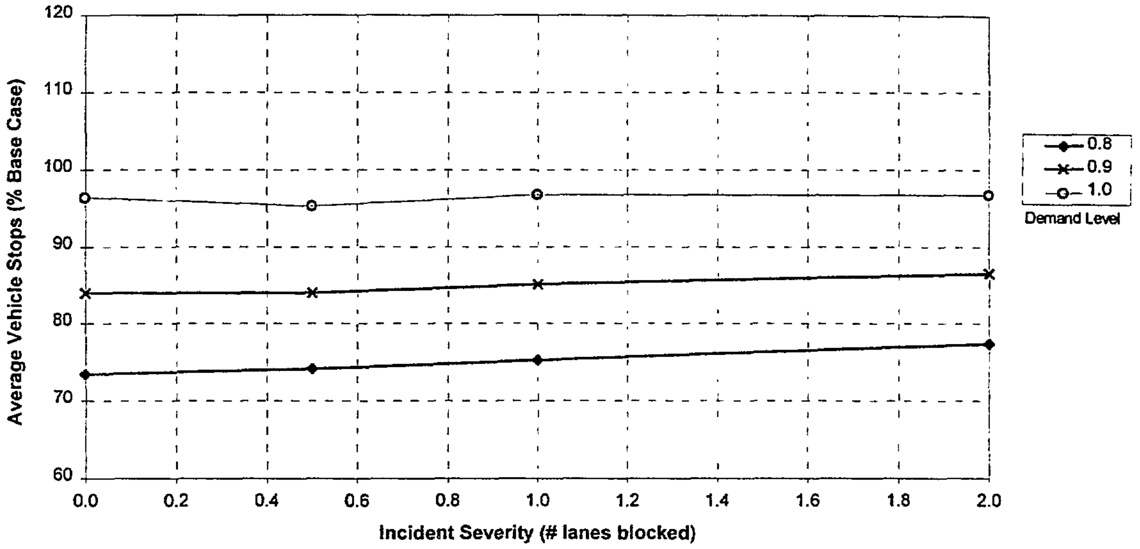

Figure B-31. Variation in average number of vehicle stops as a function of incident severity and demand level (20% LMP)

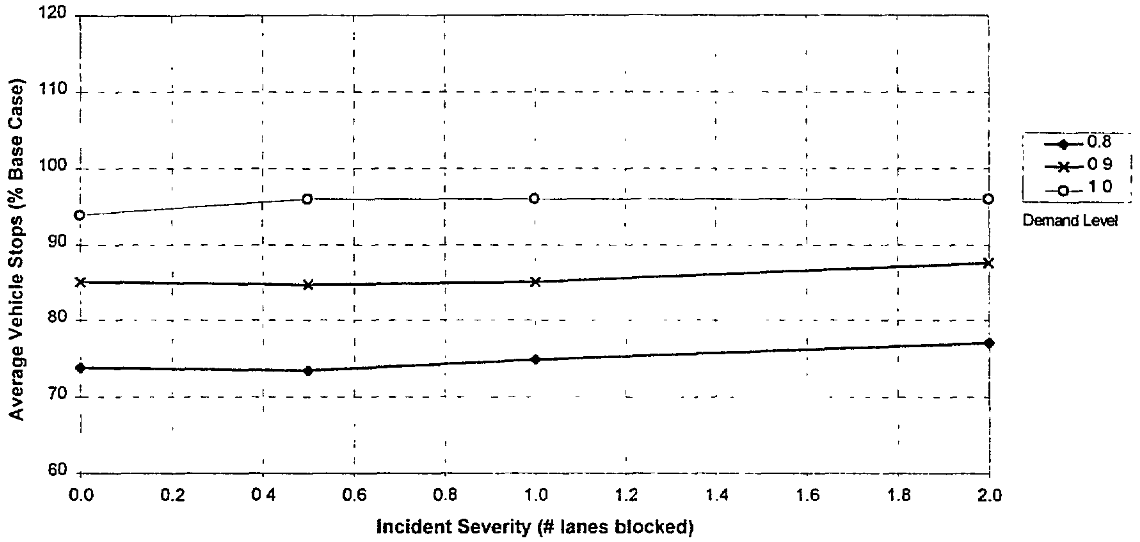

Figure B-32. Variation in average number of vehicle stops as a function of incident severity and demand level (50% LMP)

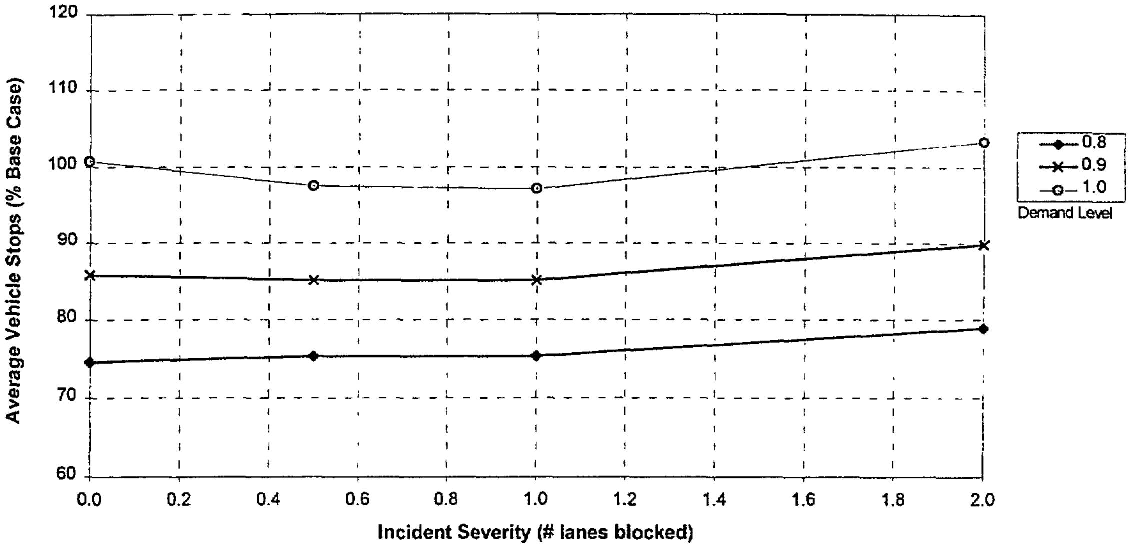

Figure B-33. Variation in average number of vehicle stops as a function of incident severity and demand level (99% LMP)

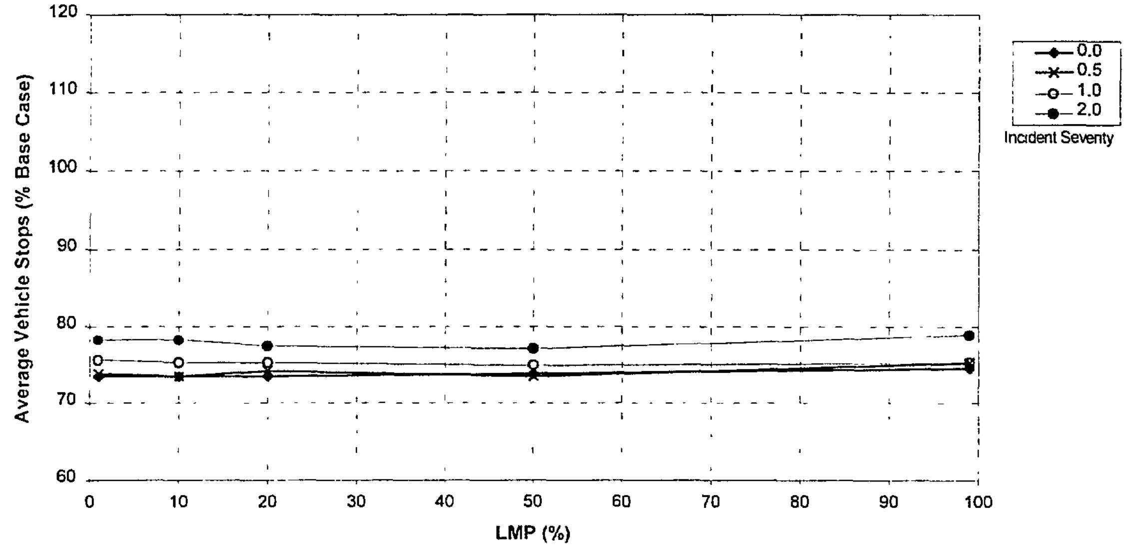

Figure B-34. Variation in average number of vehicle stops as a function of LMP and incident severity (80% demand)

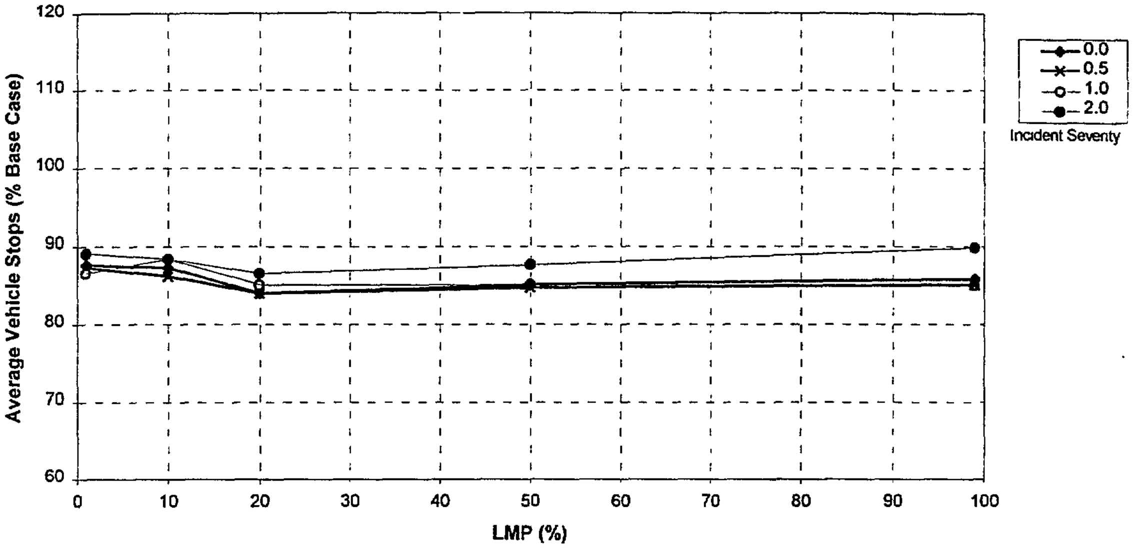

Figure B-35. Variation in average number of vehicle stops as a function of LMP and incident severity (90% demand)

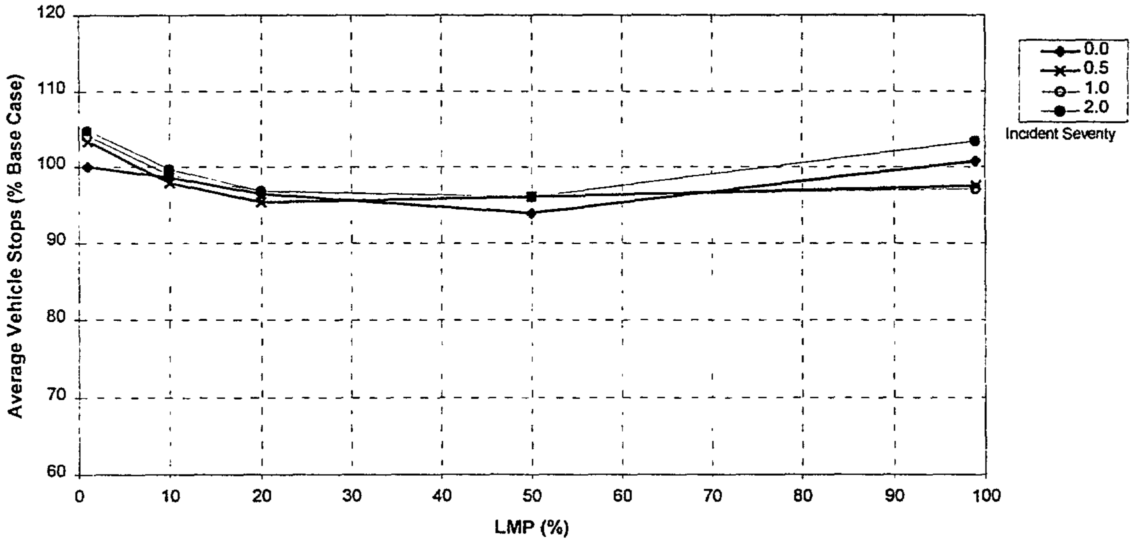

Figure B-36. Variation in average number of vehicle stops as a function of LMP and incident severity (100% demand)

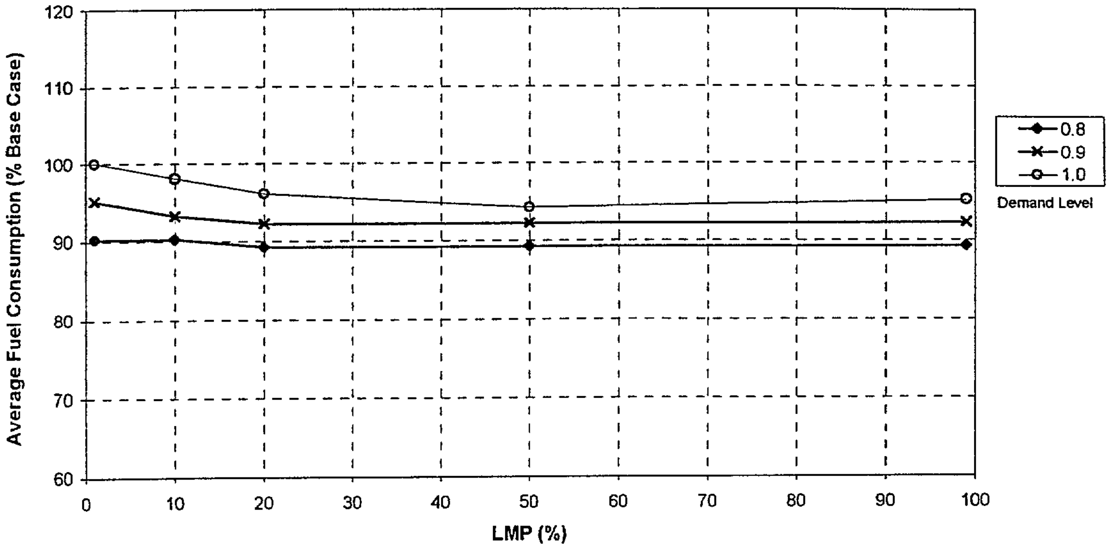

Figure B-37. Variation in average fuel consumption as a function of LMP and demand level (No incident)

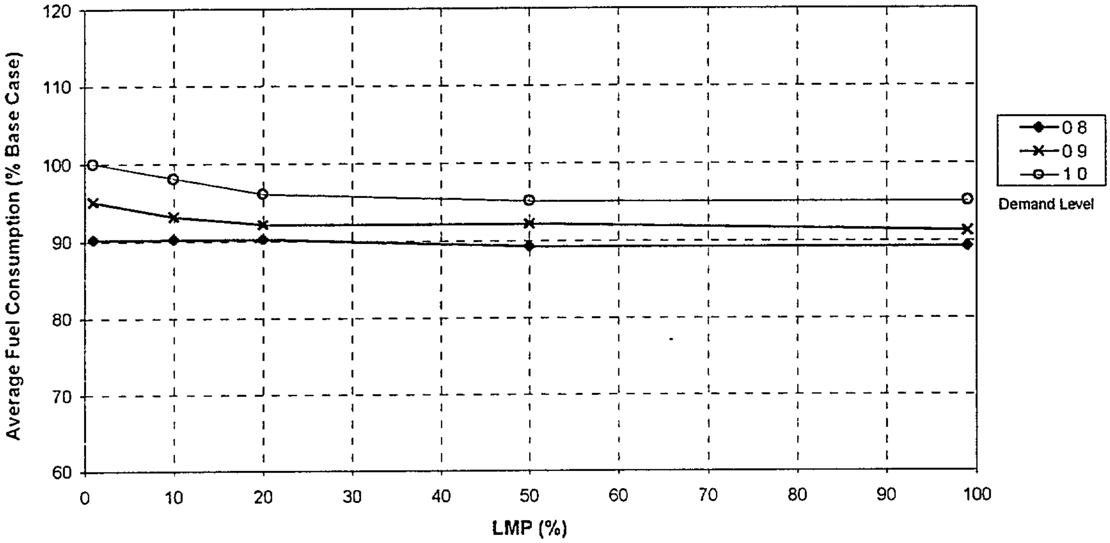

Figure B-38. Variation in average fuel consumption as a function of LMP and demand level (0.5-lane blockage)

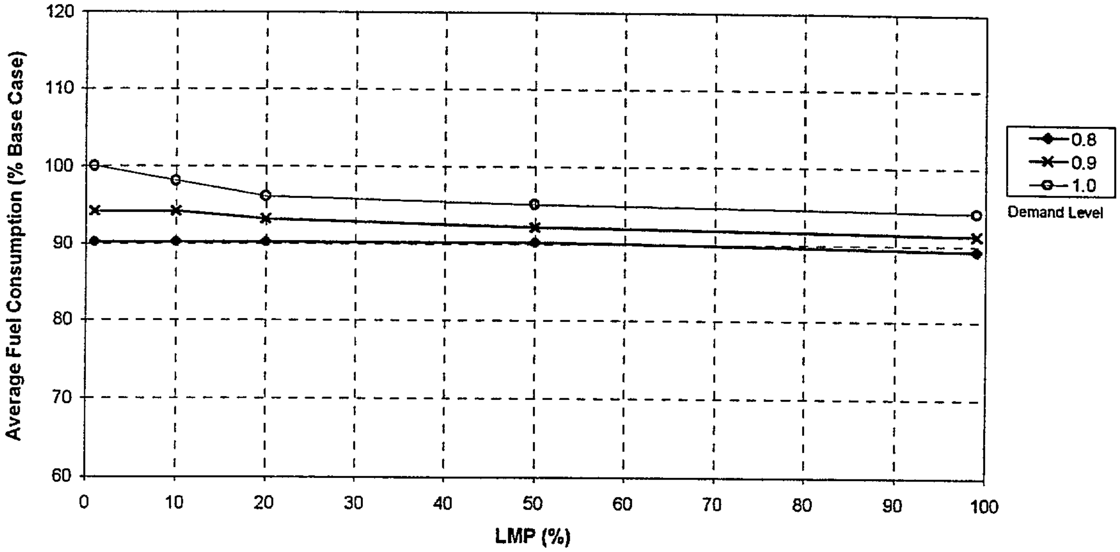

Figure B-39. Variation in average fuel consumption as a function of LMP and demand level (1-lane blockage)

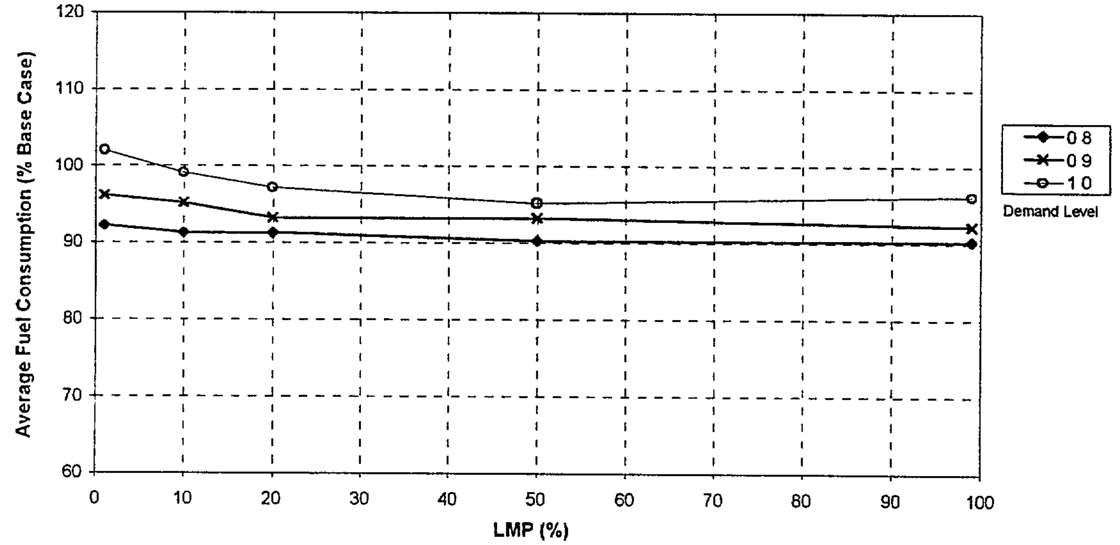

Figure B-40. Variation in average fuel consumption as a function of LMP and demand level (2-lane blockage)

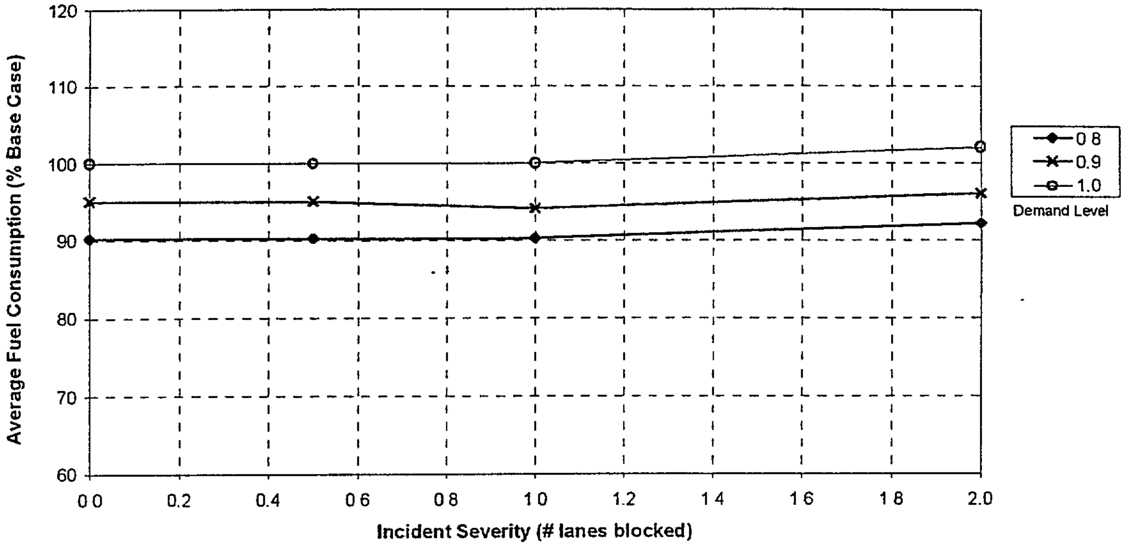

Figure B-41. Variation in average fuel consumption as a function of incident severity and demand level (1% LMP)

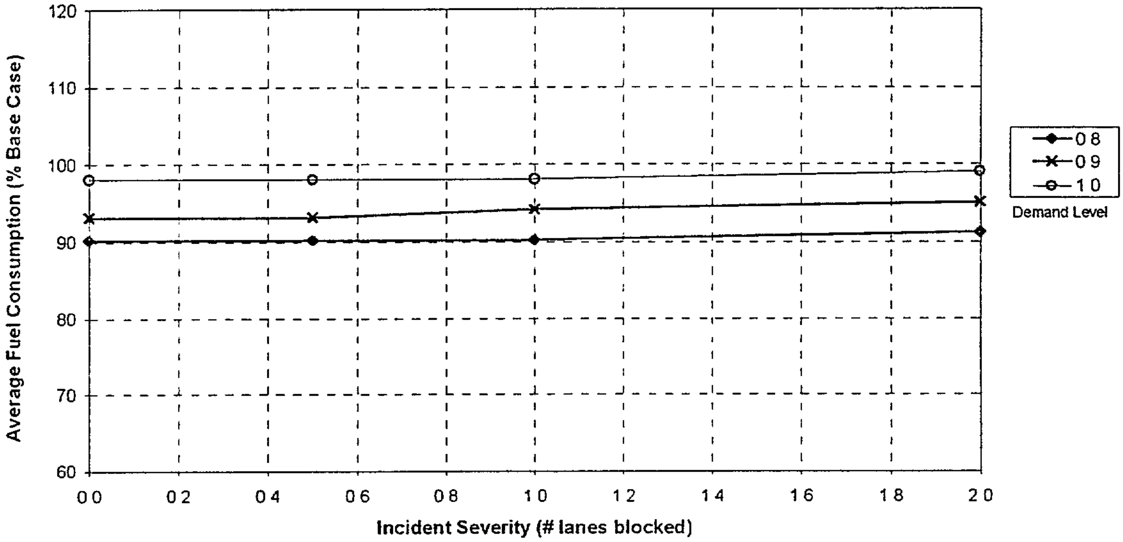

Figure B-42. Variation in average fuel consumption as a function of incident severity and demand level (10% LMP)

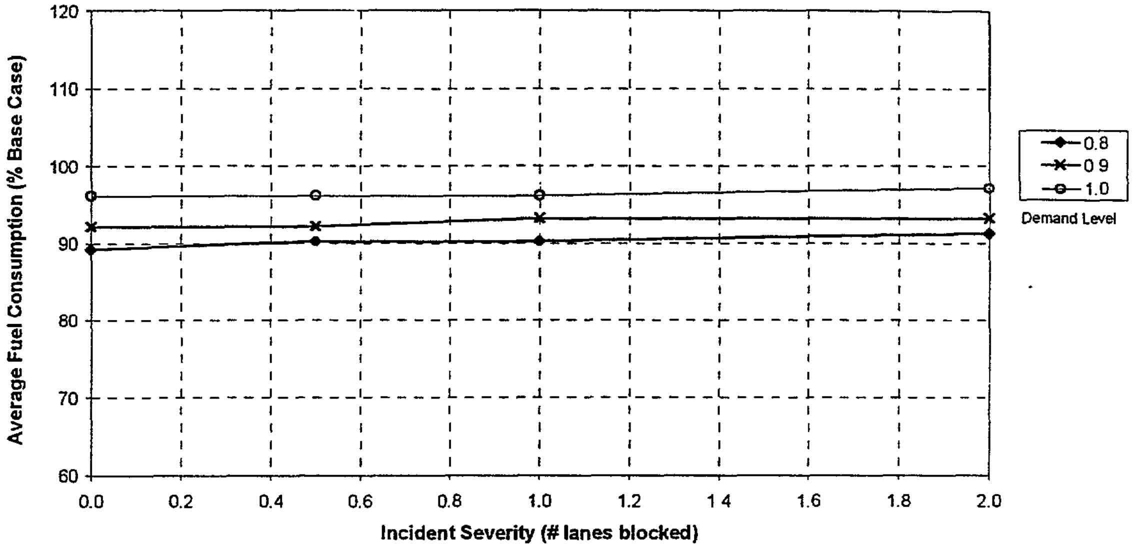

Figure B-43. Variation in average fuel consumption as a function of incident severity and demand level (20% LMP)

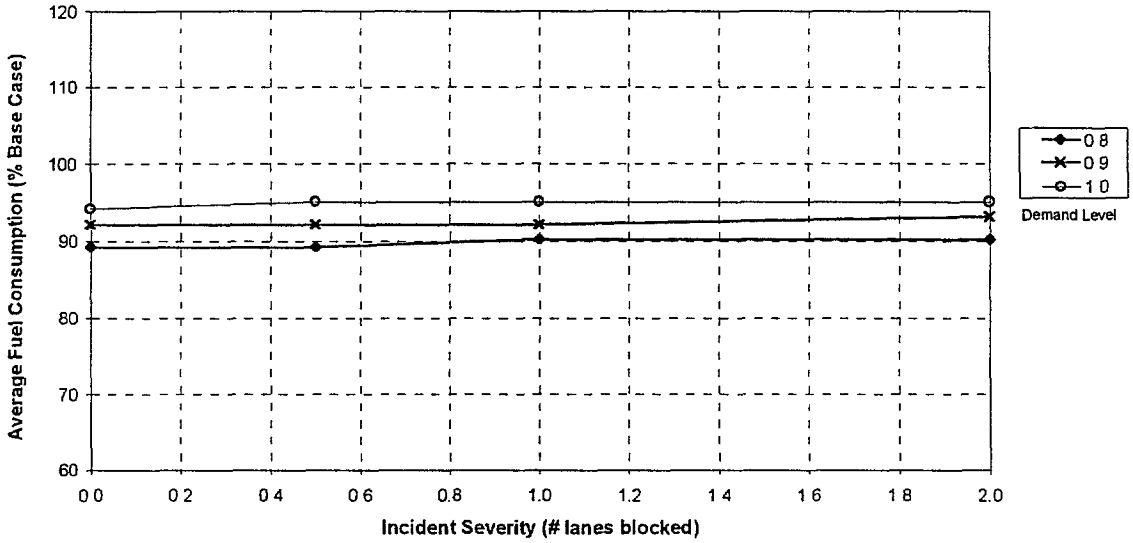

Figure B-44. Variation in average fuel consumption as a function of incident severity and demand level (50% LMP)

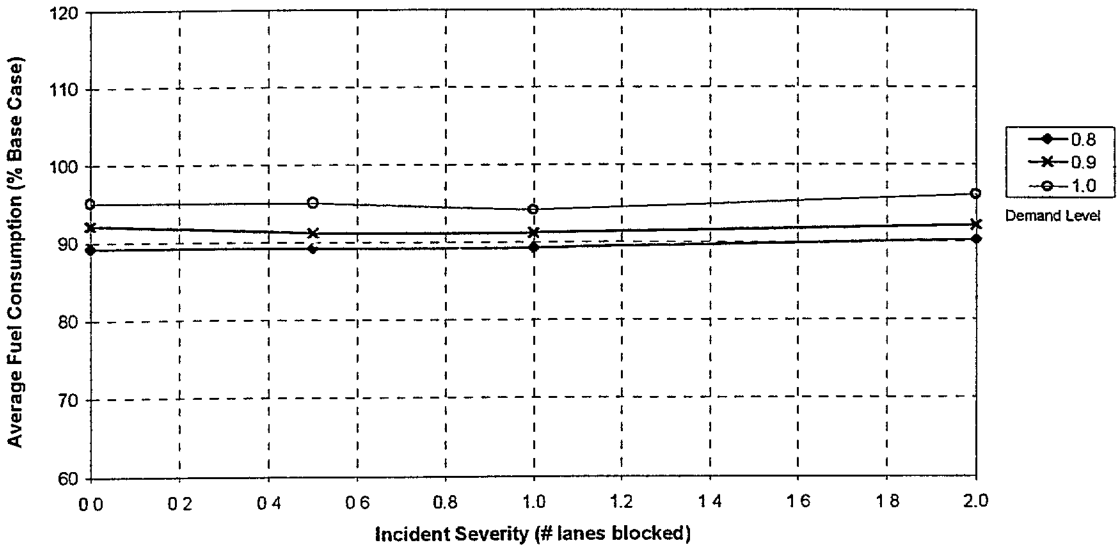

Figure B-45. Variation in average fuel consumption as a function of incident severity and demand level (99% LMP)

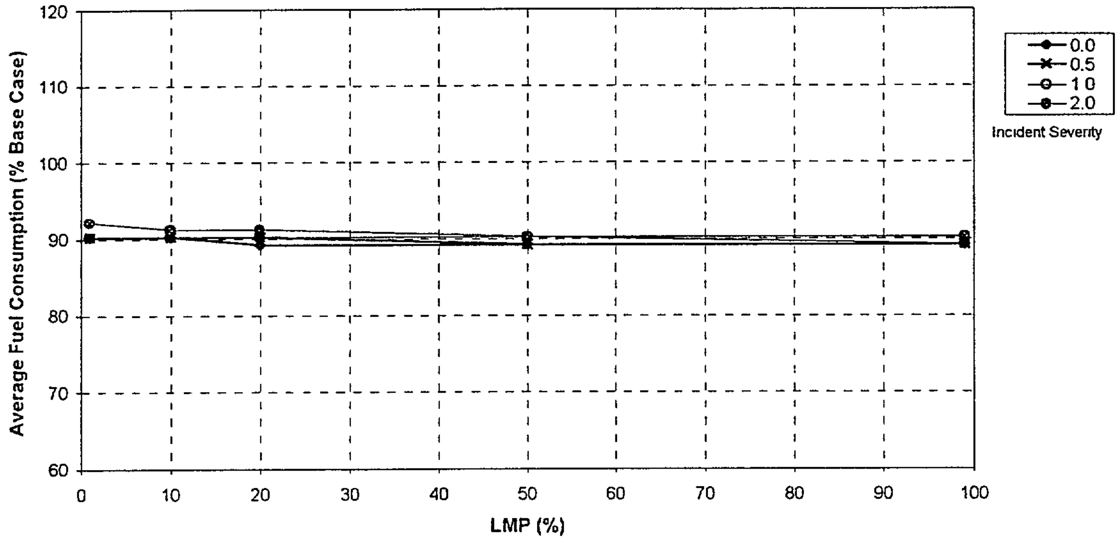

Figure B-46. Variation in average fuel consumption as a function of LMP and incident severity (80% demand)

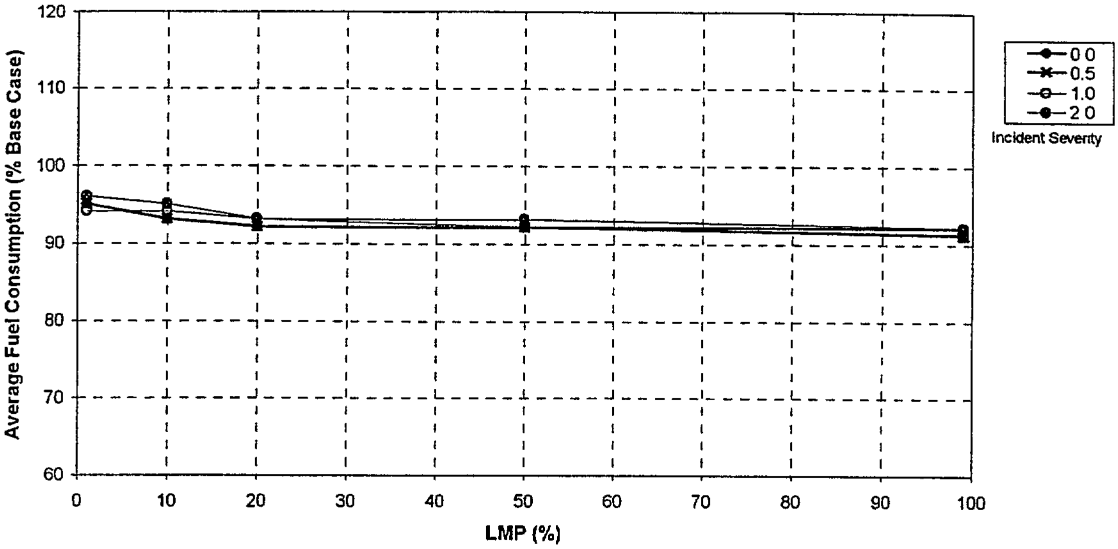

Figure B-47. Variation in average fuel consumption as a function of LMP and incident severity (90% demand)

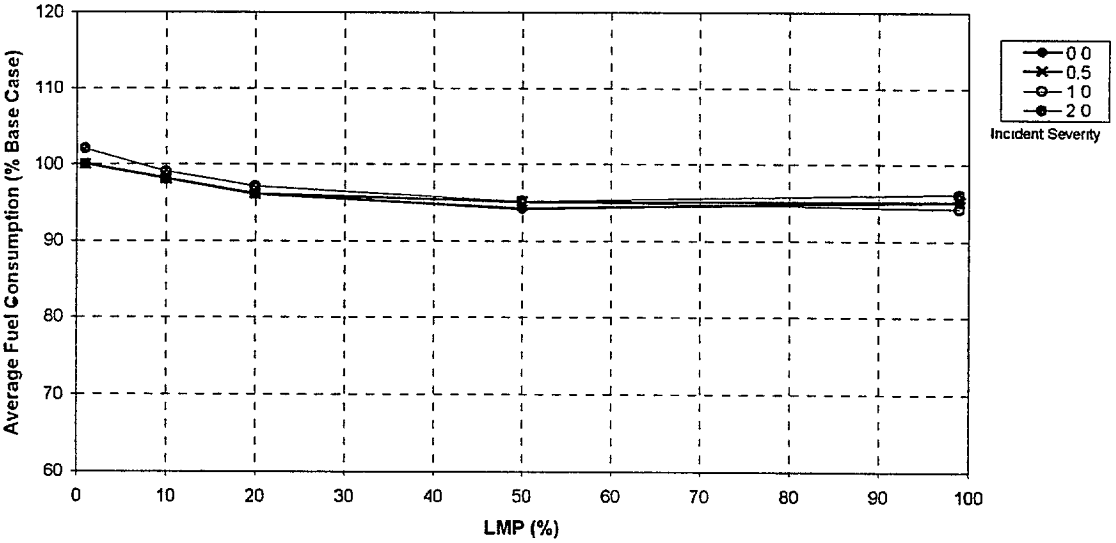

Figure B-48. Variation in average fuel consumption as a function of LMP and incident severity (100% demand)

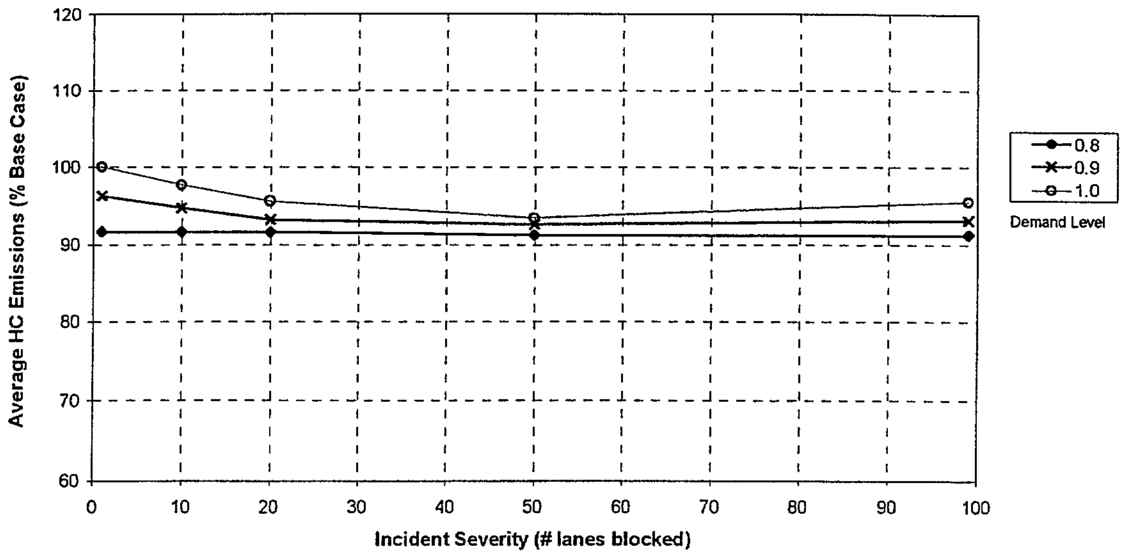

Figure B-49. Variation in average HC emissions as a function of LMP and demand level (No incident)

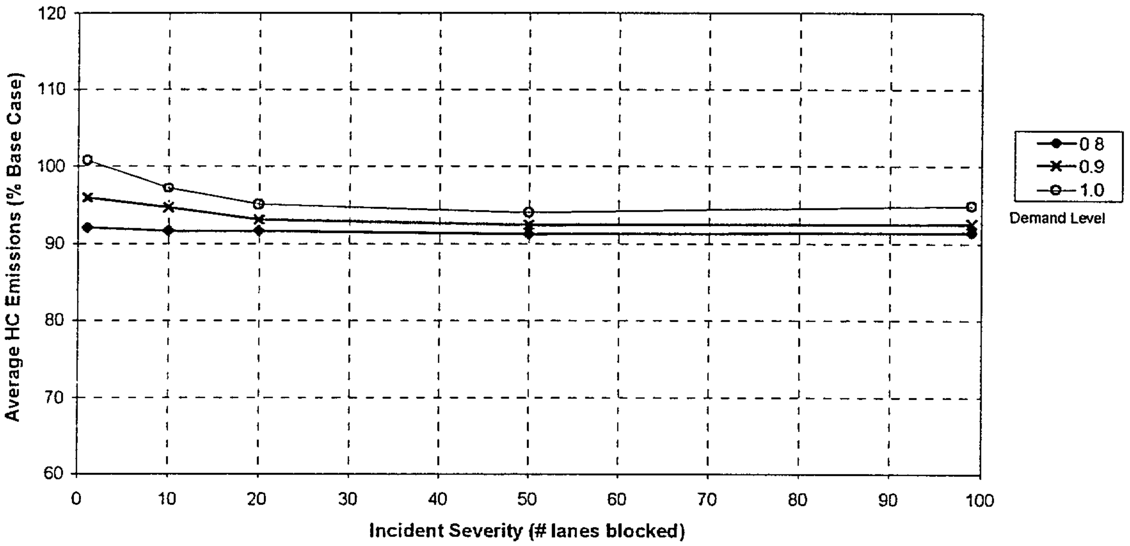

Figure B-50. Variation in average HC emissions as a function of LMP and demand level (0.5-lane blockage)

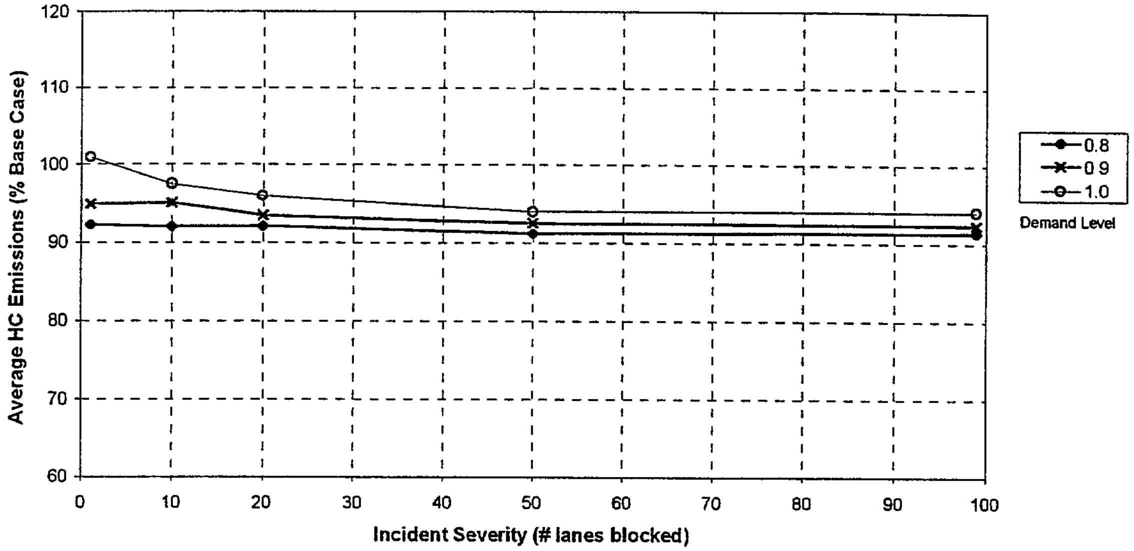

Figure B-51. Variation in average HC emissions as a function of LMP and demand level (1-lane blockage)

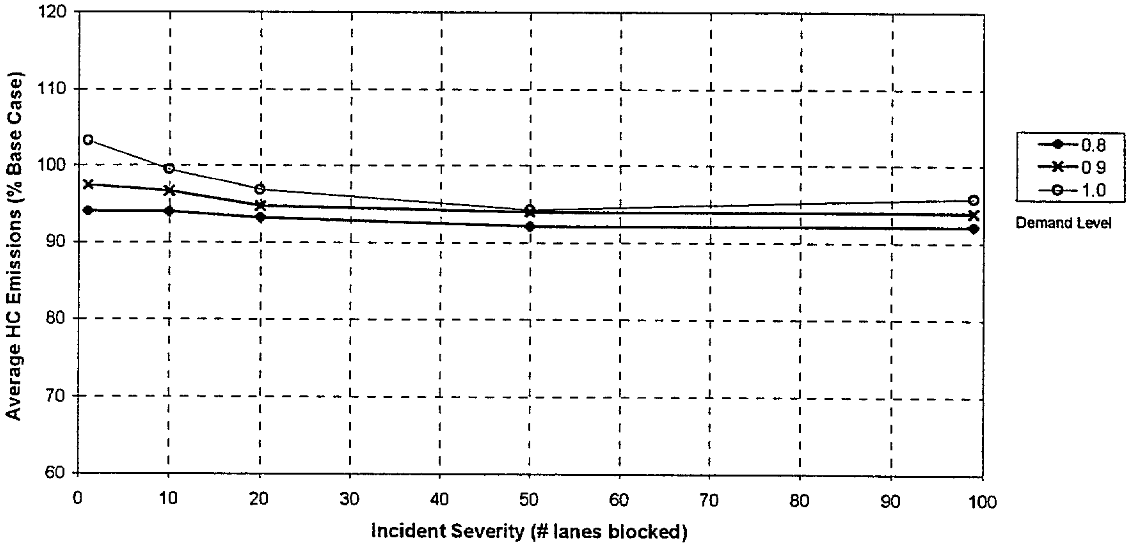

Figure B-52. Variation in average HC emissions as a function of LMP and demand level (2-lane blockage)

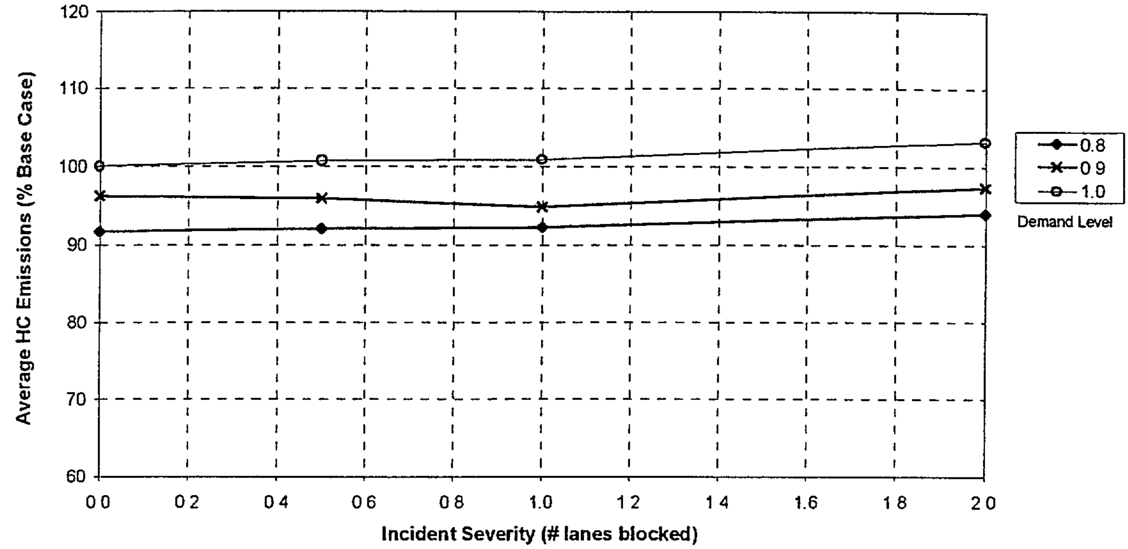

Figure B-53. Variation in average HC emissions as a function of incident severity and demand level (1% LMP)

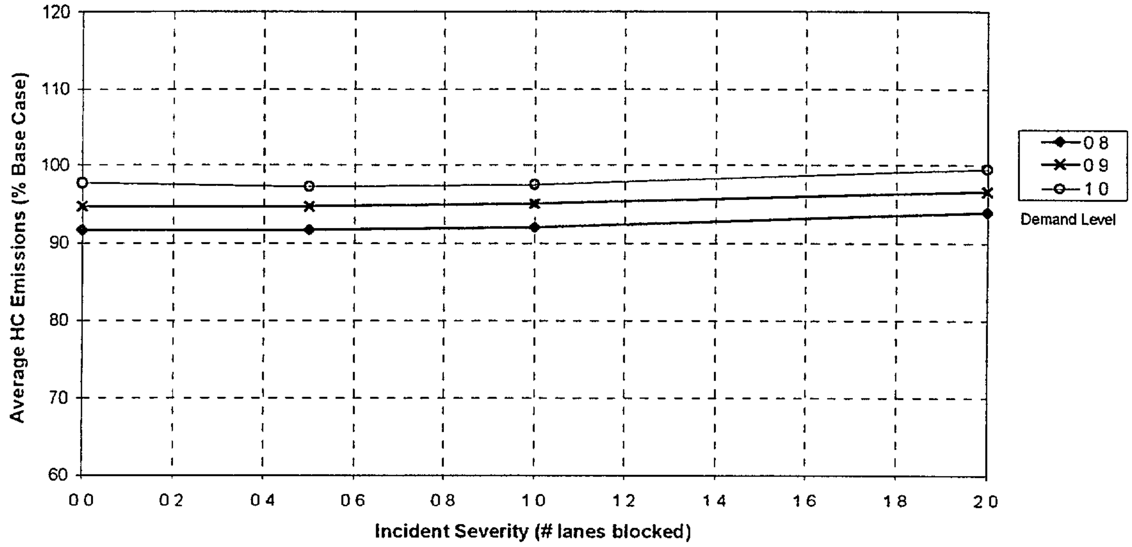

Figure B-54. Variation in average HC emissions as a function of incident severity and demand level (10% LMP)

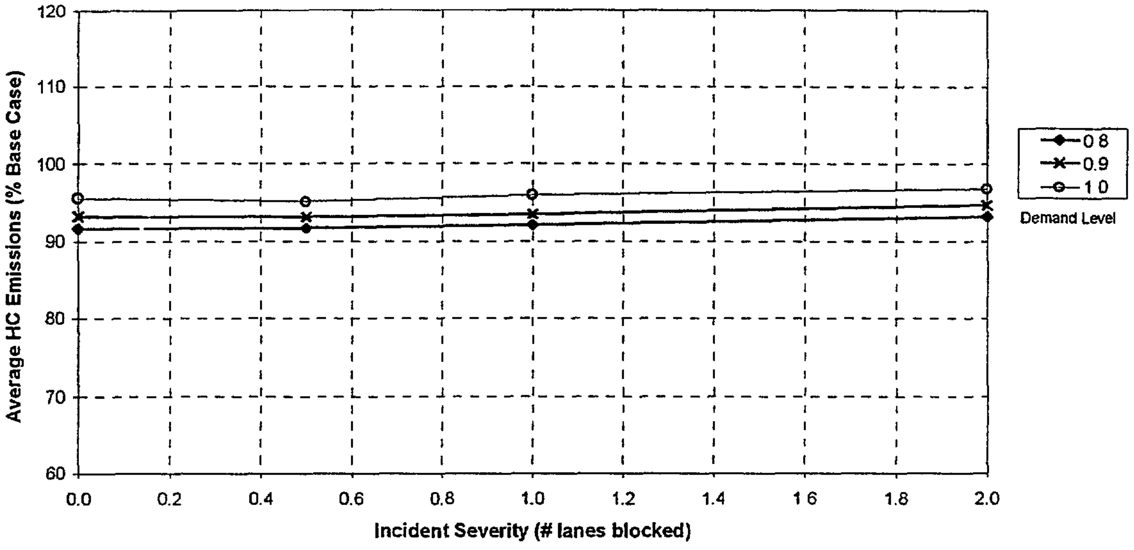

Figure B-55. Variation in average HC emissions as a function of incident severity and demand level (20% LMP)

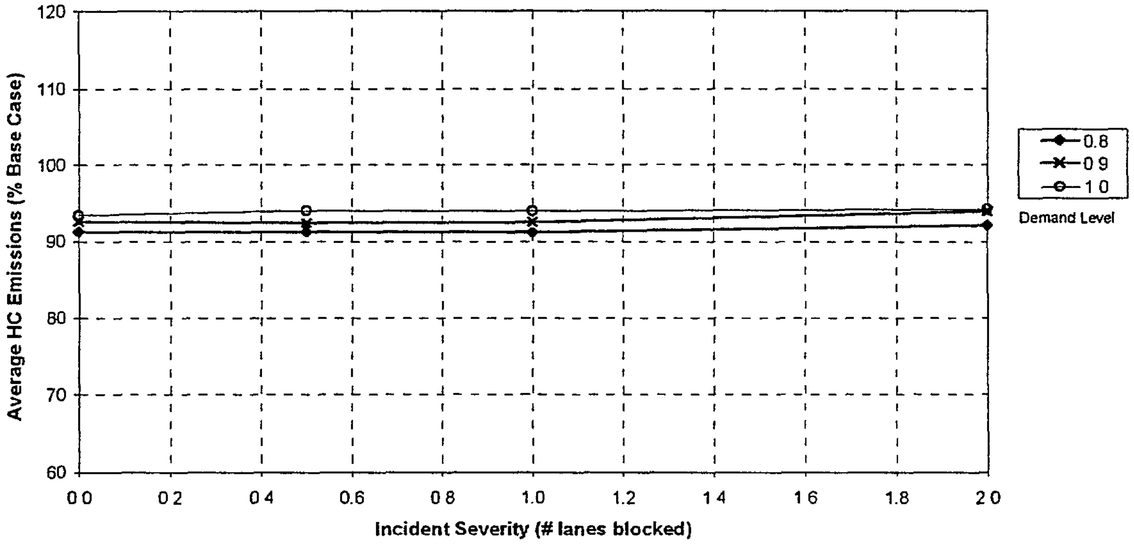

Figure B-56. Variation in average HC emissions as a function of incident severity and demand level (50% LMP)

Figure B-57. Variation in average HC emissions as a function of incident severity and demand level (99% LMP)

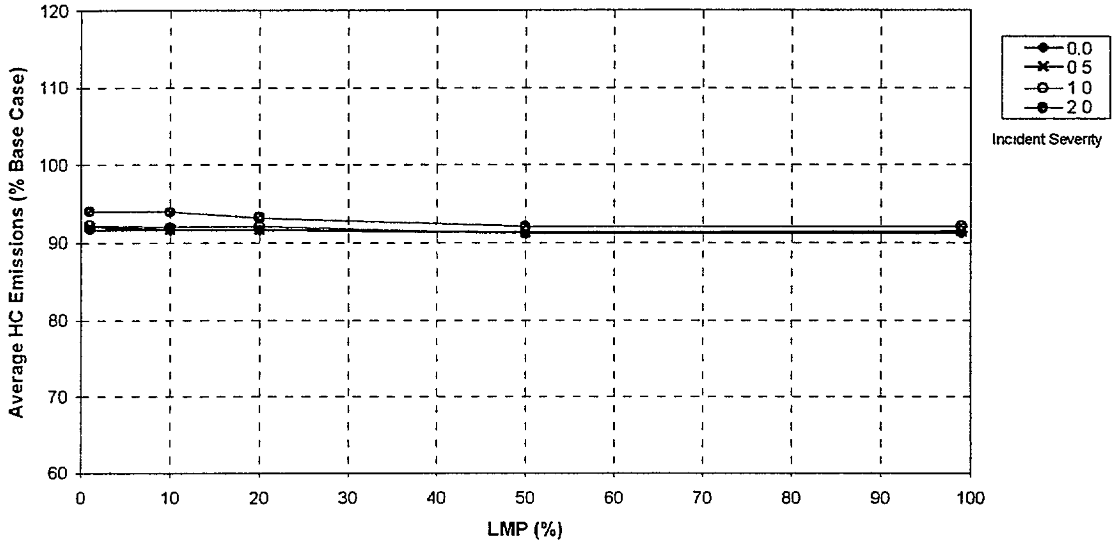

Figure B-58. Variation in average HC emissions as a function of LMP and incident severity (80% demand)

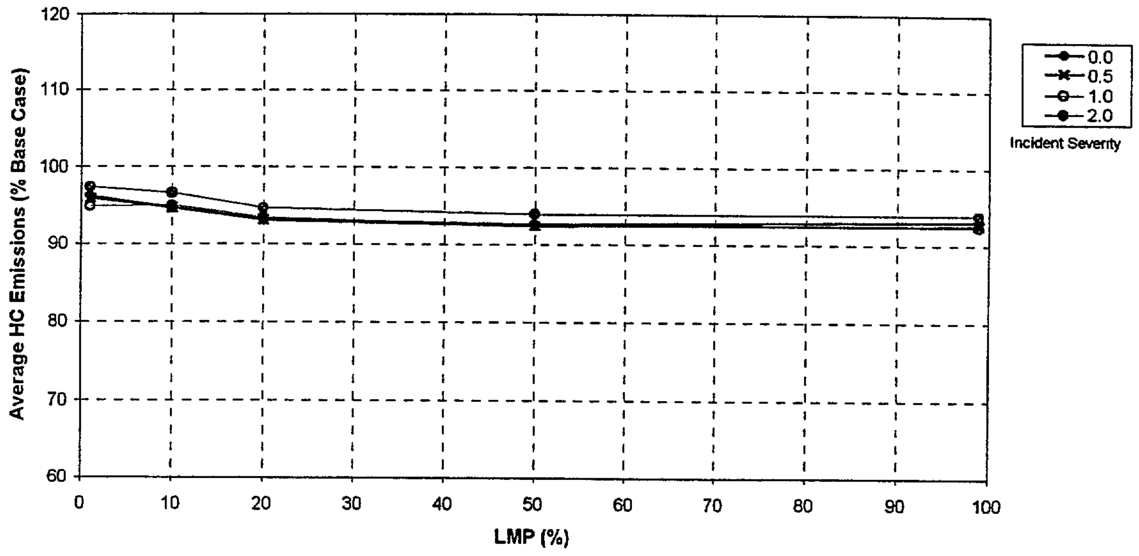

Figure B-59. Variation in average HC emissions as a function of LMP and incident severity (90% demand)

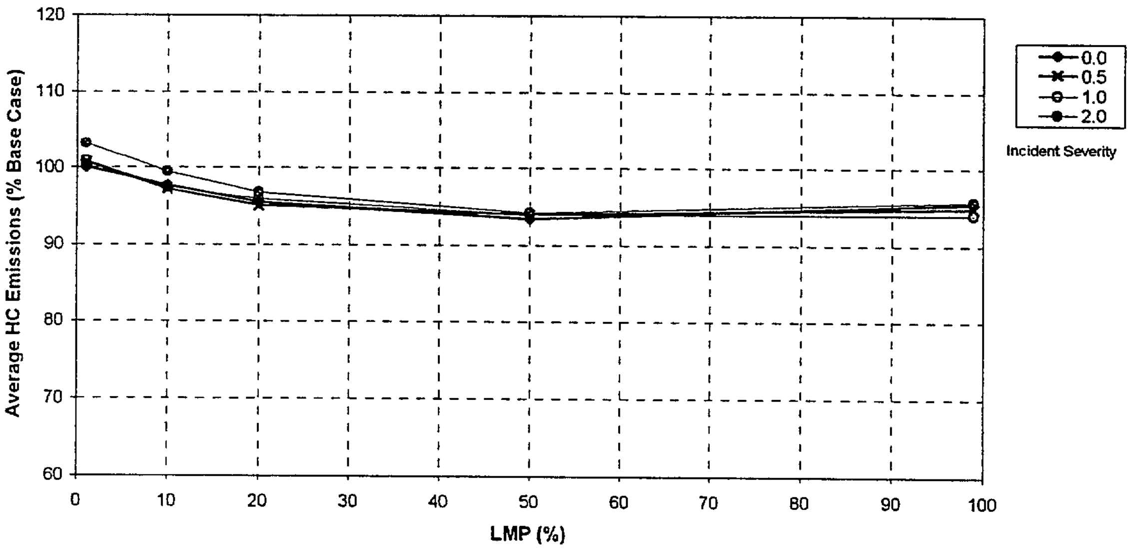

Figure B-60. Variation in average HC emissions as a function of LMP and incident severity (100% demand)

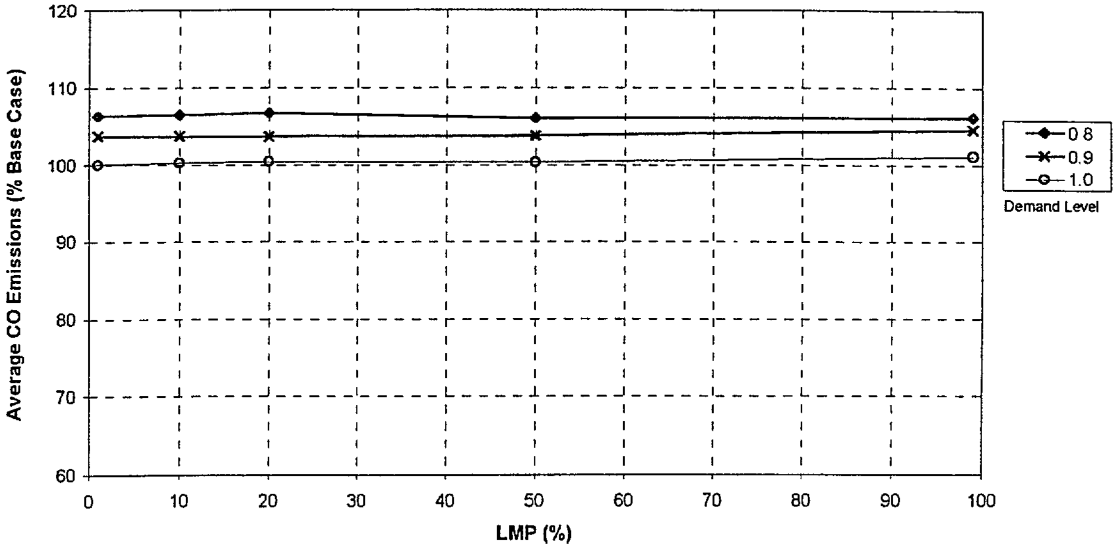

Figure B-61. Variation in averageCO emissions as a function of LMP and demand level (No incident)

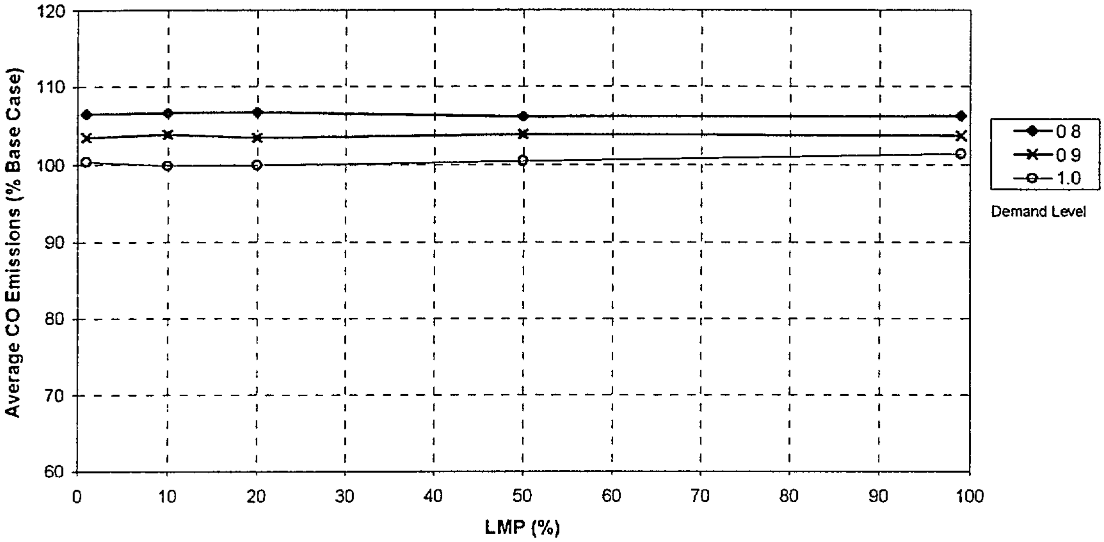

Figure B-62. Variation in averageCO emissions as a function of LMP and demand level (0.5-lane blockage)

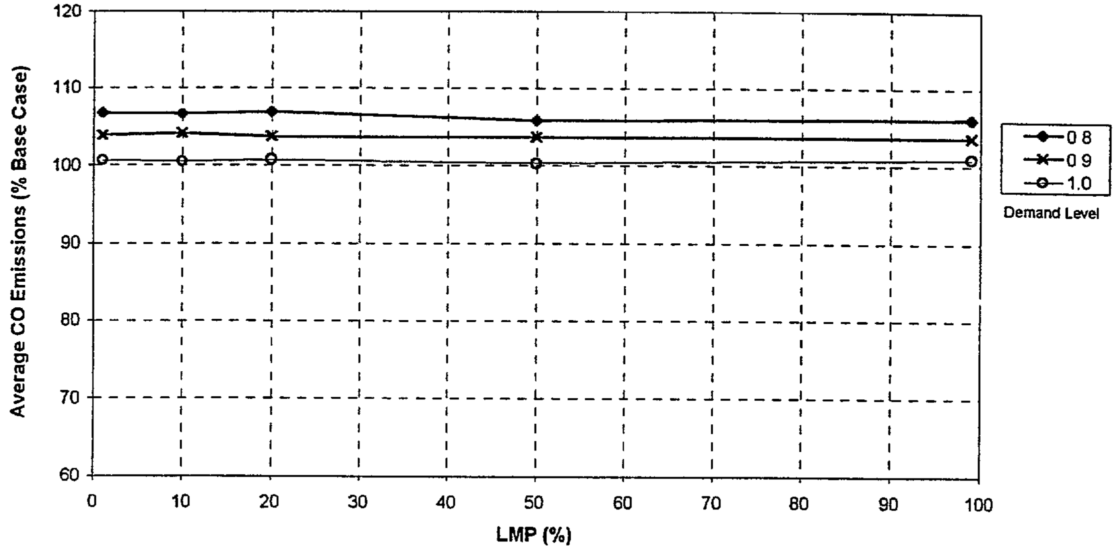

Figure B-63. Variation in averageCO emissions as a function of LMP and demand level (1-lane blockage)

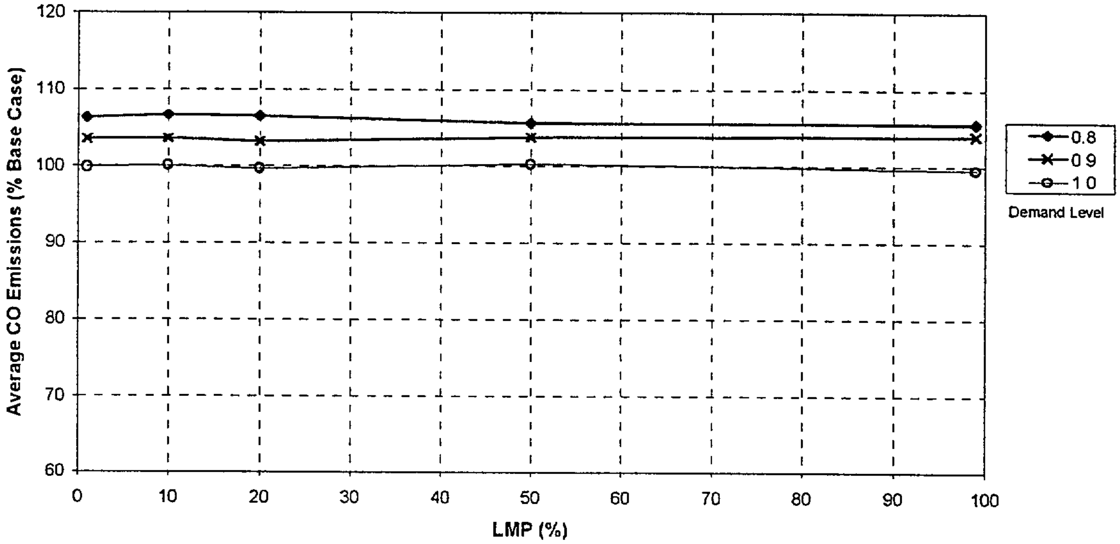

Figure B-64. Variation in averageCO emissions as a function of LMP and demand level (2-lane blockage)

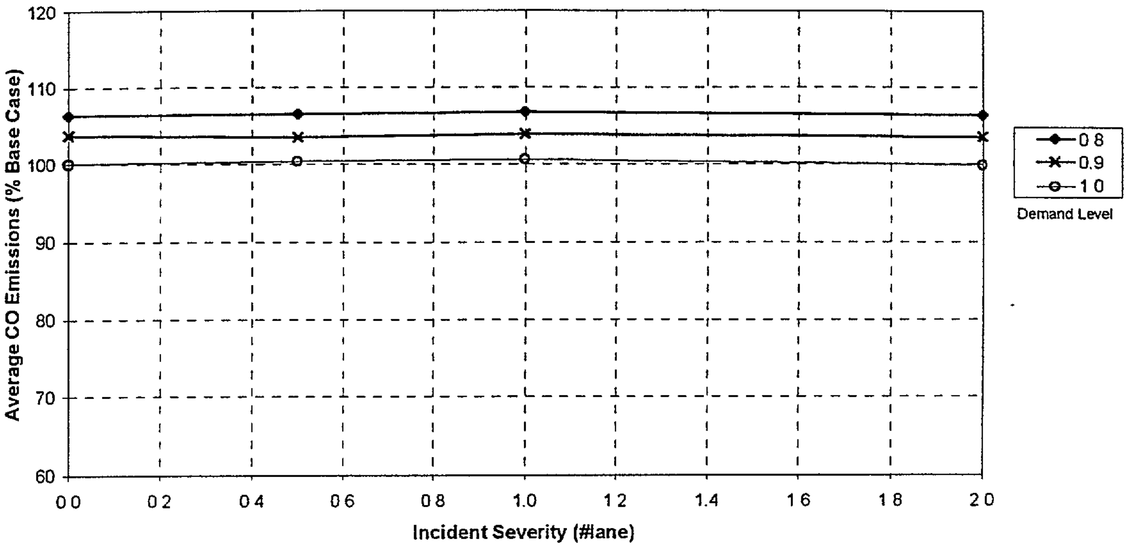

Figure B-65. Variation in average CO emissions as a function of incident severity and demand level (1% LMP)

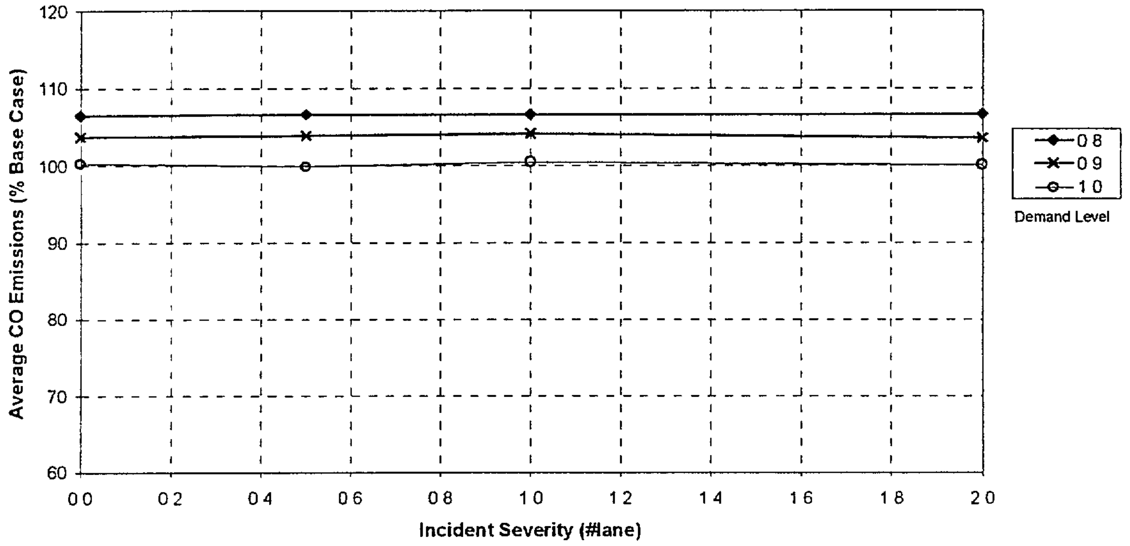

Figure B-66. Variation in average CO emissions as a function of incident severity and demand level (10% LMP)

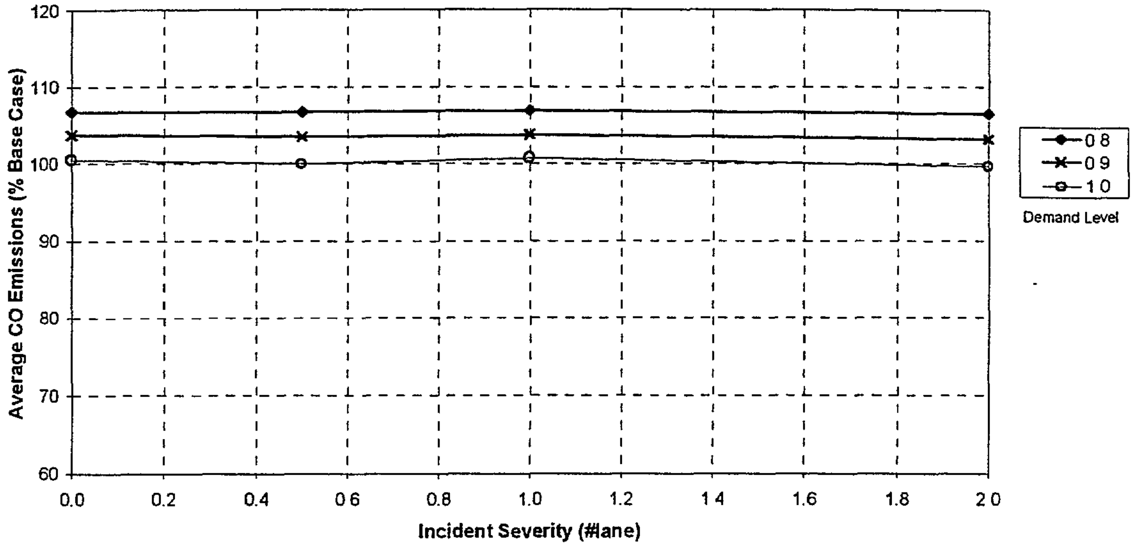

Figure B-67. Variation in average CO emissions as a function of incident severity and demand level (20% LMP)

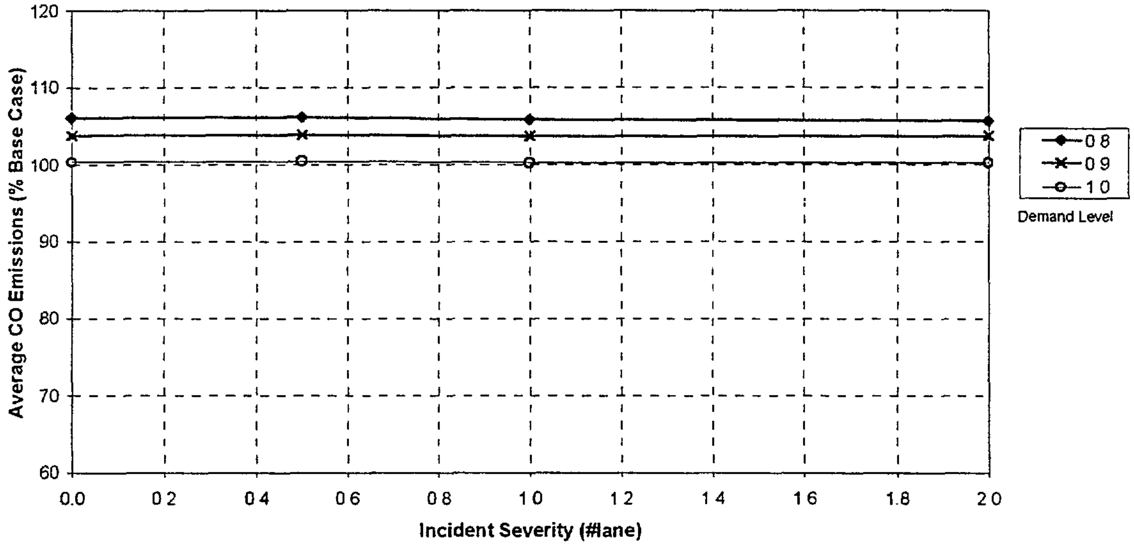

Figure B-68. Variation in average CO emissions as a function of incident severity and demand level (50% LMP)

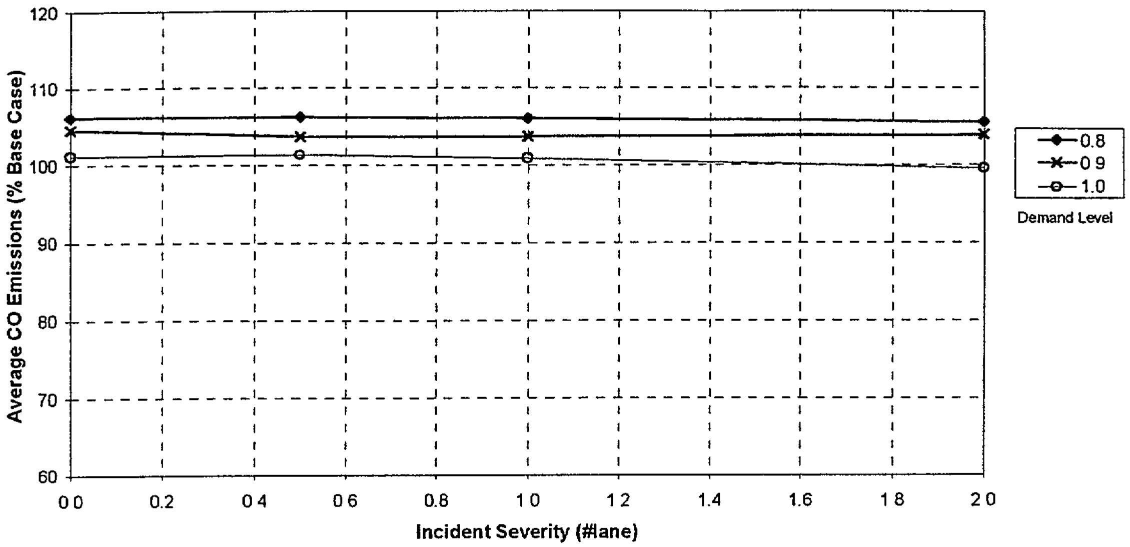

Figure B-69. Variation in average CO emissions as a function of incident severity and demand level (100% LMP)

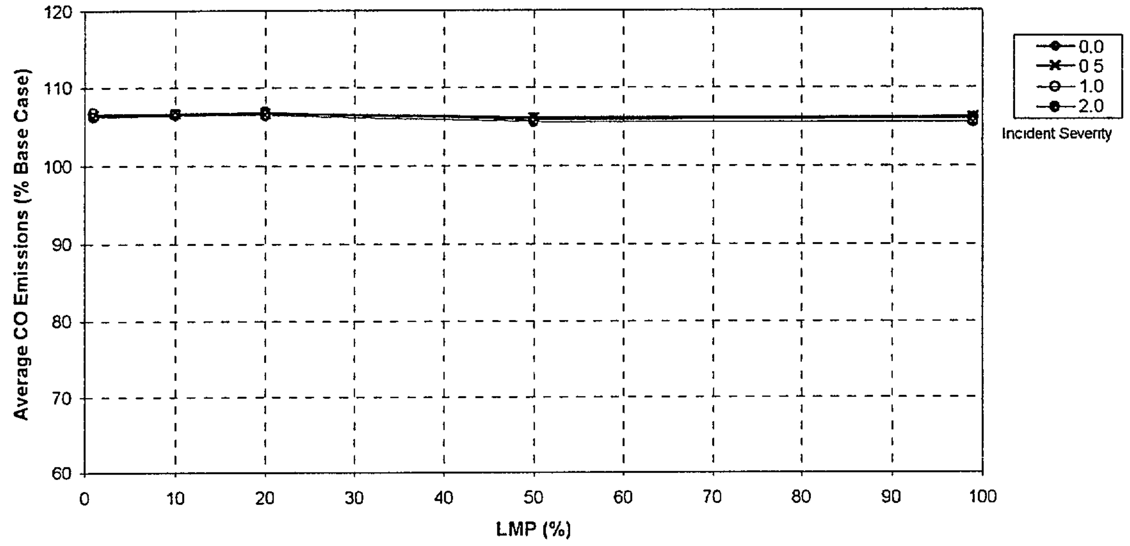

Figure B-70. Variation in average CO emissions as a function of LMP and incident severity (80% demand)

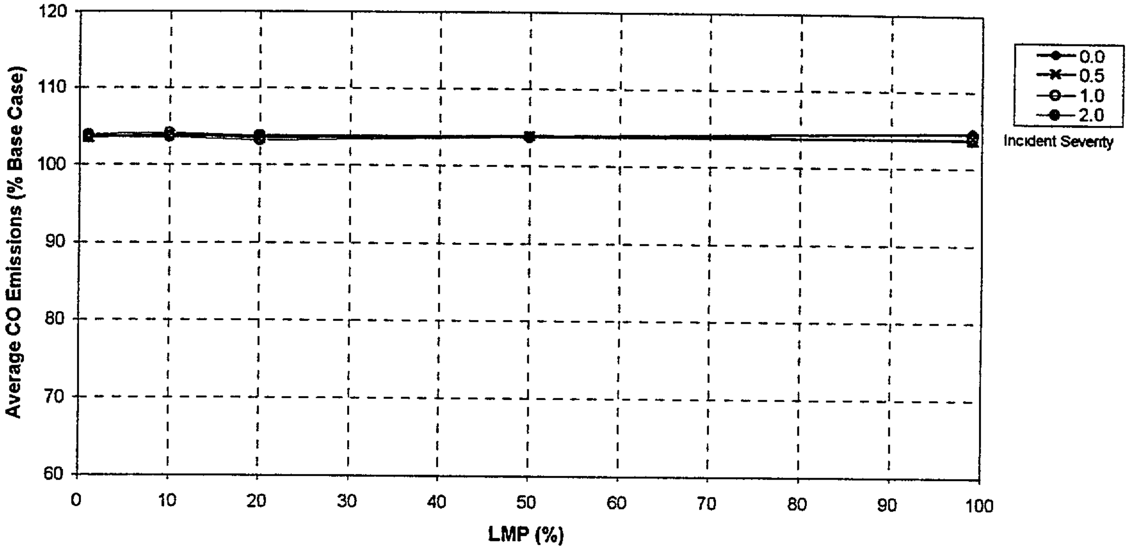

Figure B-71. Variation in average CO emissions as a function of LMP and incident severity (90% demand)

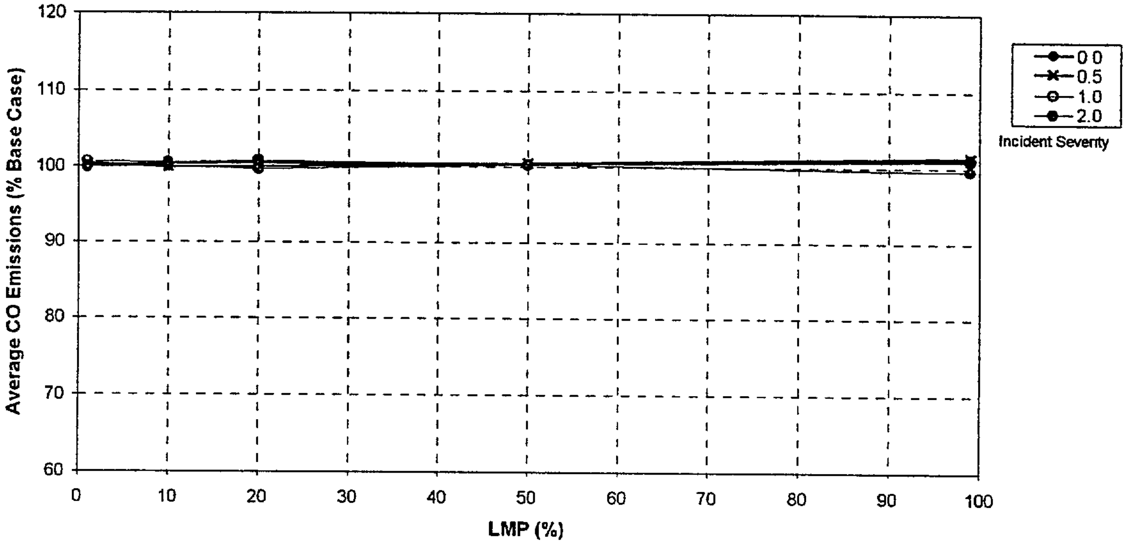

Figure B-72. Variation in average CO emissions as a function of LMP and incident severity (100% demand)

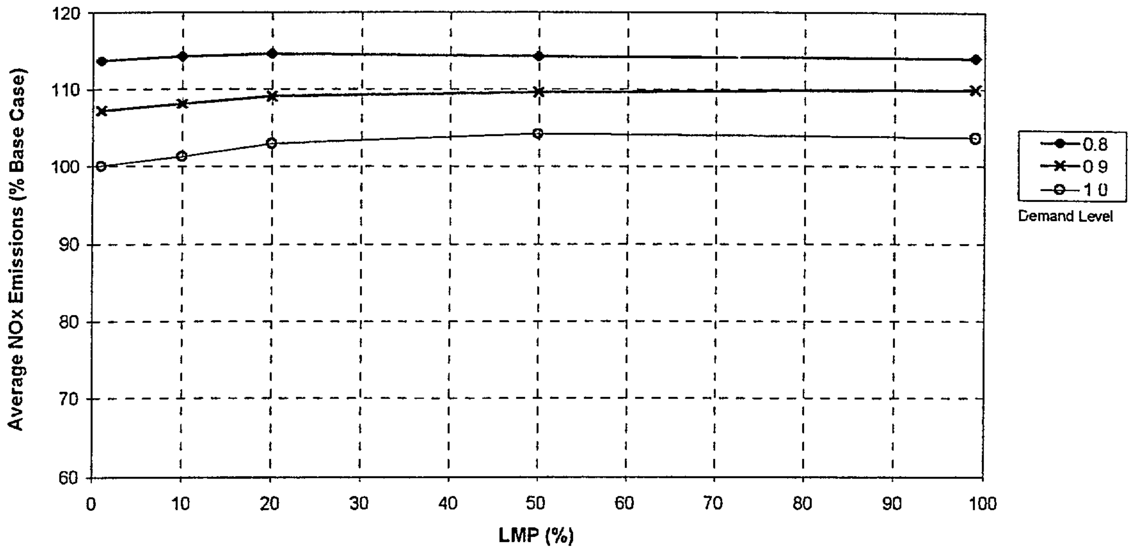

Figure B-73. Variation in average NO_x emissions as a function of LMP and demand level (No incident)

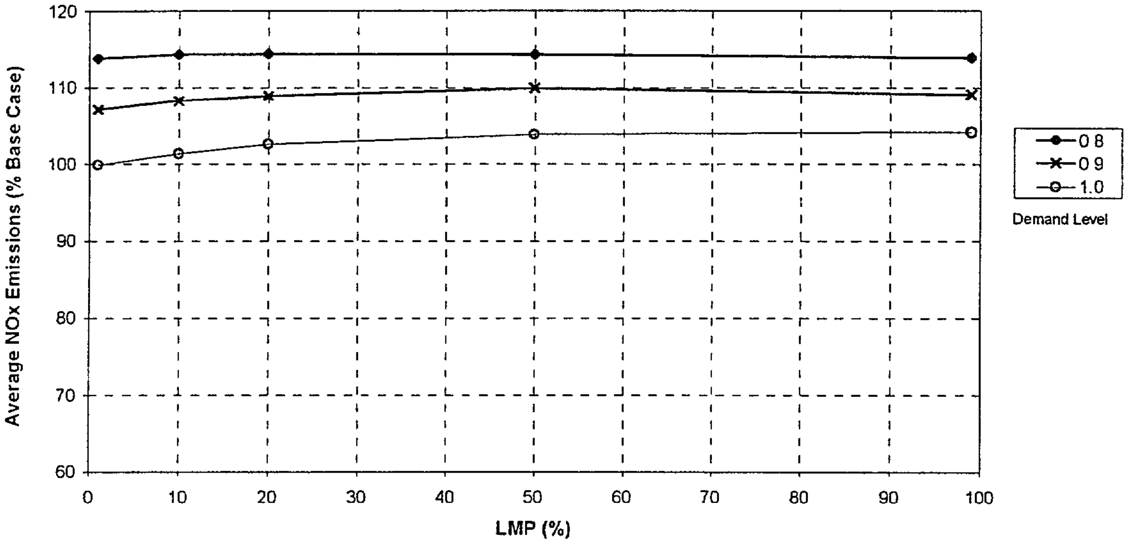

Figure B-74. Variation in average NO_x emissions as a function of LMP and demand level (0.5-lane blockage)

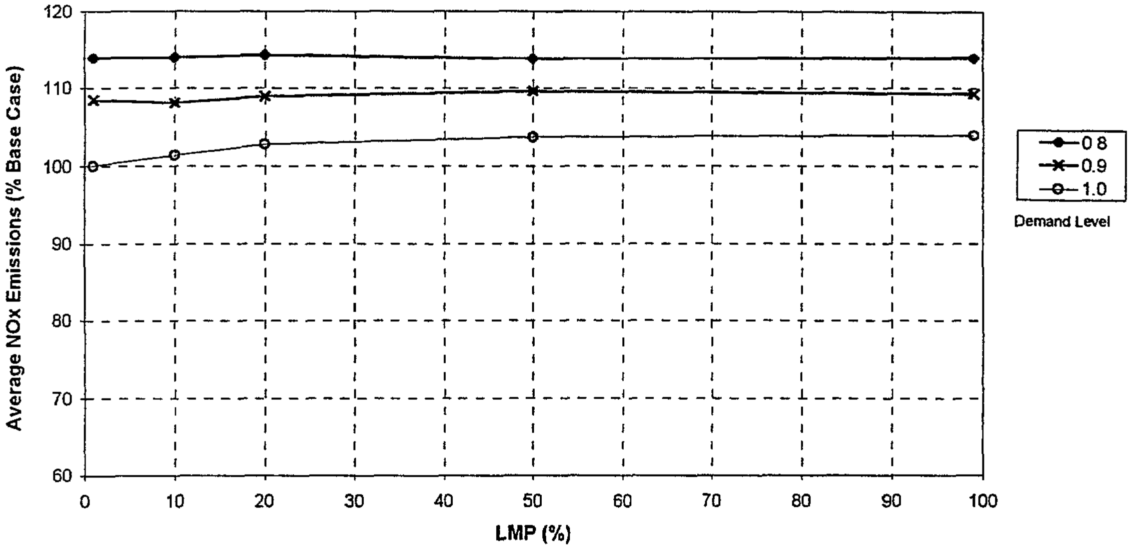

Figure B-75. Variation in average NO_x emissions as a function of LMP and demand level (1-lane blockage)

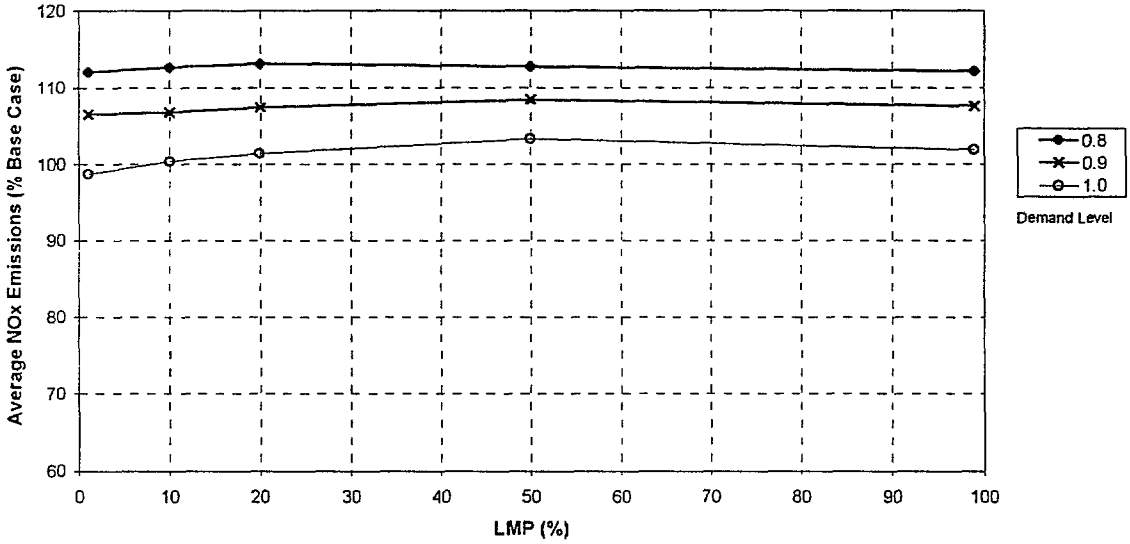

Figure B-76. Variation in average NO_x emissions as a function of LMP and demand level (2-lane blockage)

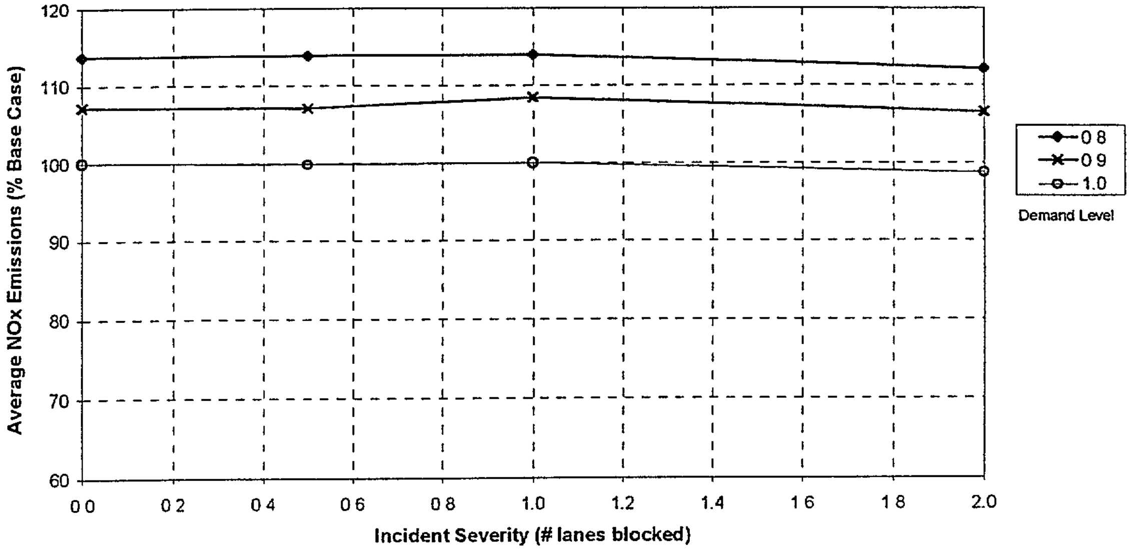

Figure B-77. Variation in average NO_x emissions as a function of incident severity and demand level (1% LMP)

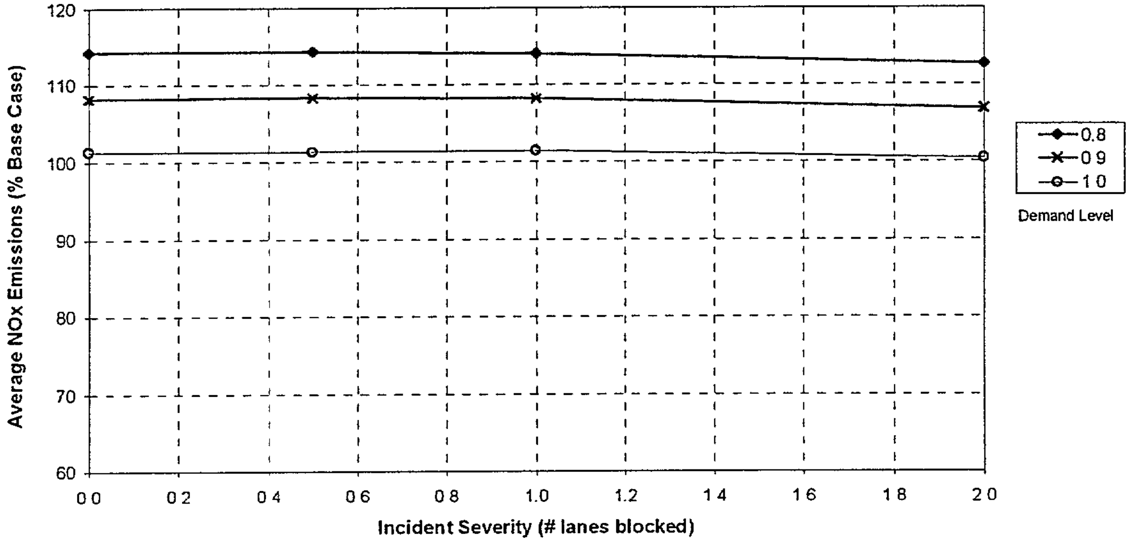

Figure B-78. Variation in average NO_x emissions as a function of incident severity and demand level (10% LMP)

Figure B-79. Variation in average NO_x emissions as a function of incident severity and demand level (20% LMP)

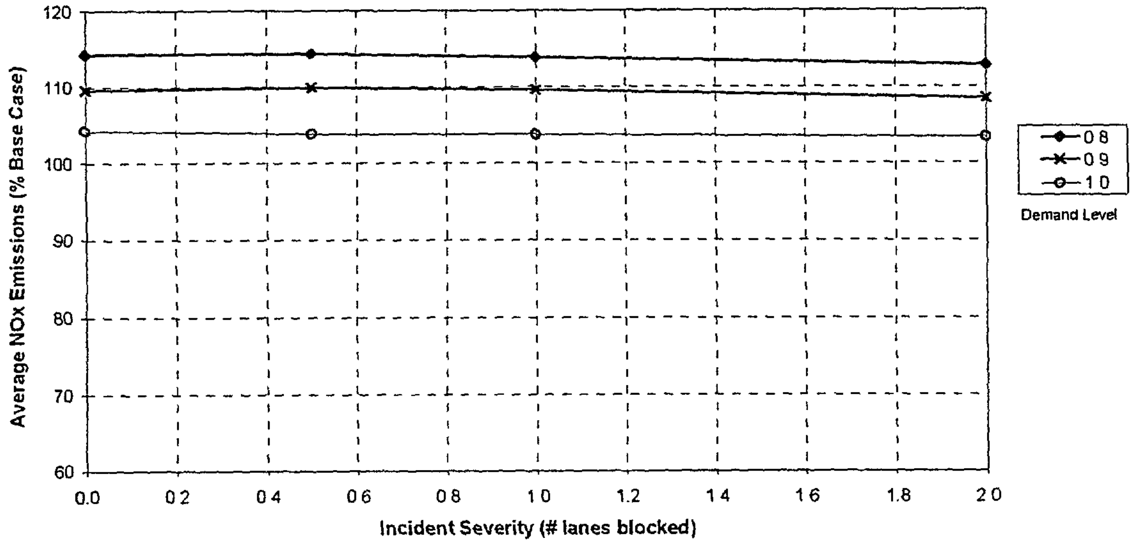

Figure B-80. Variation in average NO_x emissions as a function of incident severity and demand level (50% LMP)

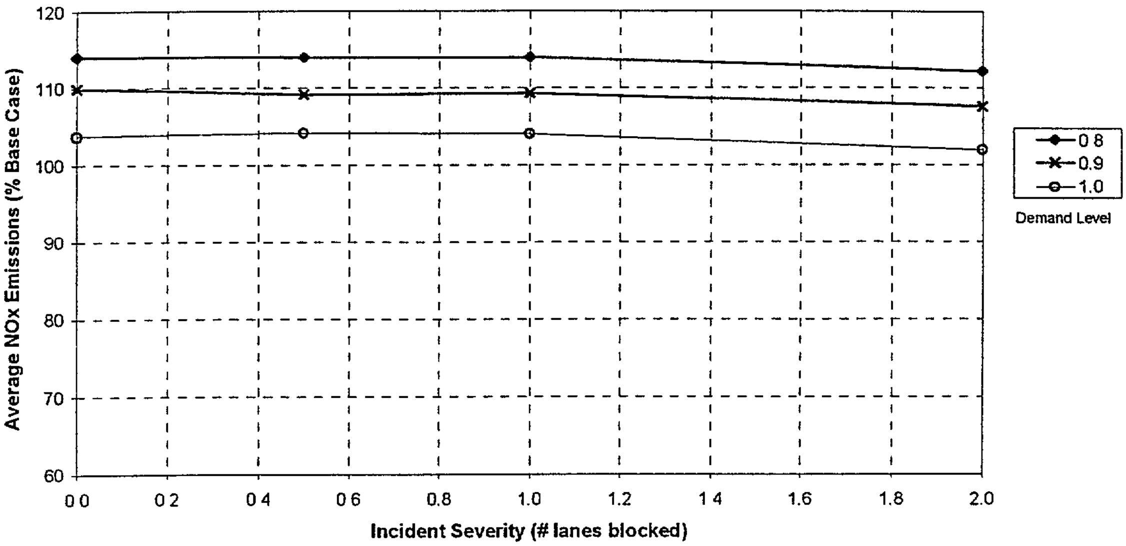

Figure B-81. Variation in average NO_x emissions as a function of incident severity and demand level (99% LMP)

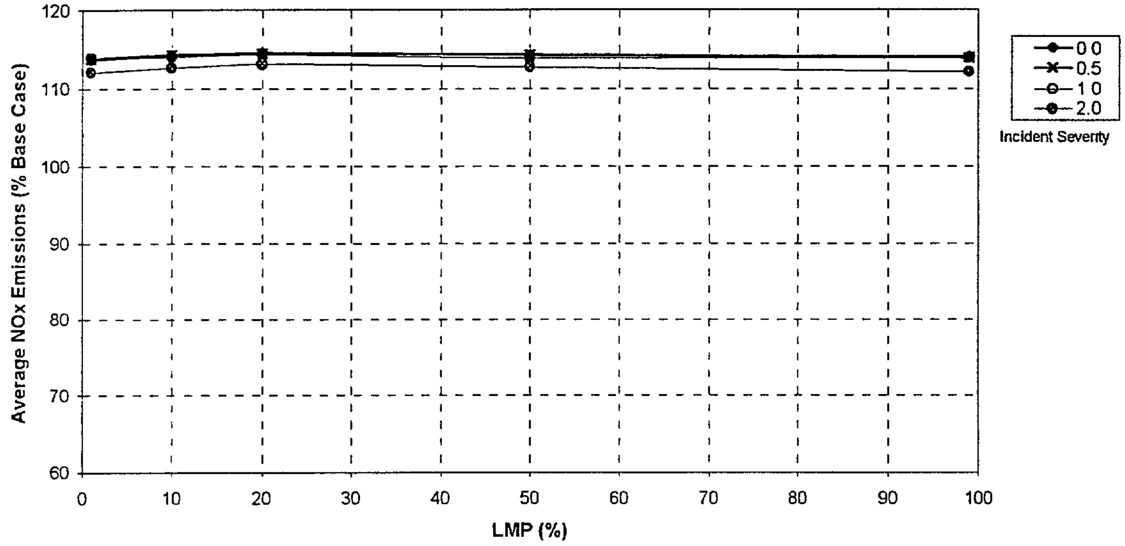

Figure B-82. Variation in average NO_x emissions as a function of LMP and incident severity (80% demand)

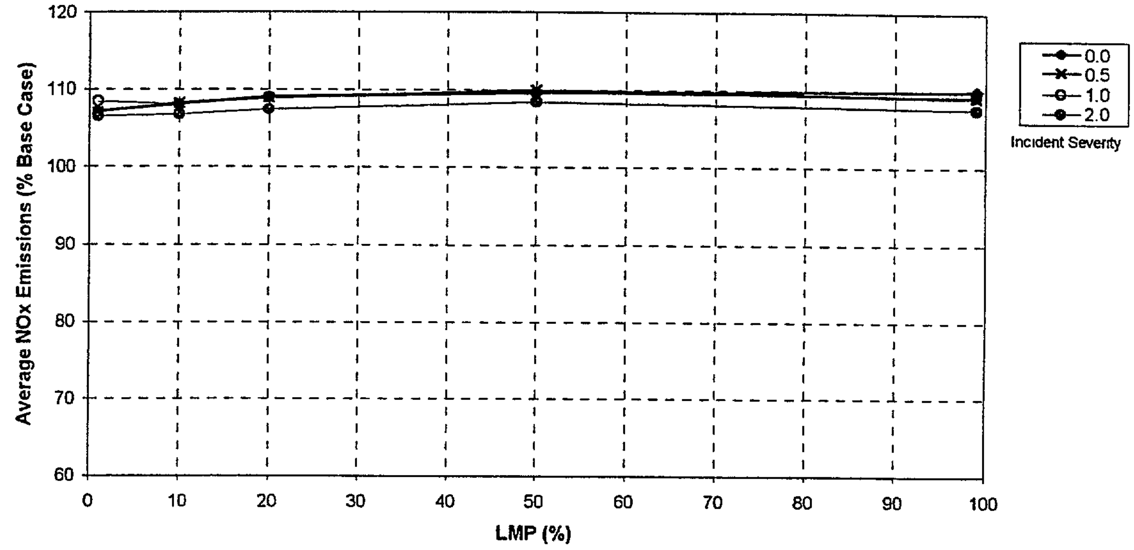

Figure B-83. Variation in average NO_x emissions as a function of LMP and incident severity (90% demand)

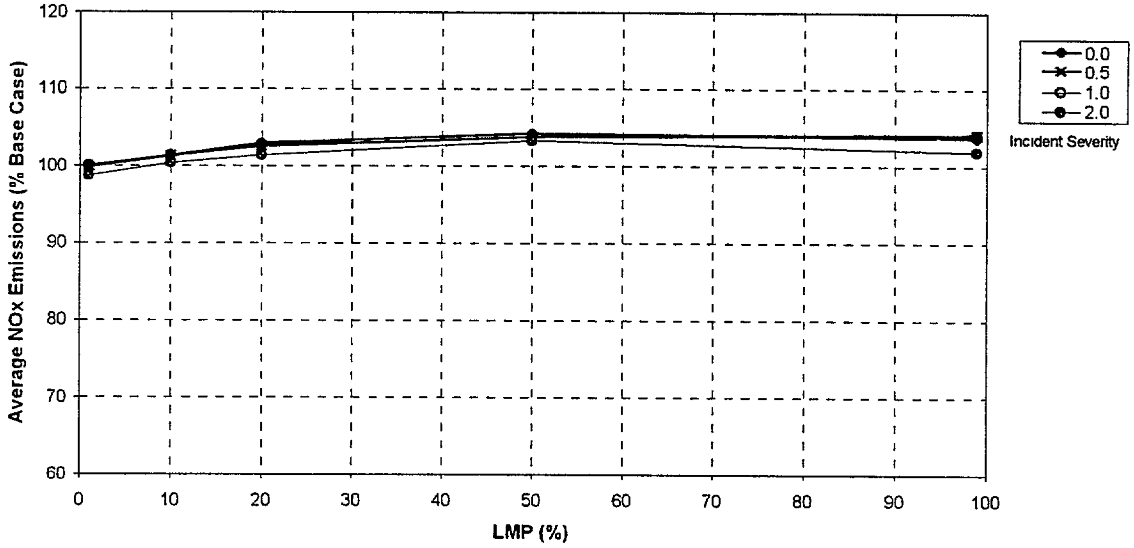

Figure B-84. Variation in average NO_x emissions as a function of LMP and incident severity (100% demand)

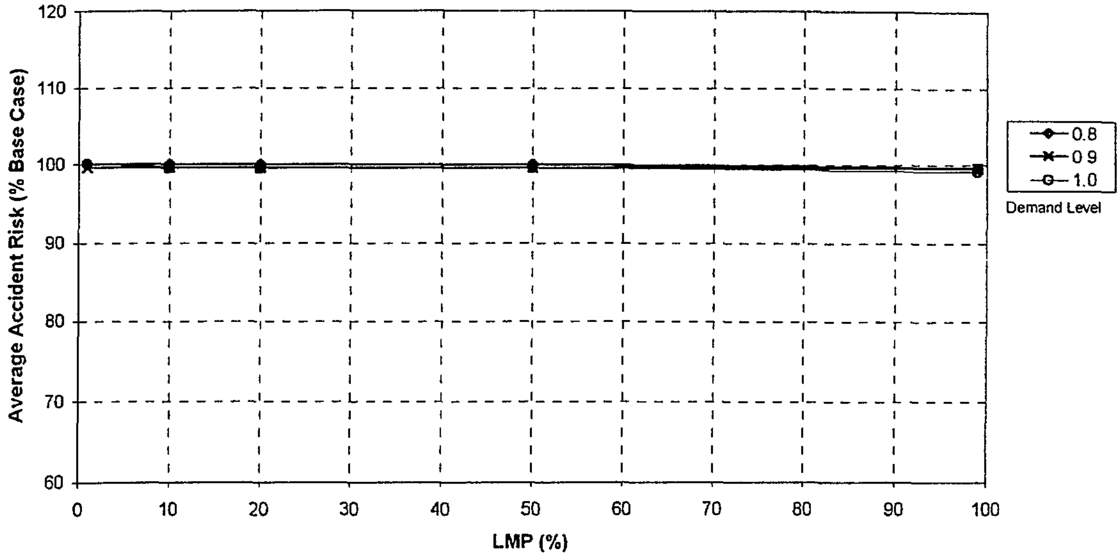

Figure B-85. Variation in average accident risk as a function of LMP and demand level (No incident)

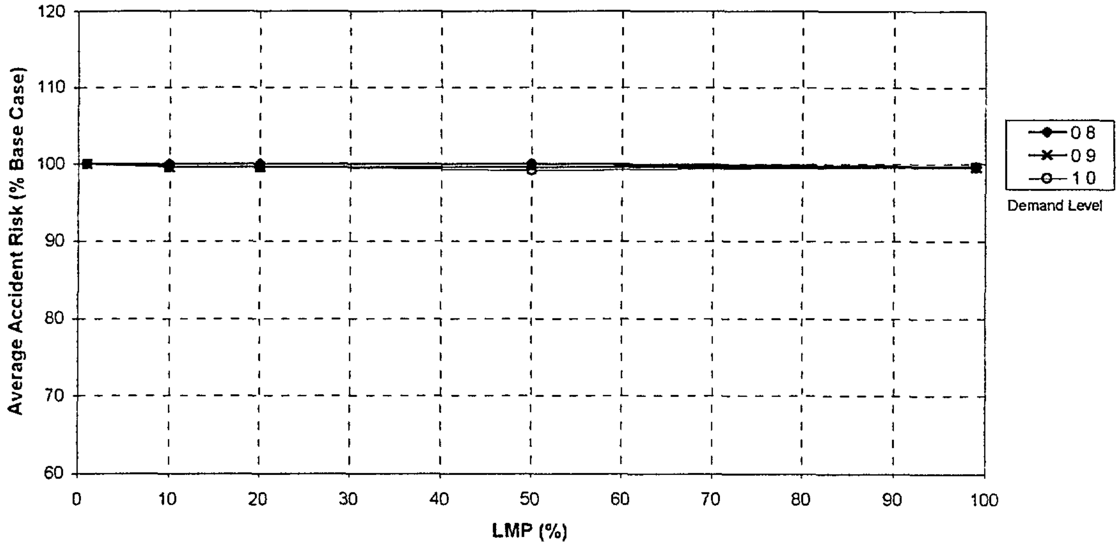

Figure B-86. Variation in average accident risk as a function of LMP and demand level (0.5-lane blockage)

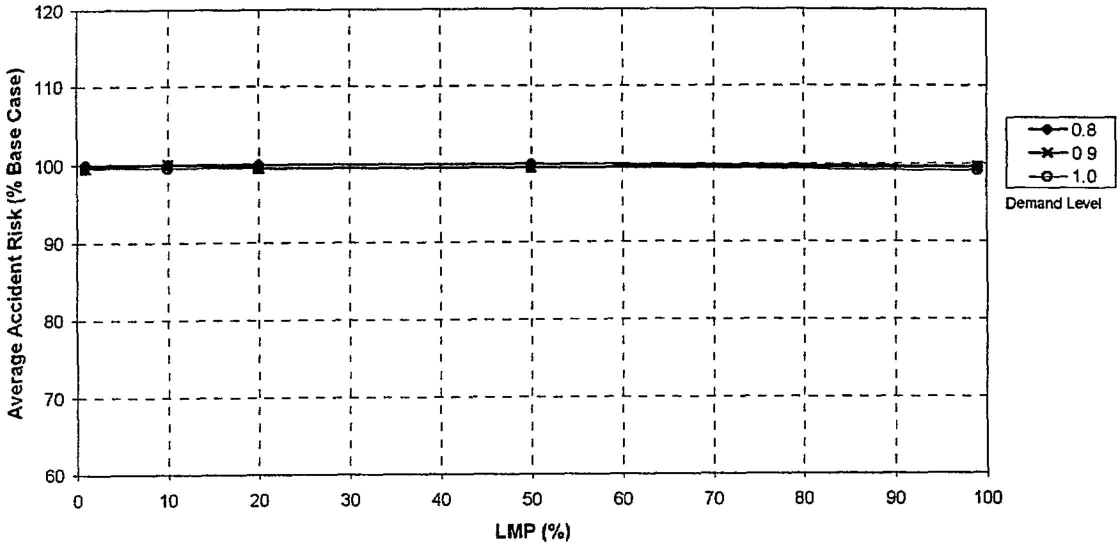

Figure B-87. Variation in average accident risk as a function of LMP and demand level (1-lane blockage)

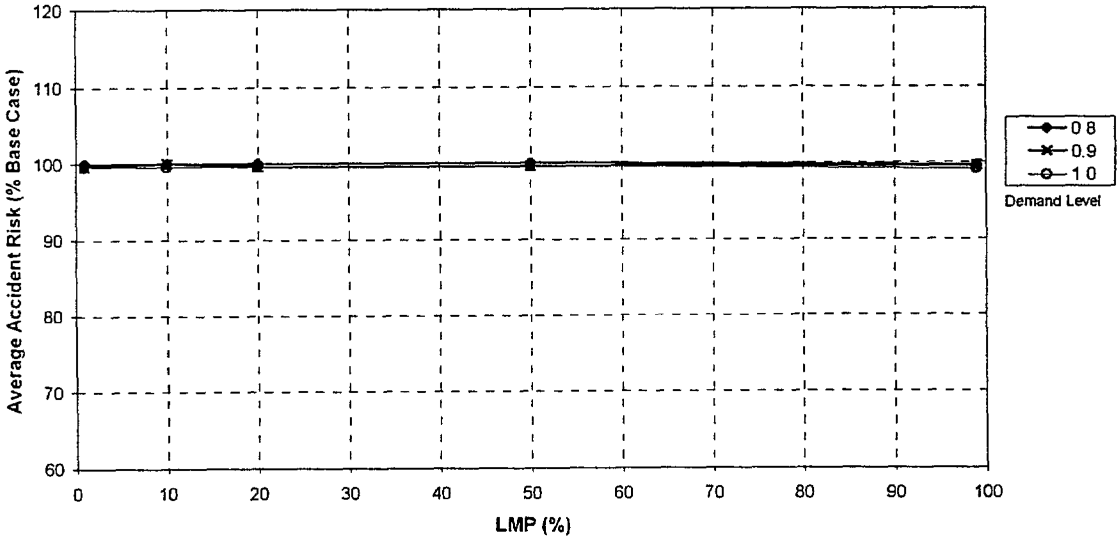

Figure B-88. Variation in average accident risk as a function of LMP and demand level (2-lane blockage)

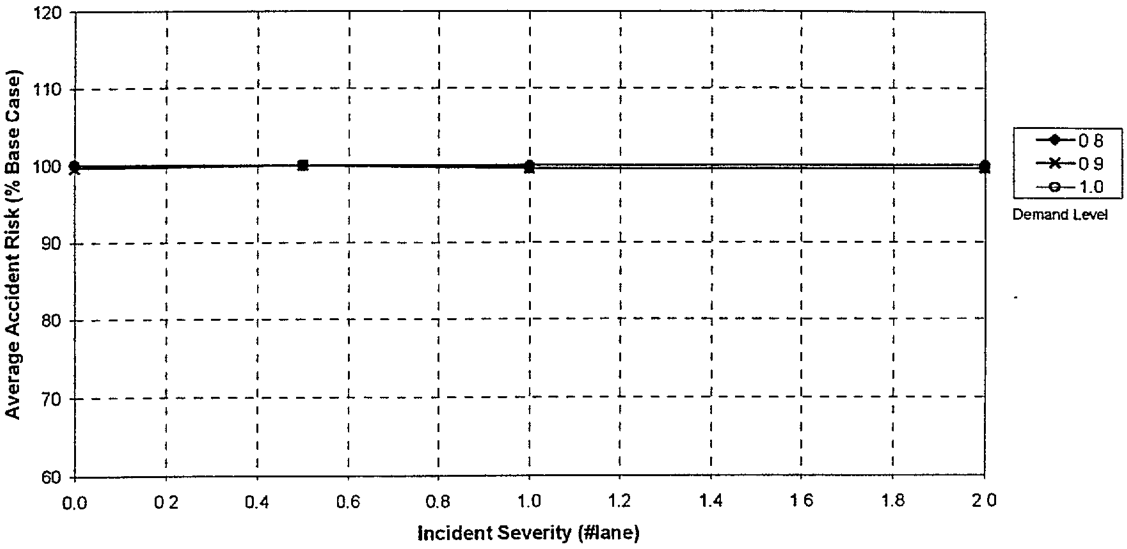

Figure B-89. Variation in average accident risk as a function of incident severity and demand level (1% LMP)

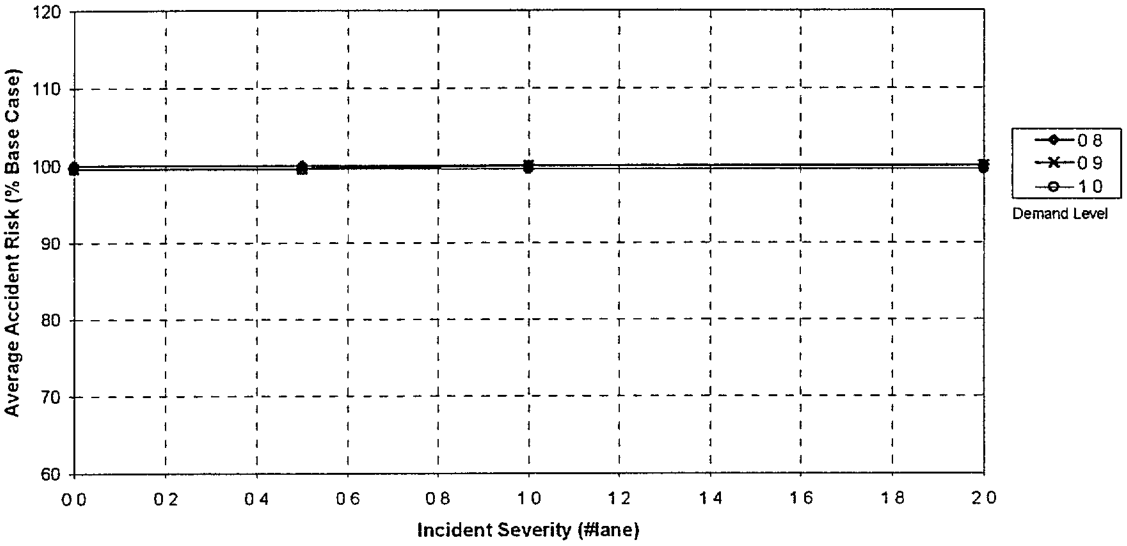

Figure B-90. Variation in average accident risk as a function of incident severity and demand level (10% LMP)

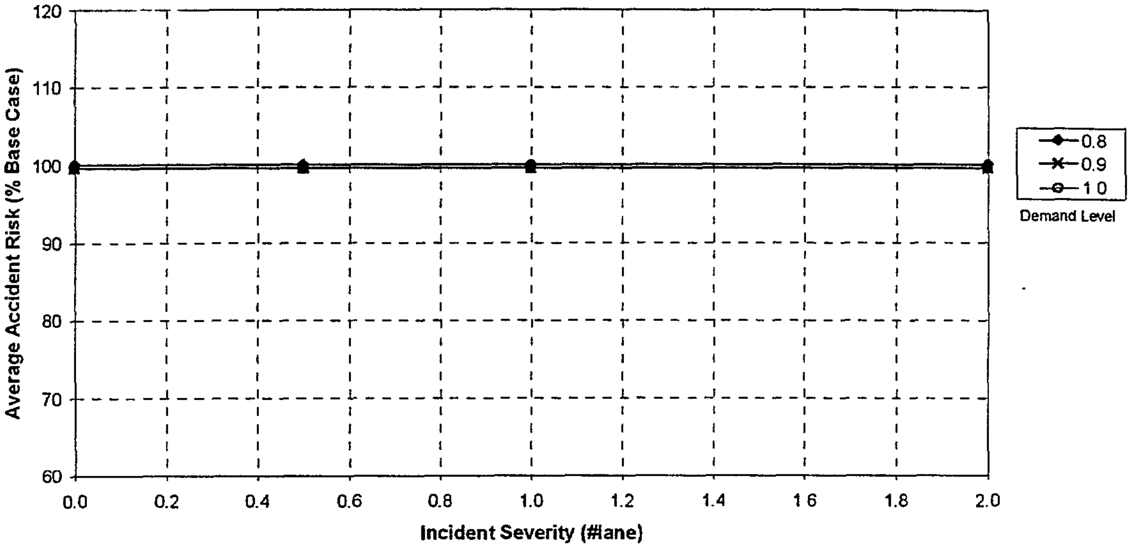

Figure B-91. Variation in average accident risk as a function of incident severity and demand level (20% LMP)

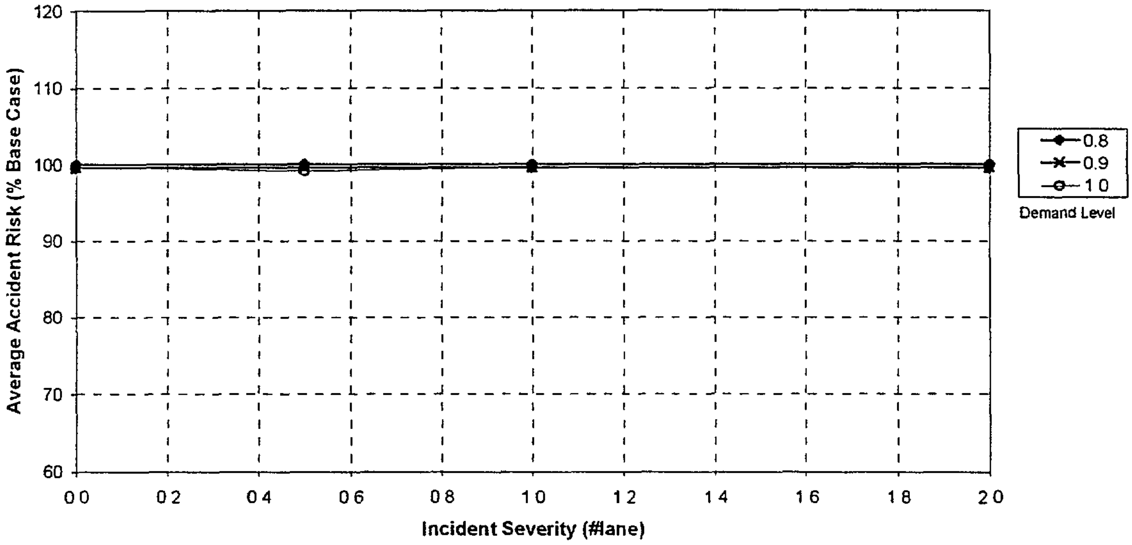

Figure B-92. Variation in average accident risk as a function of incident severity and demand level (50% LMP)

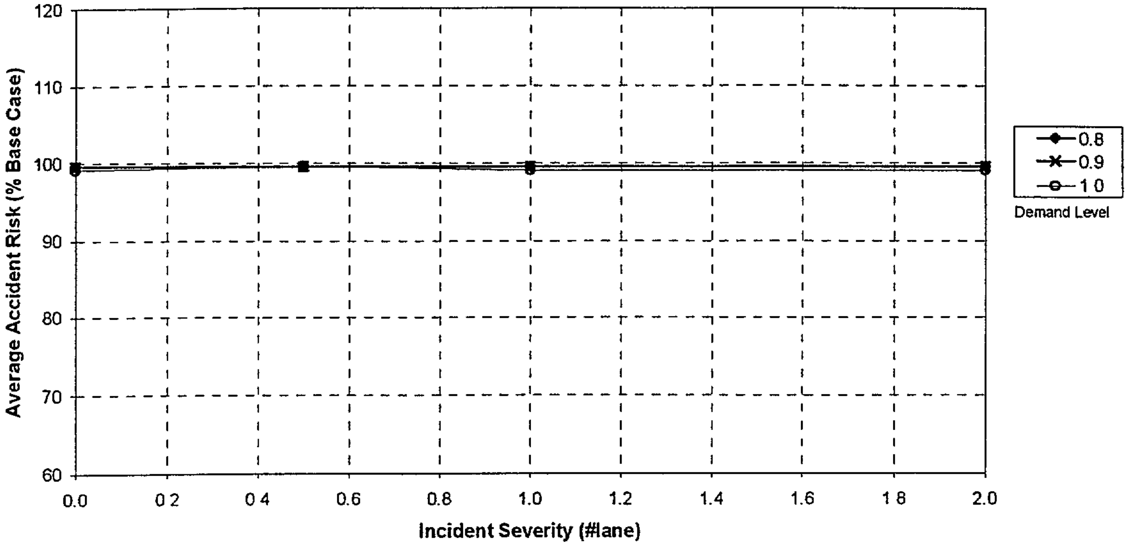

Figure B-93. Variation in average accident risk as a function of incident severity and demand level (99% LMP)

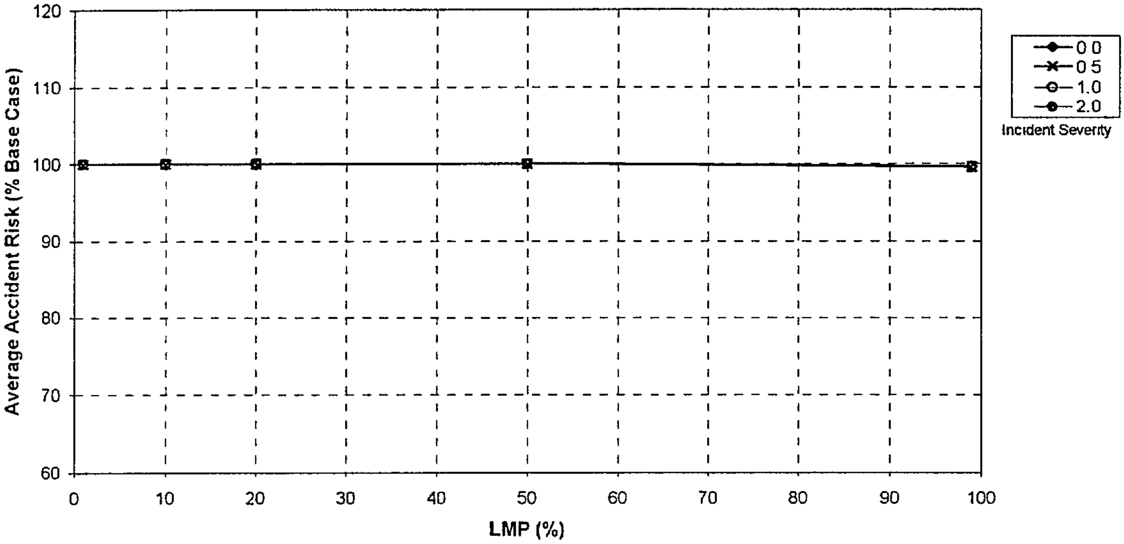

Figure B-94. Variation in average accident risk as a function of LMP and incident severity (80% demand)

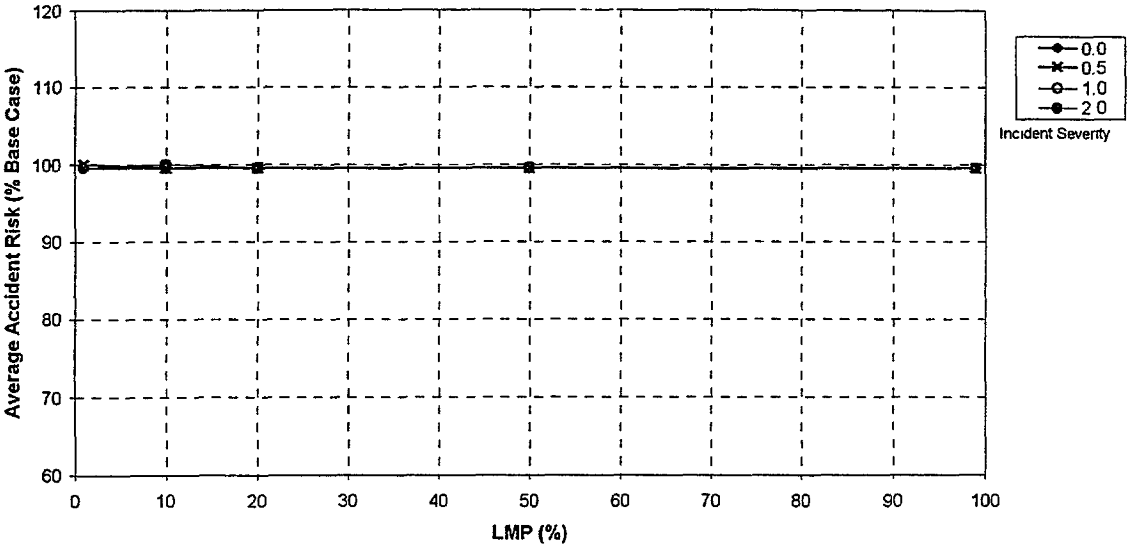

Figure B-95. Variation in average accident risk as a function of LMP and incident severity (90% demand)

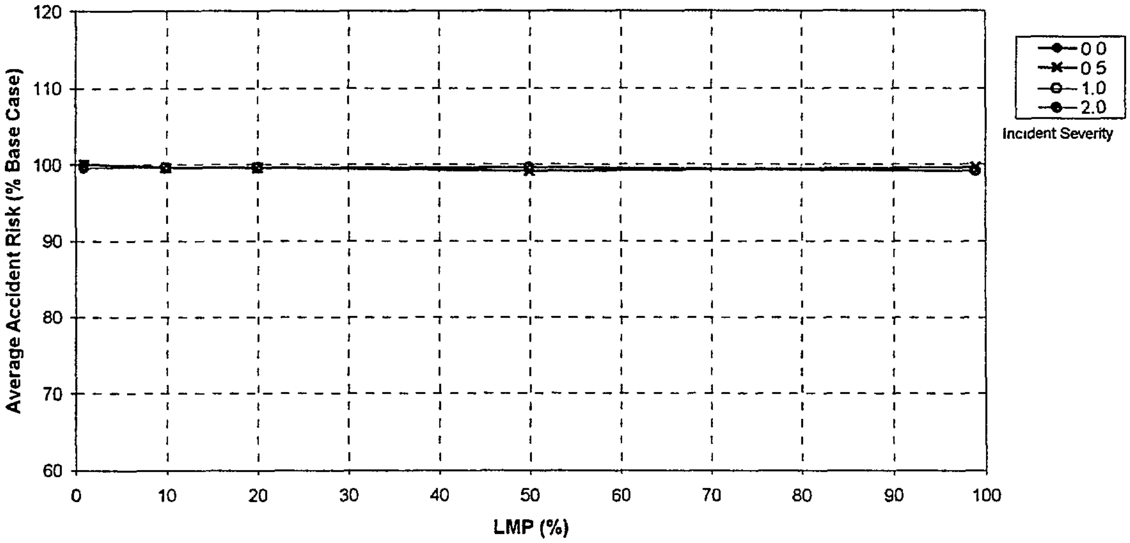

Figure B-96. Variation in average accident risk as a function of LMP and incident severity (100% demand)

APPENDIX (C)
SIMULATION RESULTS FOR BACKGROUND TRAFFIC

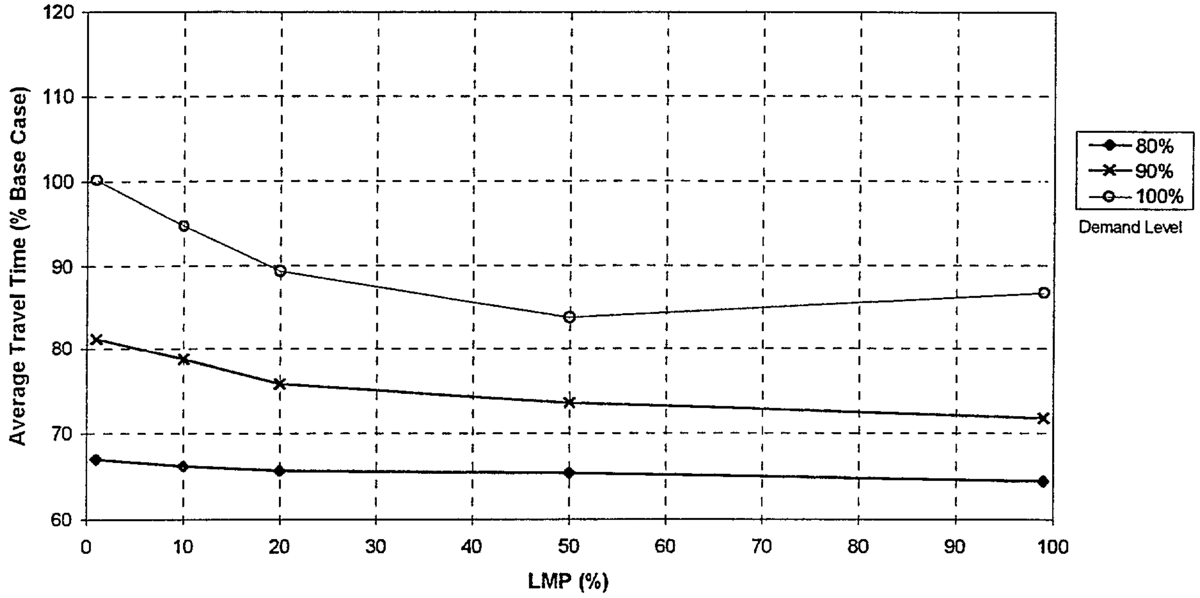

Figure C-1. Variation in average trip time of background vehicles as a function of LMP and demand level (No inident)

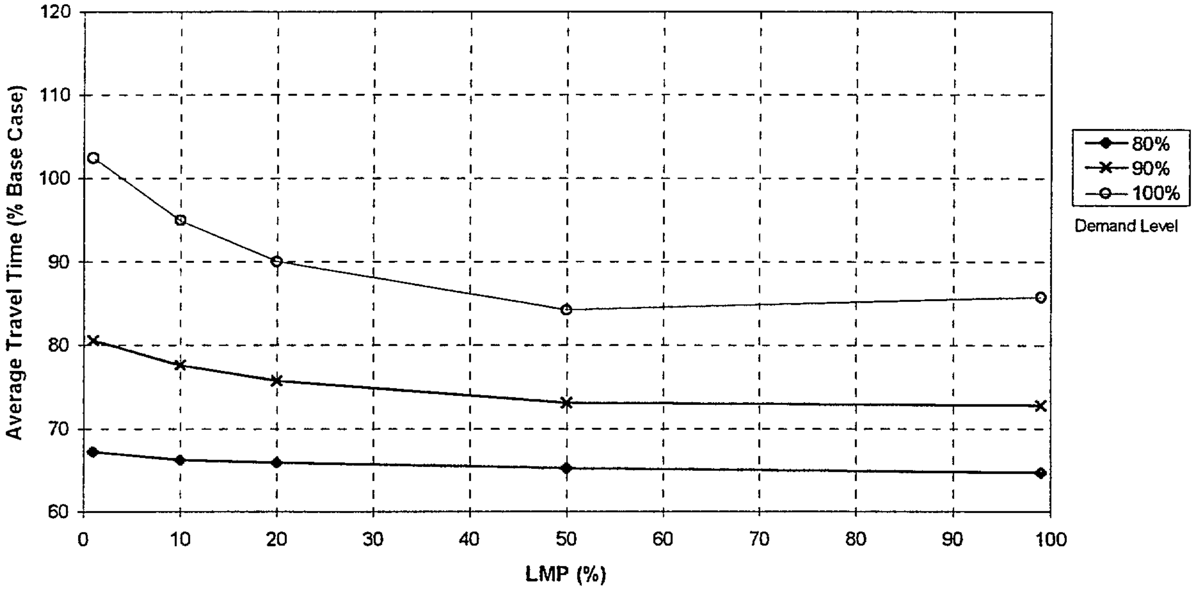

Figure C-2. Variation in average trip time of background vehicles as a function of LMP and demand level (0.5-lane blockage)

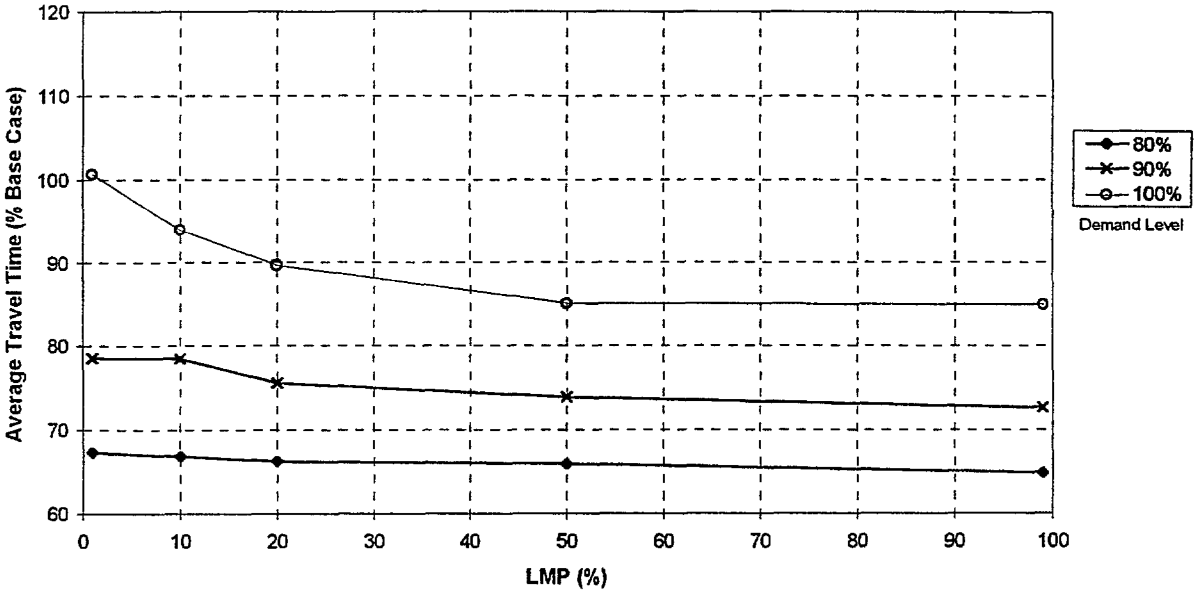

Figure C-3. Variation in average trip time of background vehicles as a function of LMP and demand level (1-lane blockage)

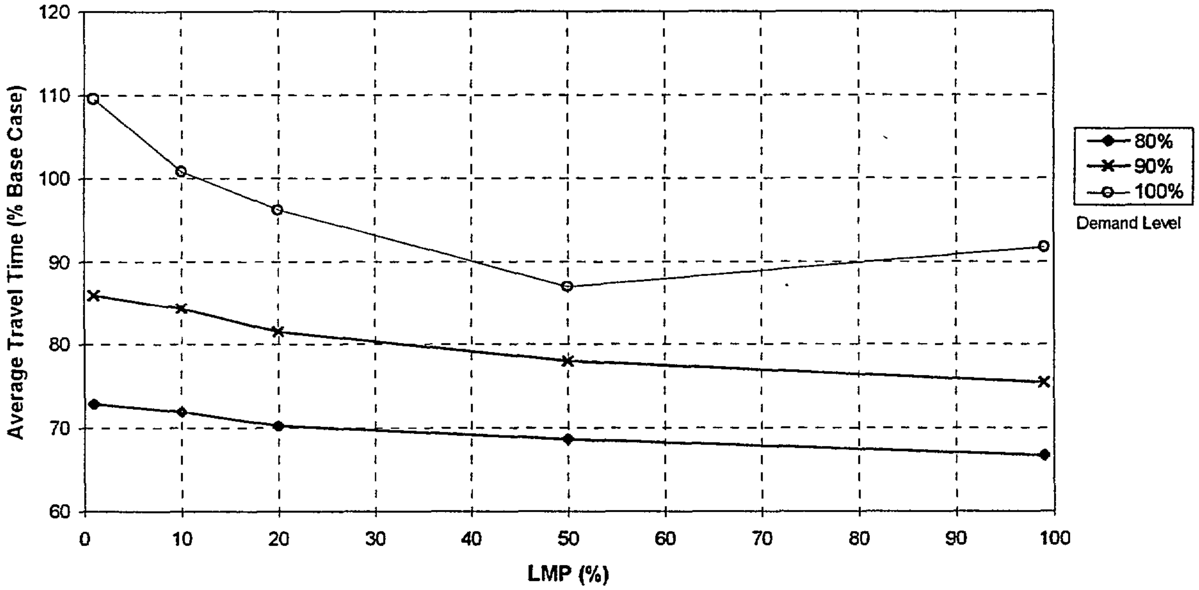

Figure C-4. Variation in average trip time of background vehicles as a function of LMP and demand level (2-lane blockage)

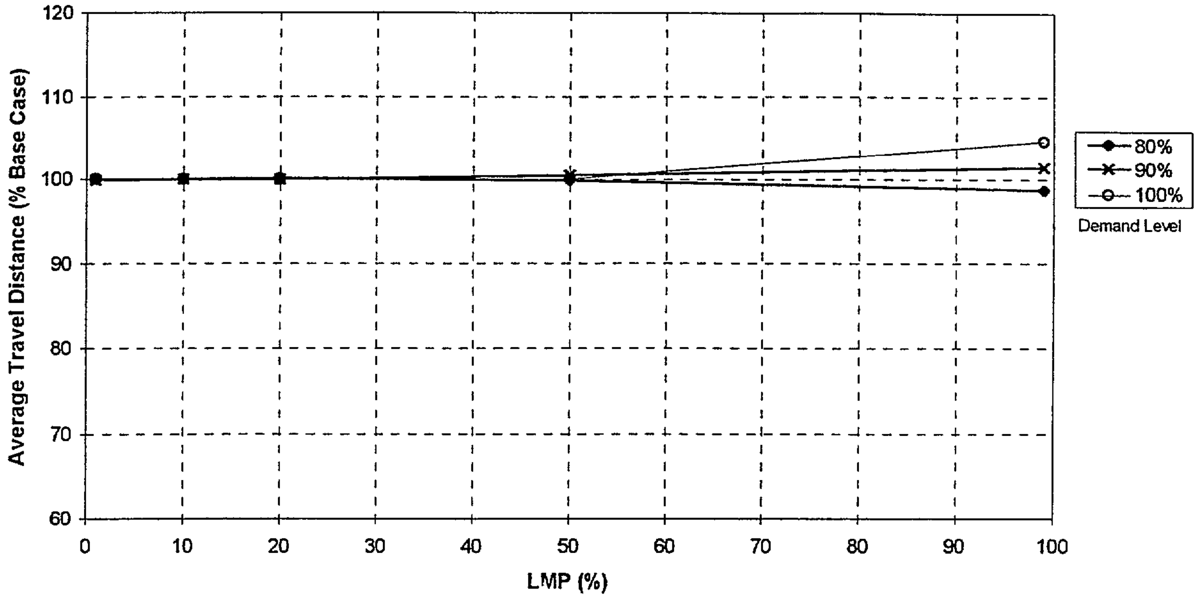

Figure C-5. Variation in average trip length of background vehicles as a function of LMP and demand level (No incident)

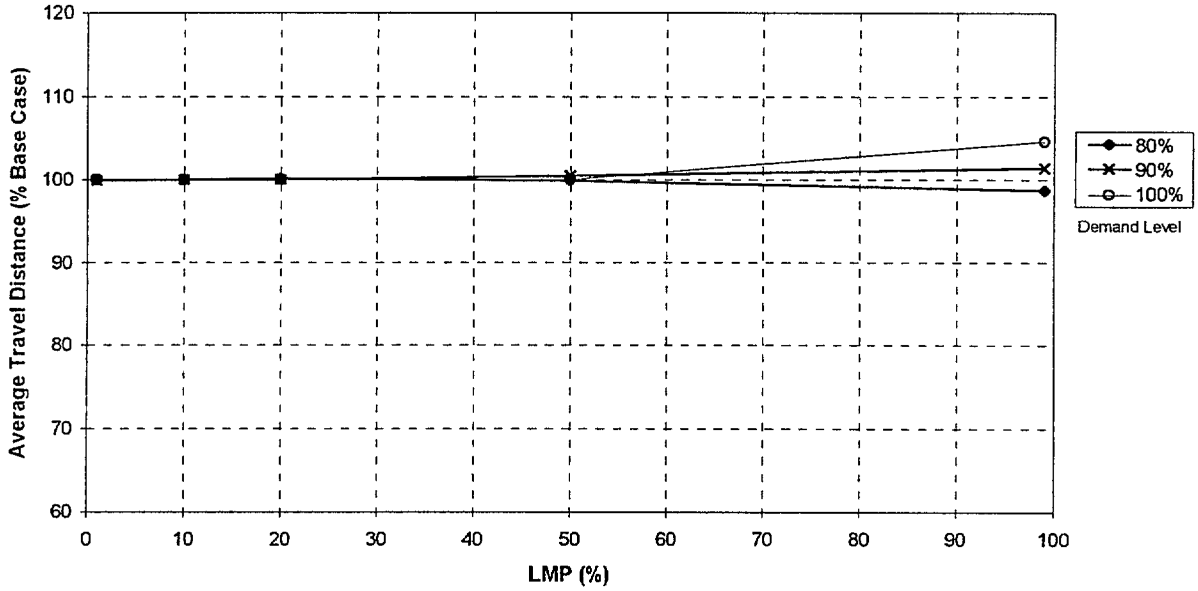

Figure C-6. Variation in average trip length of background vehicles as a function of LMP and demand level (0.5-lane blockage)

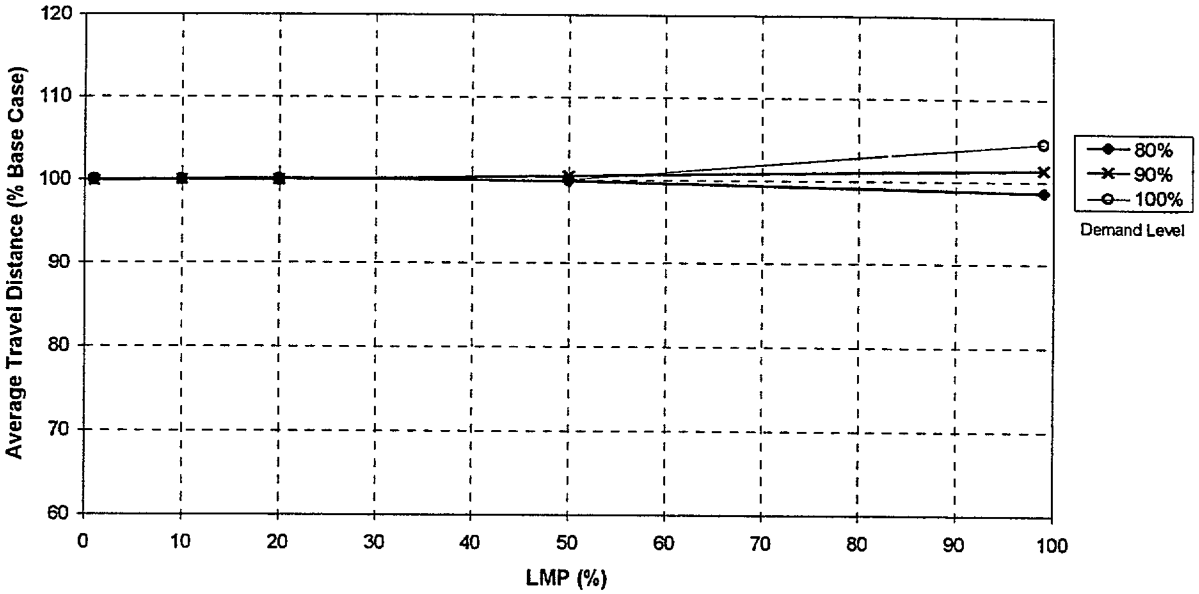

Figure C-7. Variation in average trip length of background vehicles as a function of LMP and demand level (1-lane blockage)

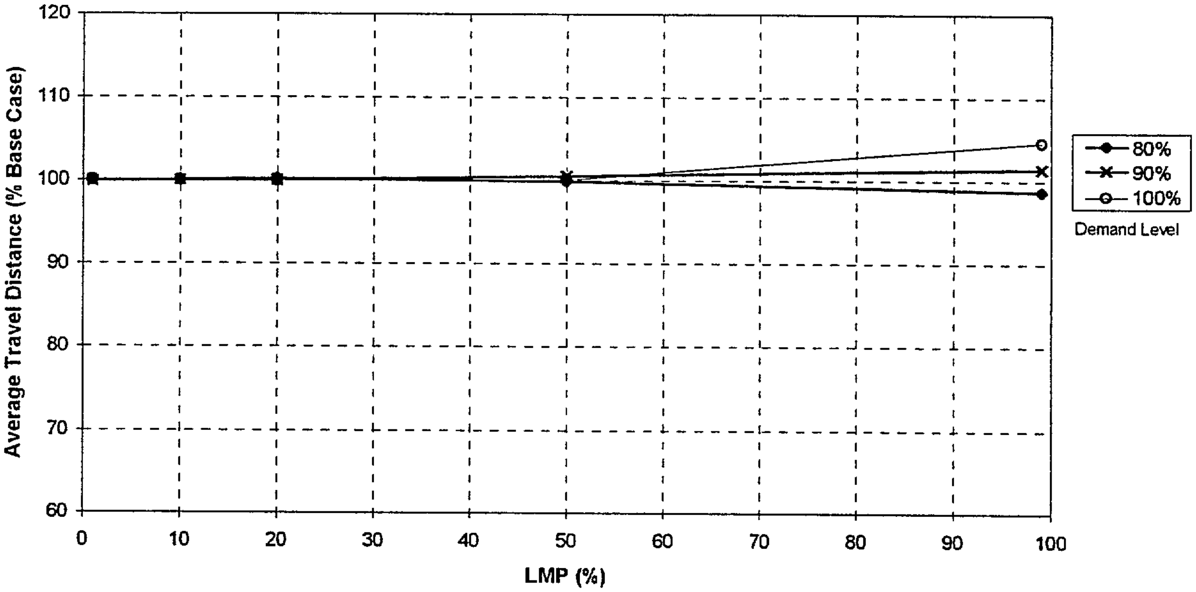

Figure C-8. Variation in average trip length of background vehicles as a function of LMP and demand level (2-lane blockage)

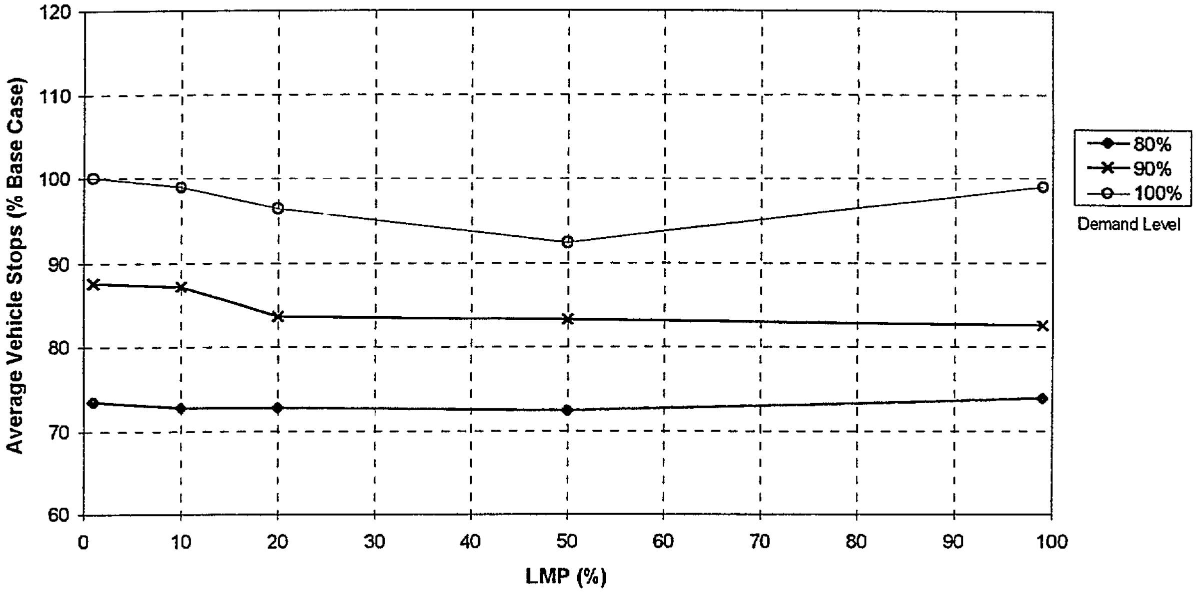

Figure C-9. Variation in average vehicle stops of background vehicles as a function of LMP and demand level (No incident)

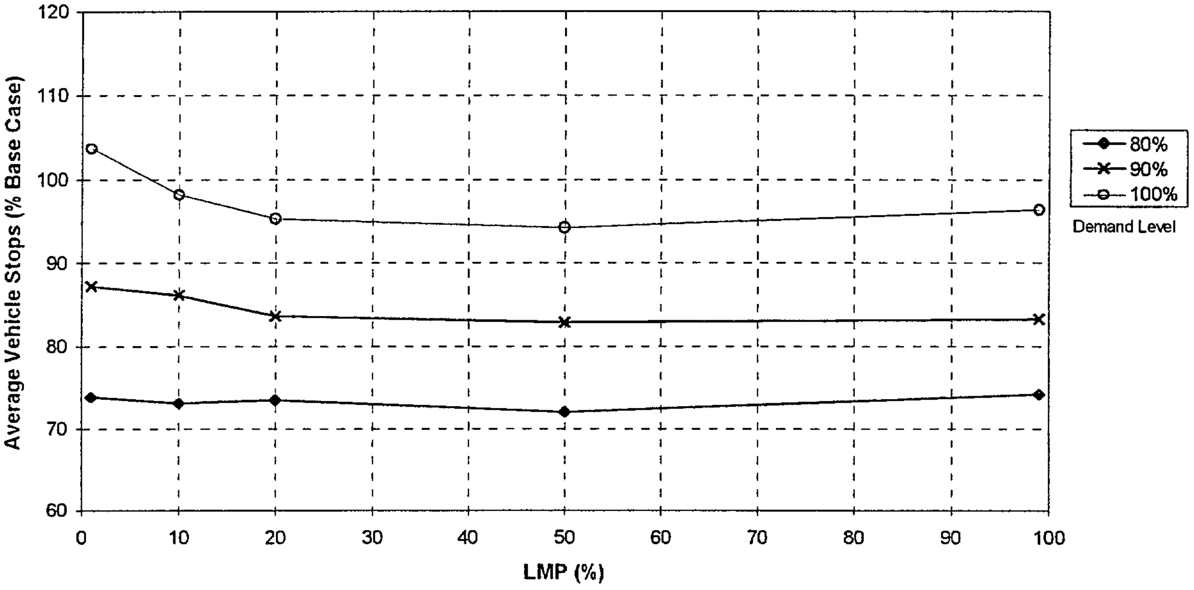

Figure C-10. Variation in average vehicle stops of background vehicles as a function of LMP and demand level (0.5-lane blockage)

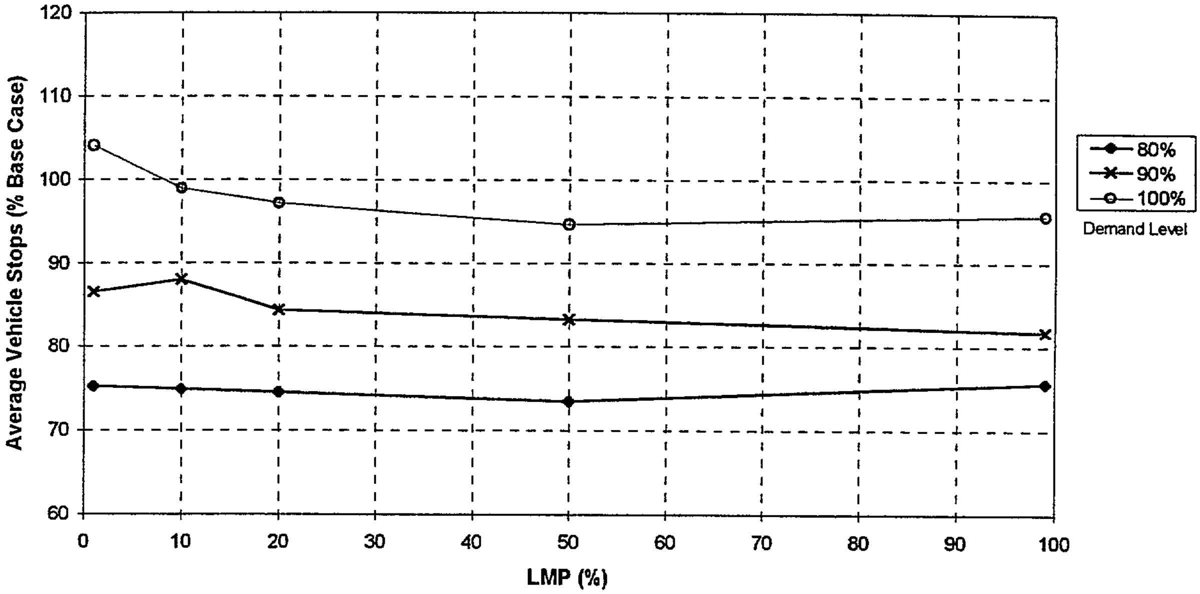

Figure C-11. Variation in average vehicle stops of background vehicles as a function of LMP and demand level (1-lane blockage)

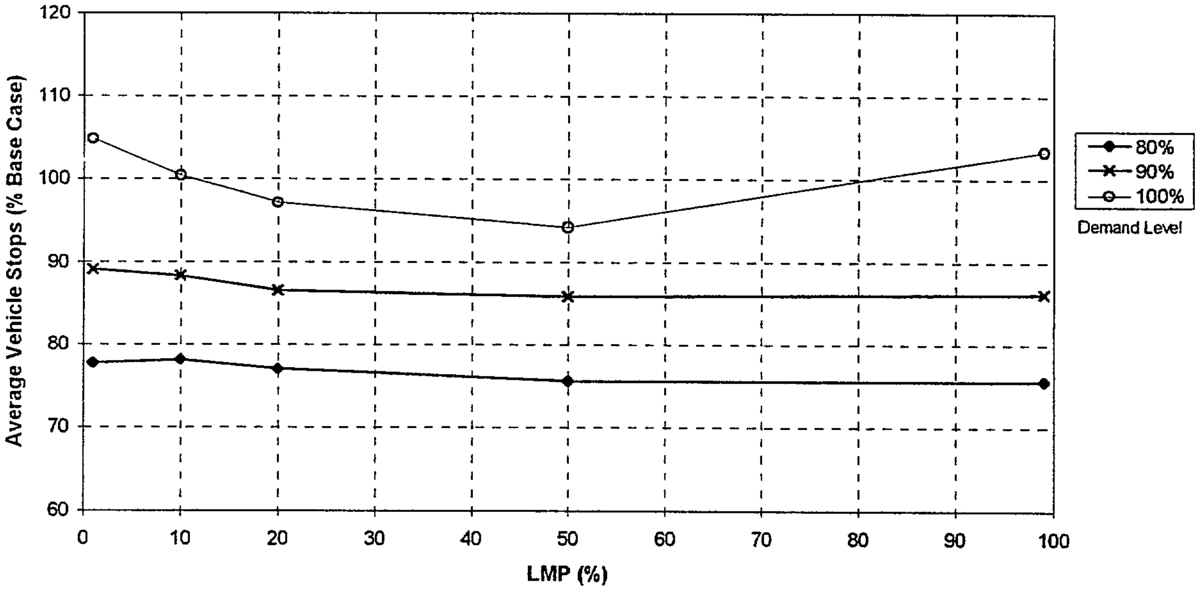

Figure C-12. Variation in average vehicle stops of background vehicles as a function of LMP and demand level (2-lane blockage)

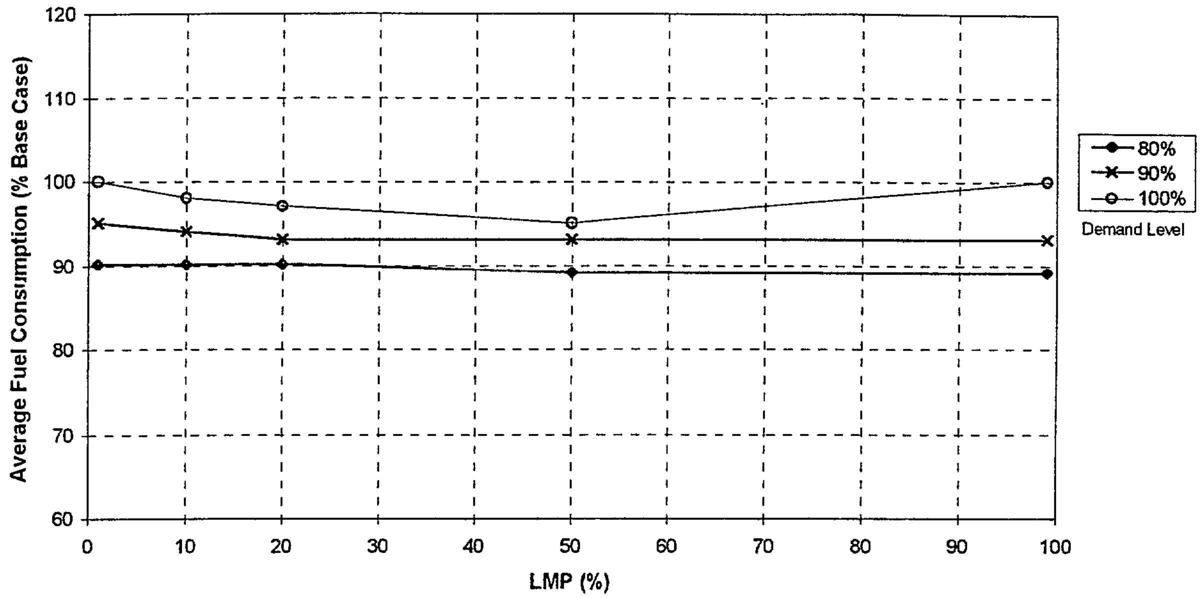

Figure C-13. Variation in average fuel consumption of background vehicles as a function of LMP and demand level (No incident)

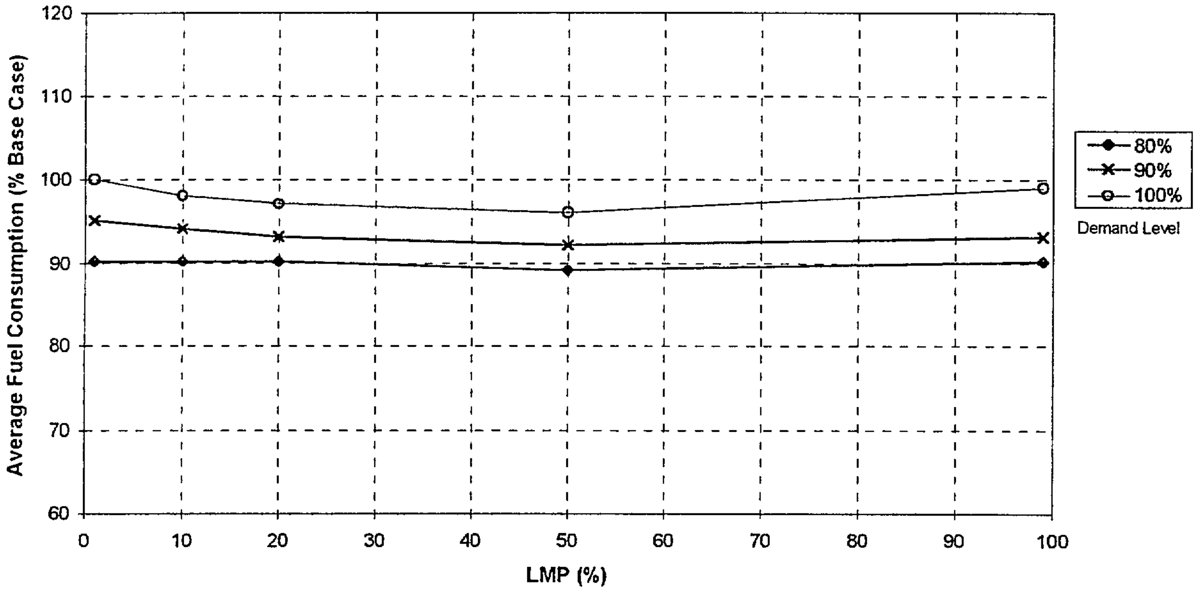

Figure C-14. Variation in average fuel consumption of background vehicles as a function of LMP and demand level (0.5-lane blockage)

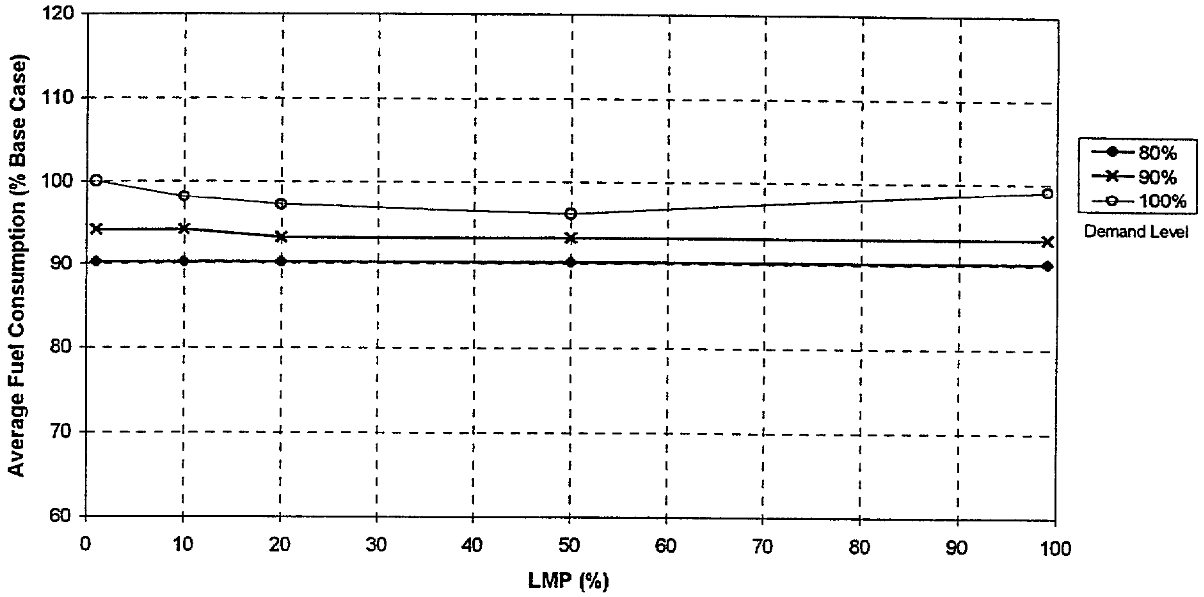

Figure C-15. Variation in average fuel consumption of background vehicles as a function of LMP and demand level (1-lane blockage)

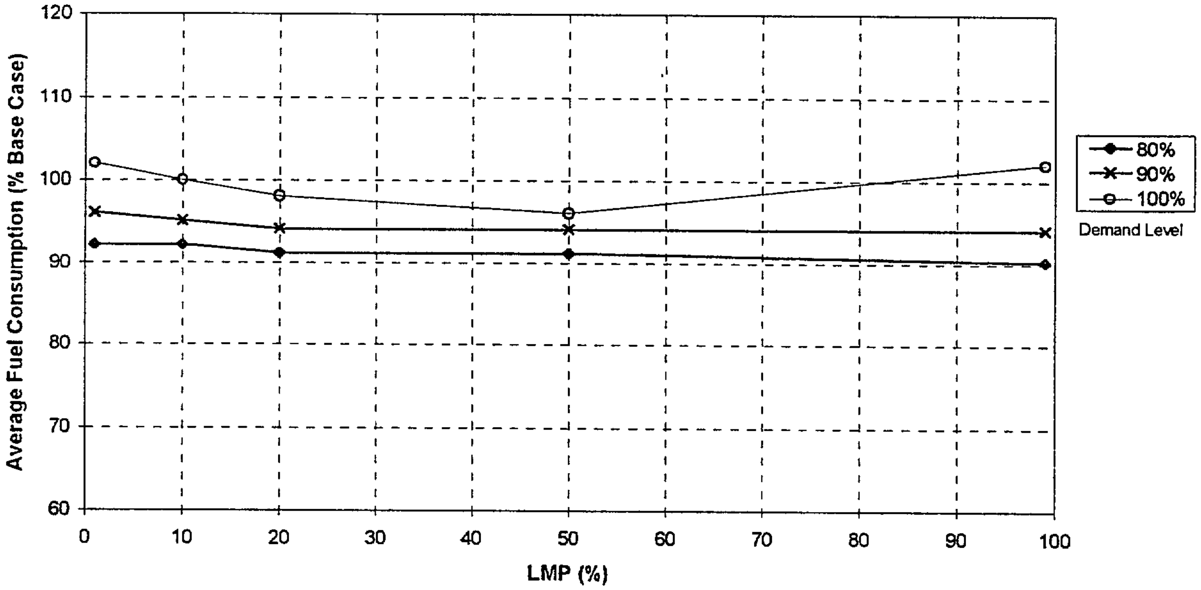

Figure C-16. Variation in average fuel consumption of background vehicles as a function of LMP and demand level (2-lane blockage)

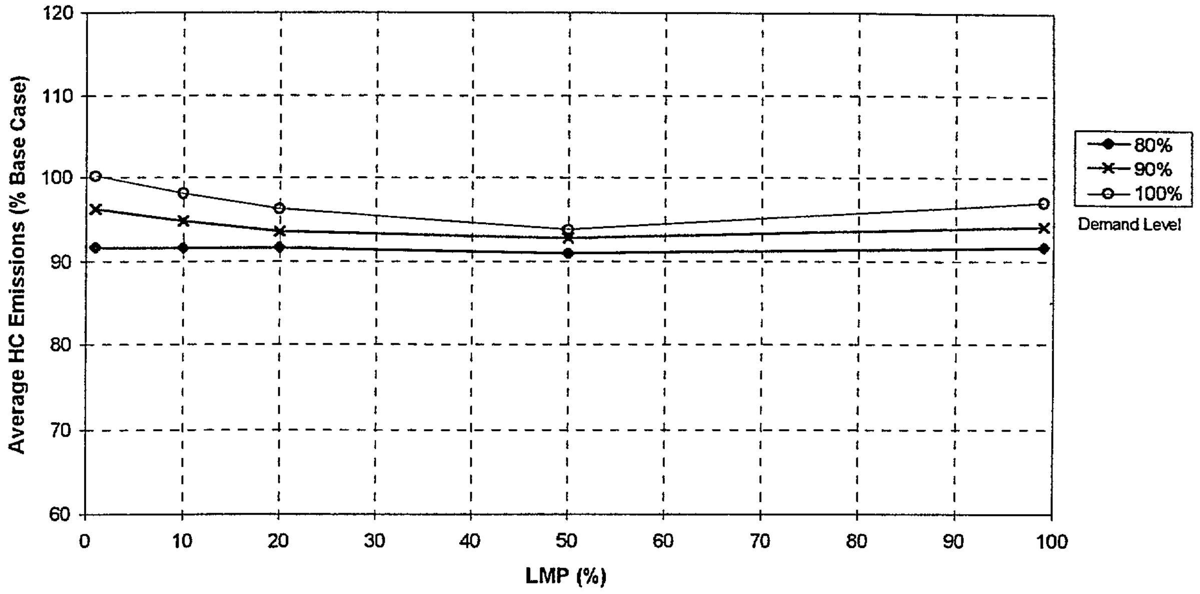

Figure C-17. Variation in average HC emissions of background vehicles as a function of LMP and demand level (No incident)

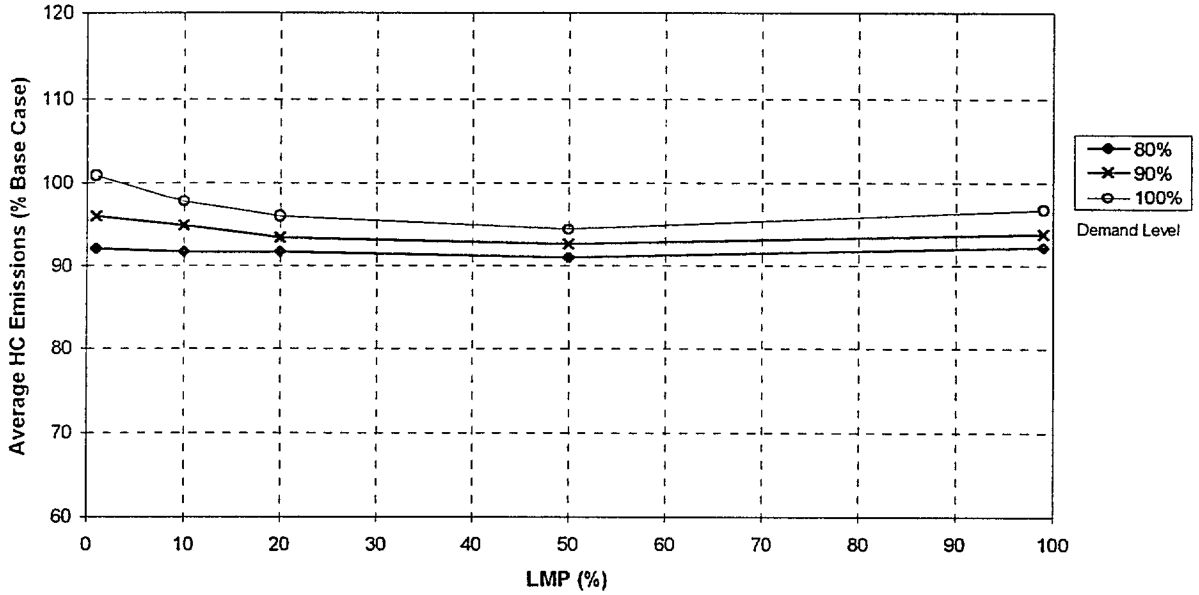

Figure C-18. Variation in average HC emissions of background vehicles as a function of LMP and demand level (0.5-lane blockage)

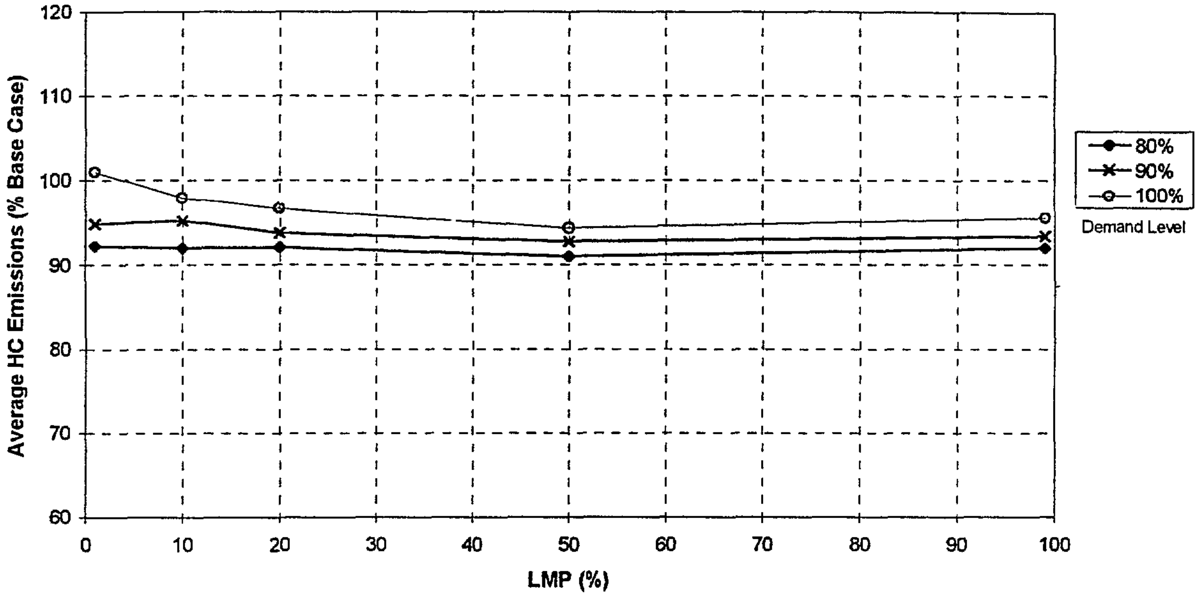

Figure C-19. Variation in average HC emissions of background vehicles as a function of LMP and demand level (1-lane blockage)

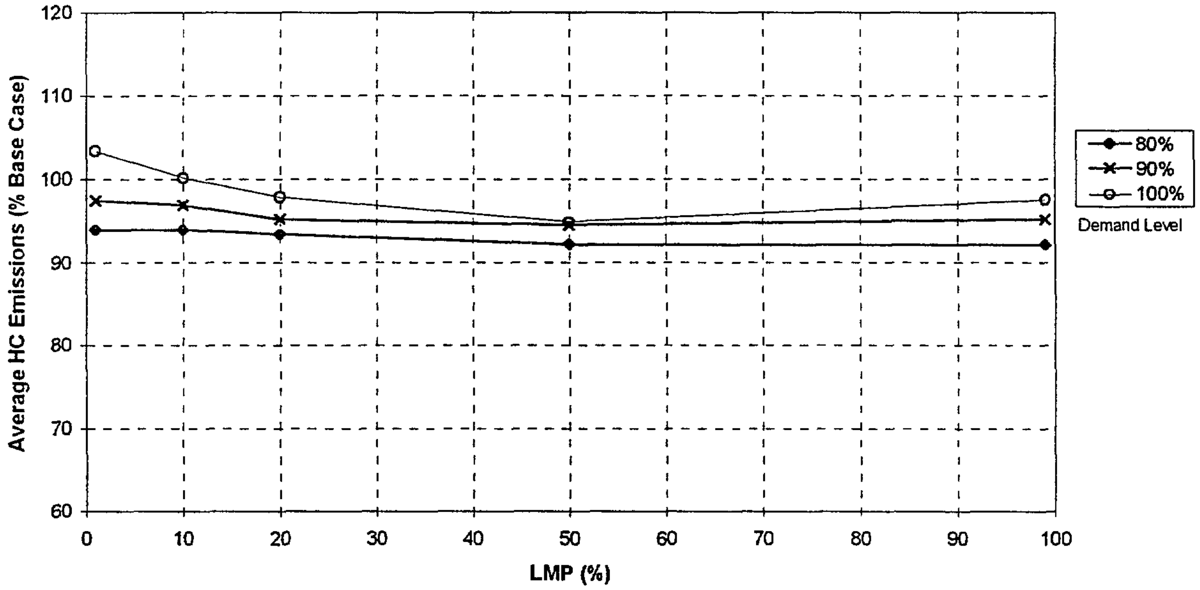

Figure C-20. Variation in average HC emissions of background vehicles as a function of LMP and demand level (2-lane blockage)

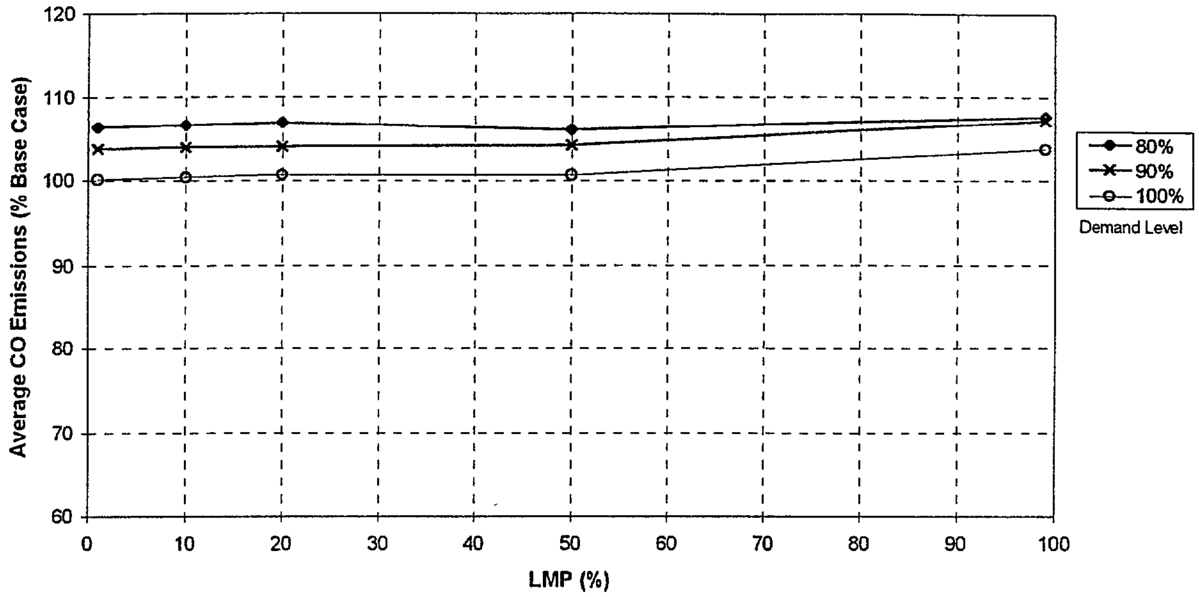

Figure C-21. Variation in average CO emissions of background vehicles as a function of LMP and demand level (No incident)

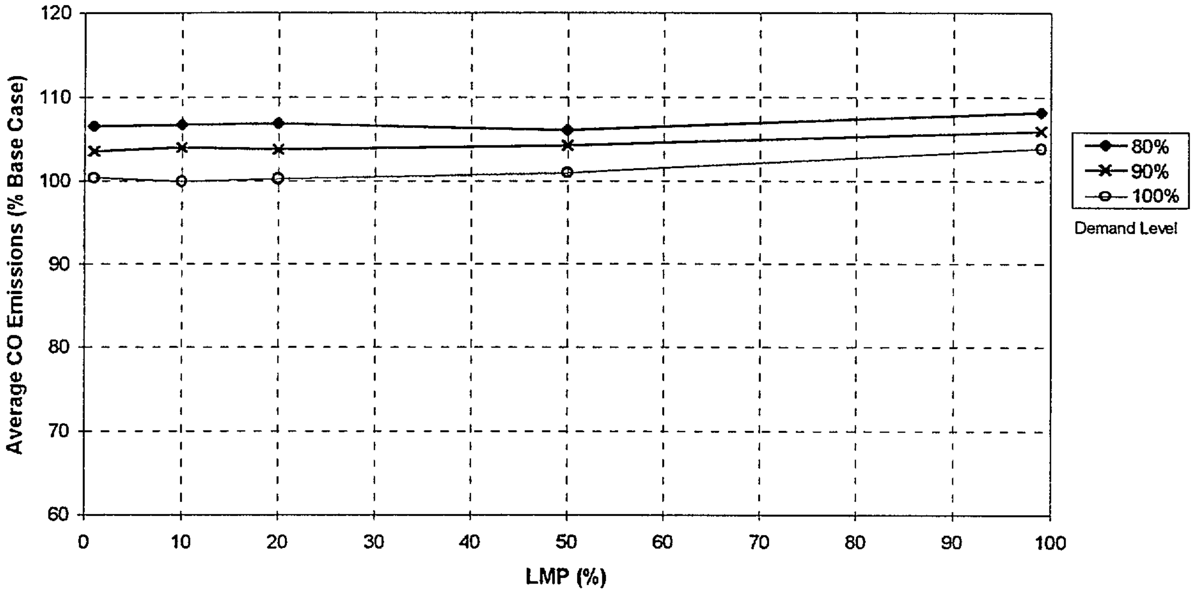

Figure C-22. Variation in average CO emissions of background vehicles as a function of LMP and demand level (0.5-lane blockage)

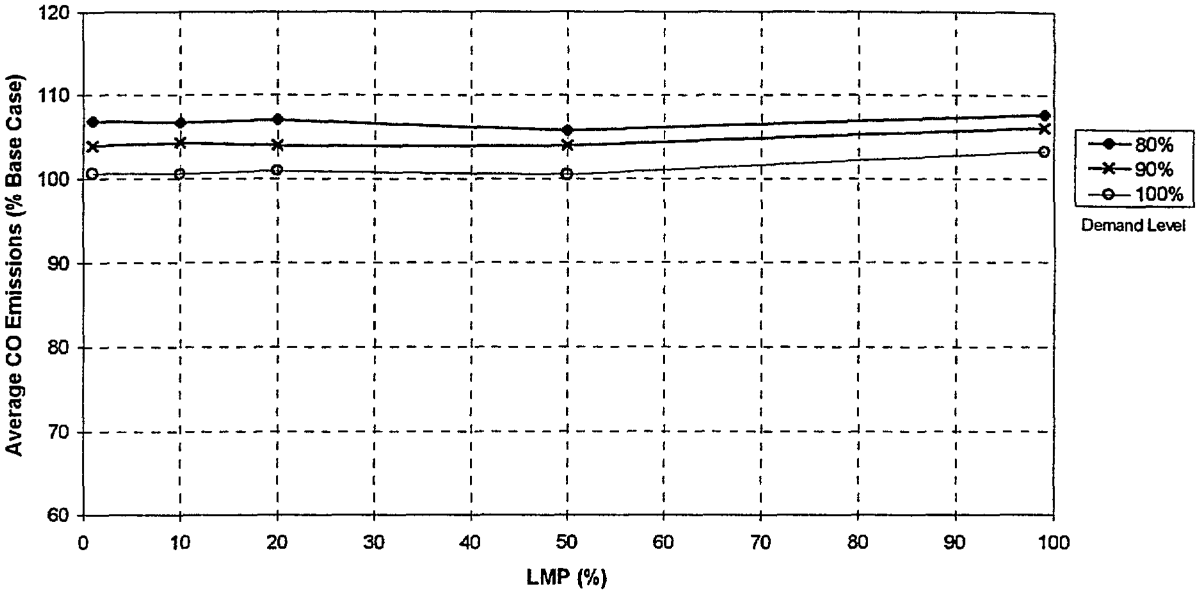

Figure C-23. Variation in average CO emissions of background vehicles as a function of LMP and demand level (1-lane blockage)

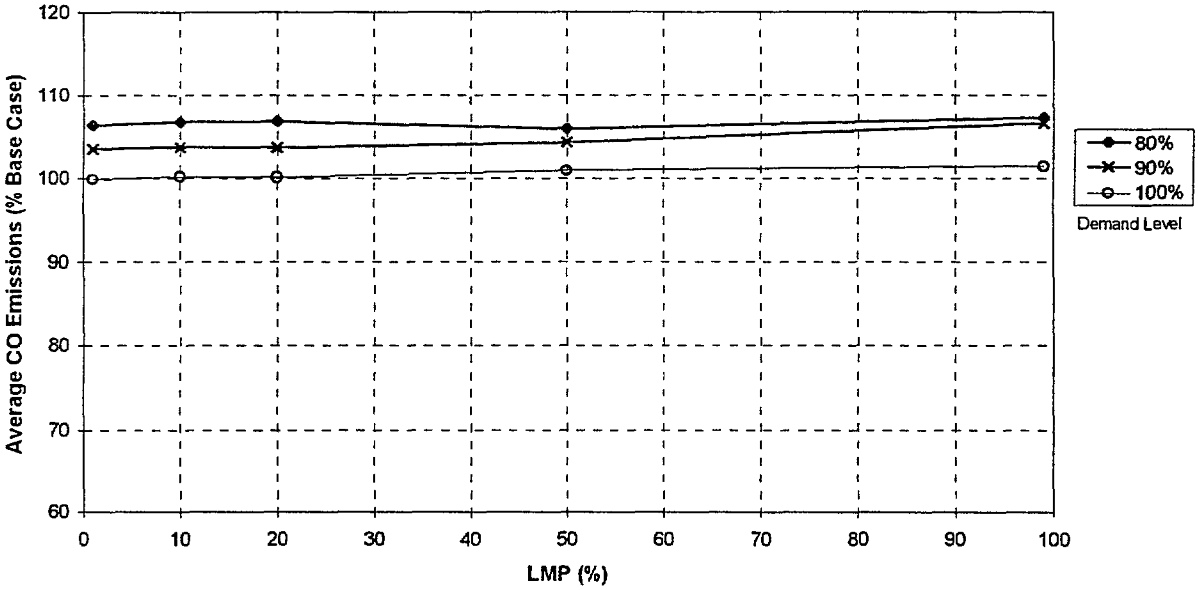

Figure C-24. Variation in average CO emissions of background vehicles as a function of LMP and demand level (2-lane blockage)

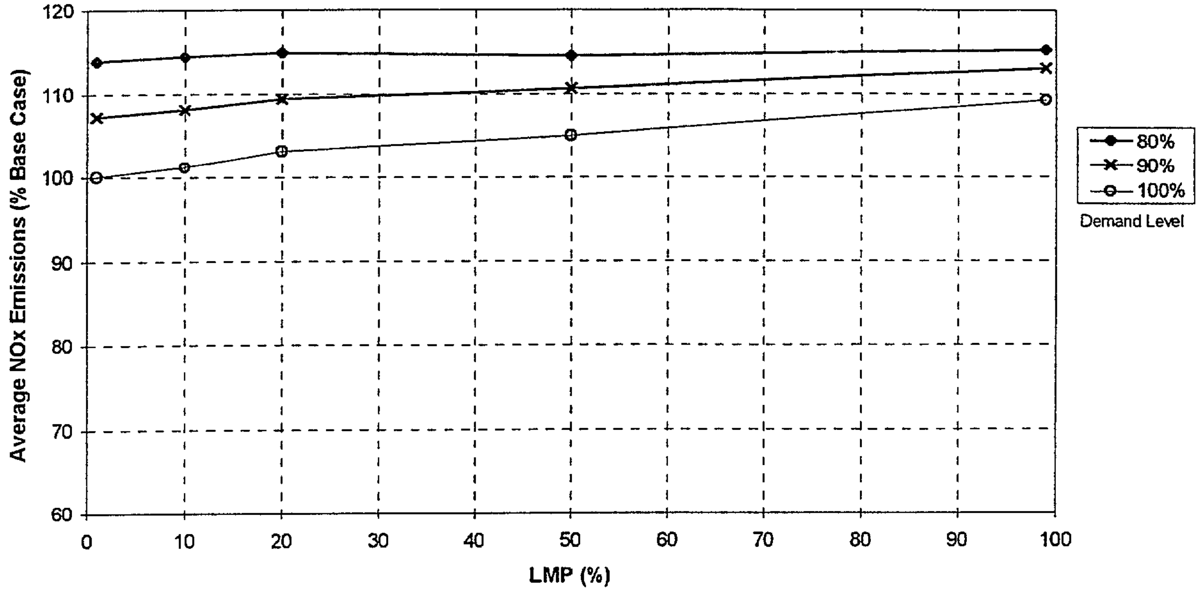

Figure C-25. Variation in average NO_x emissions of background vehicles as a function of LMP and demand level (No incident)

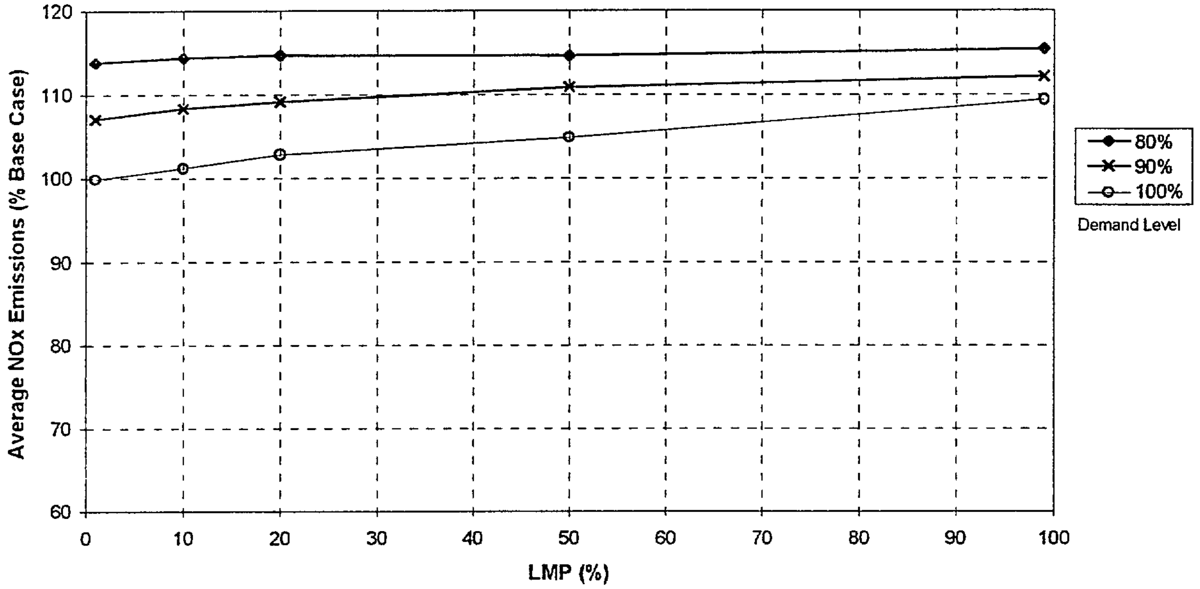

Figure C-26. Variation in average NO_x emissions of background vehicles as a function of LMP and demand level (0.5-lane blockage)

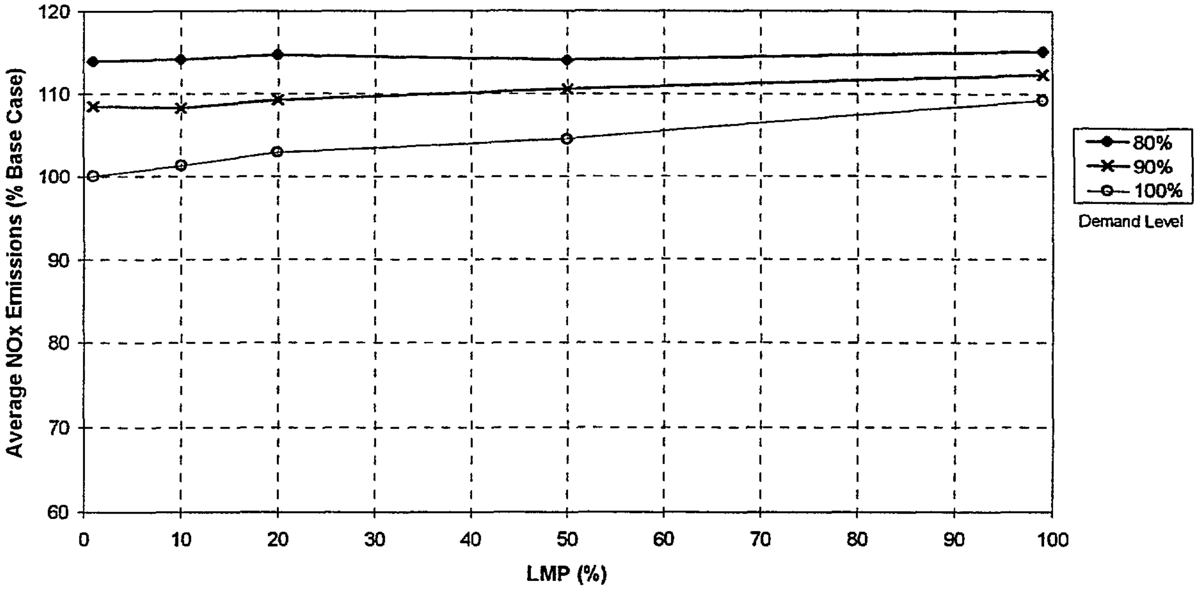

Figure C-27. Variation in average NO_x emissions of background vehicles as a function of LMP and demand level (1-lane blockage)

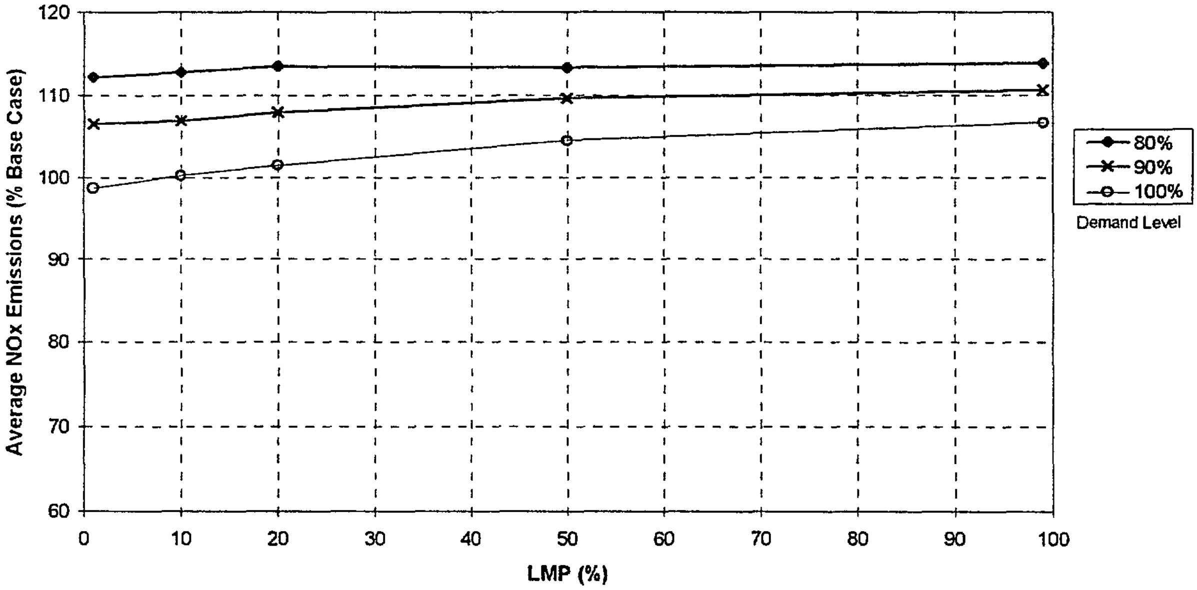

Figure C-28. Variation in average NO_x emissions of background vehicles as a function of LMP and demand level (2-lane blockage)

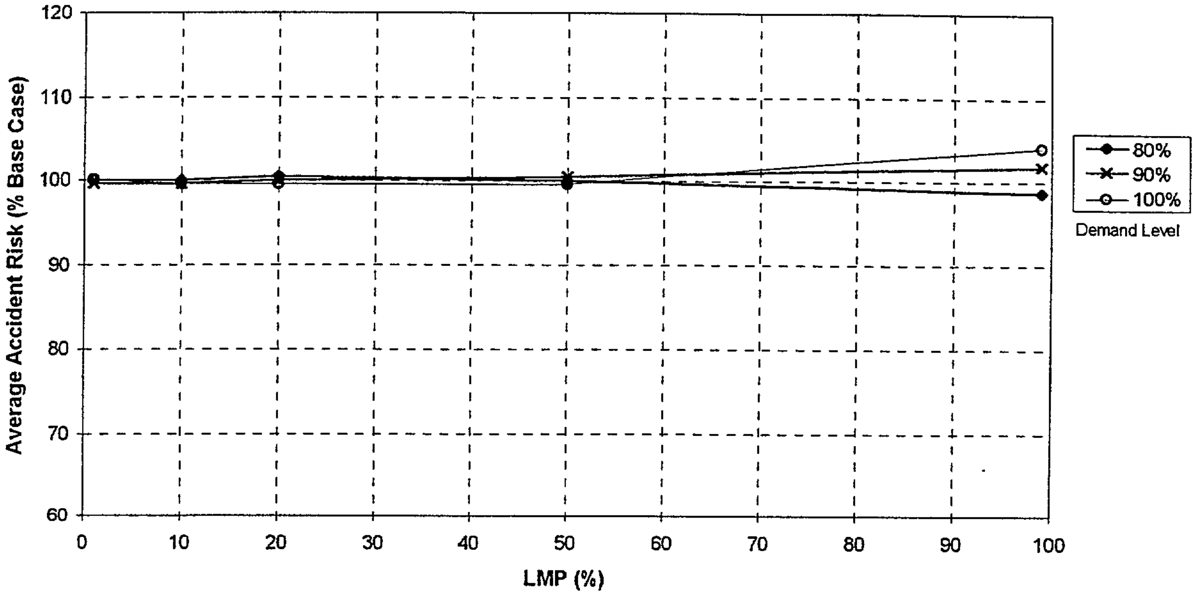

Figure C-29. Variation in average accident risk of background vehicles as a function of LMP and demand level (No incident)

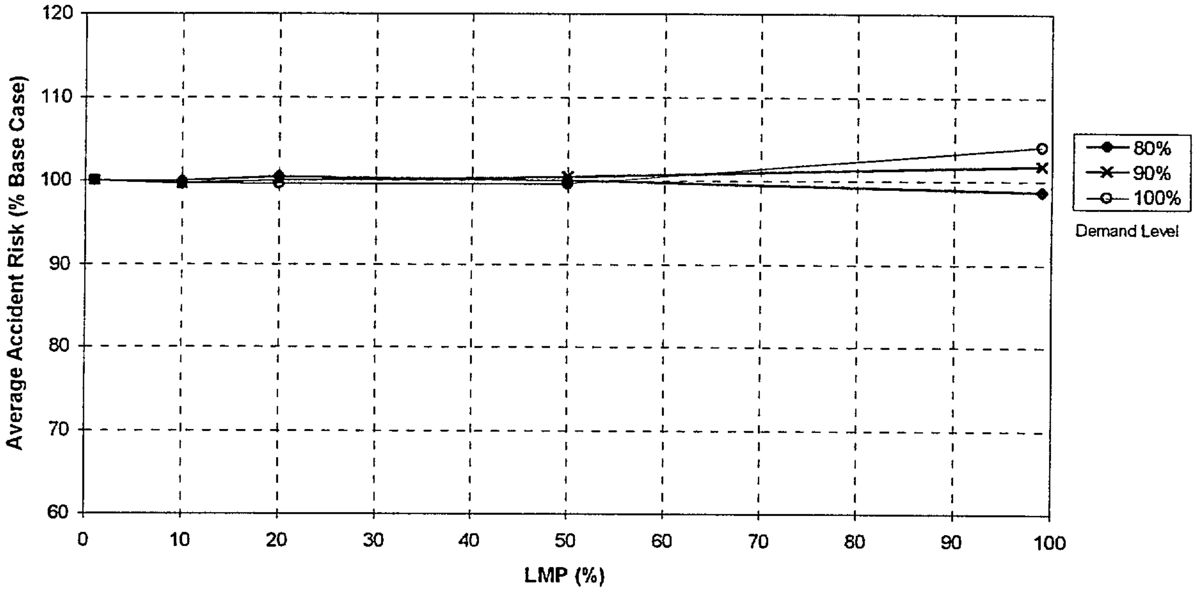

Figure C-30. Variation in average accident risk of background vehicles as a function of LMP and demand level (0.5-lane blockage)

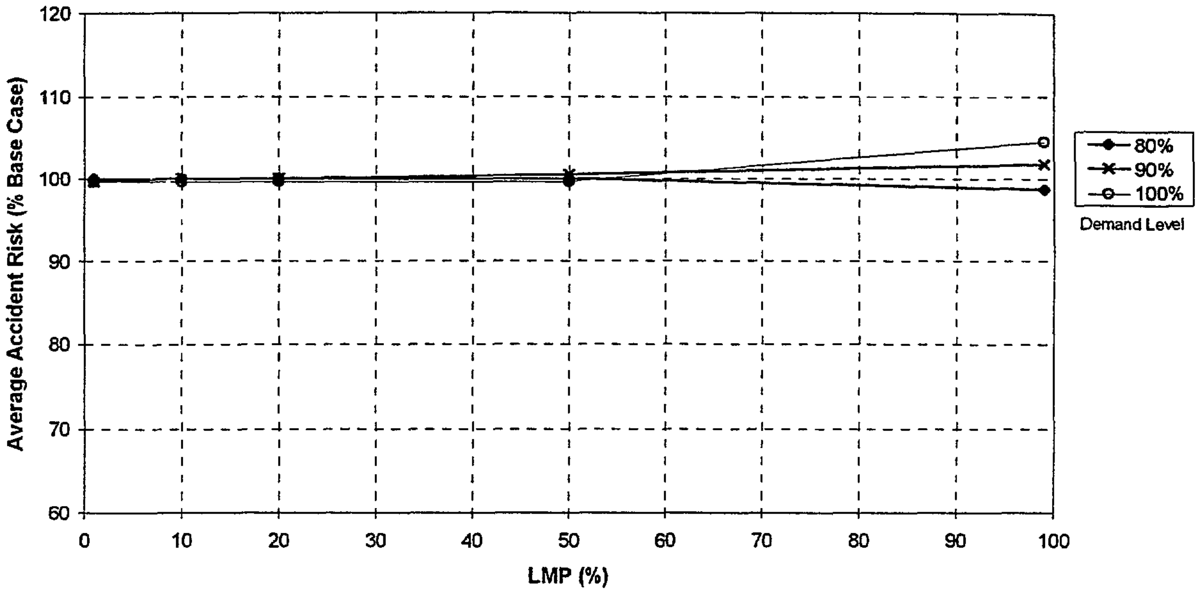

Figure C-31. Variation in average accident risk of background vehicles as a function of LMP and demand level (1-lane blockage)

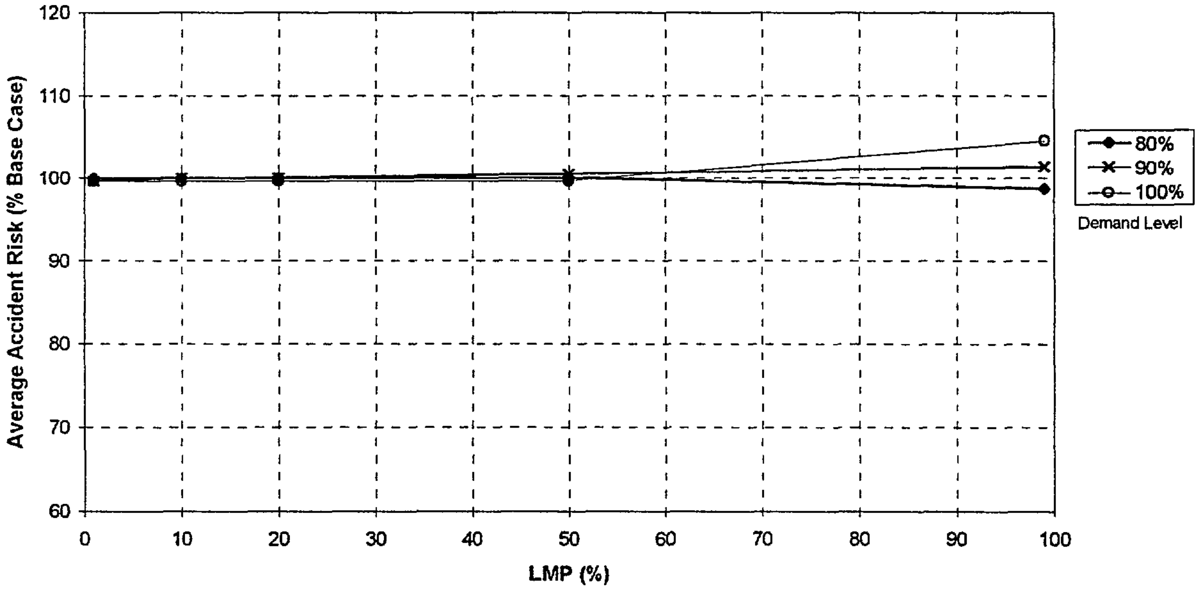

Figure C-32. Variation in average accident risk of background vehicles as a function of LMP and demand level (2-lane blockage)

APPENDIX (D)
SIMULATION RESULTS OF GENESIS SYSTEM

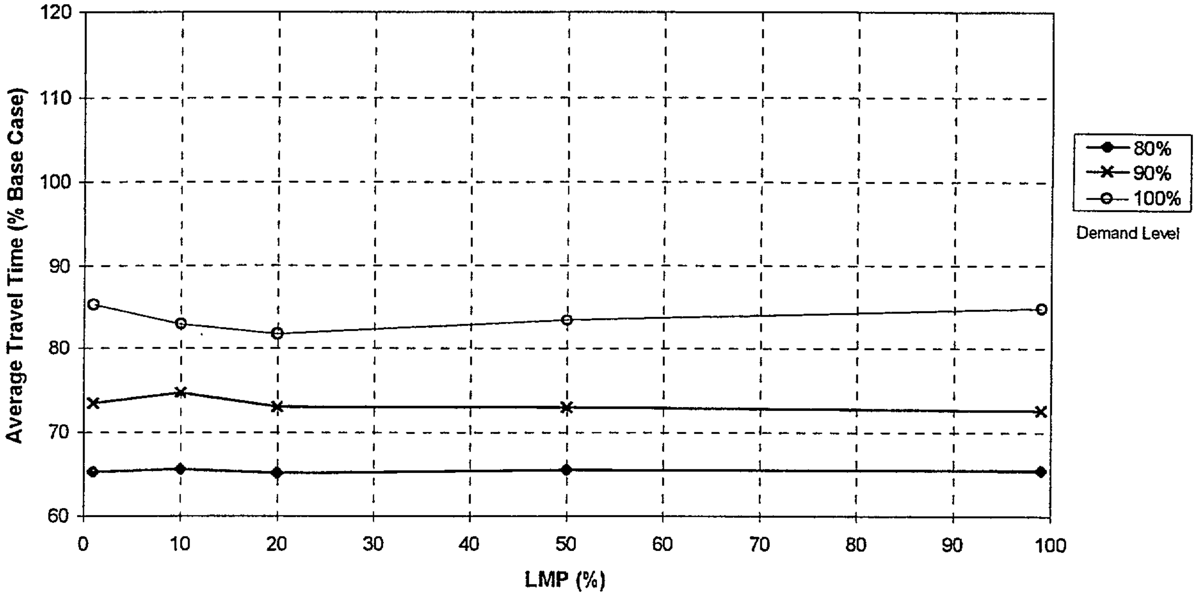

Figure D-1. Variation in average trip time of Genesis equipped vehicles as a function of LMP and demand level (No inident)

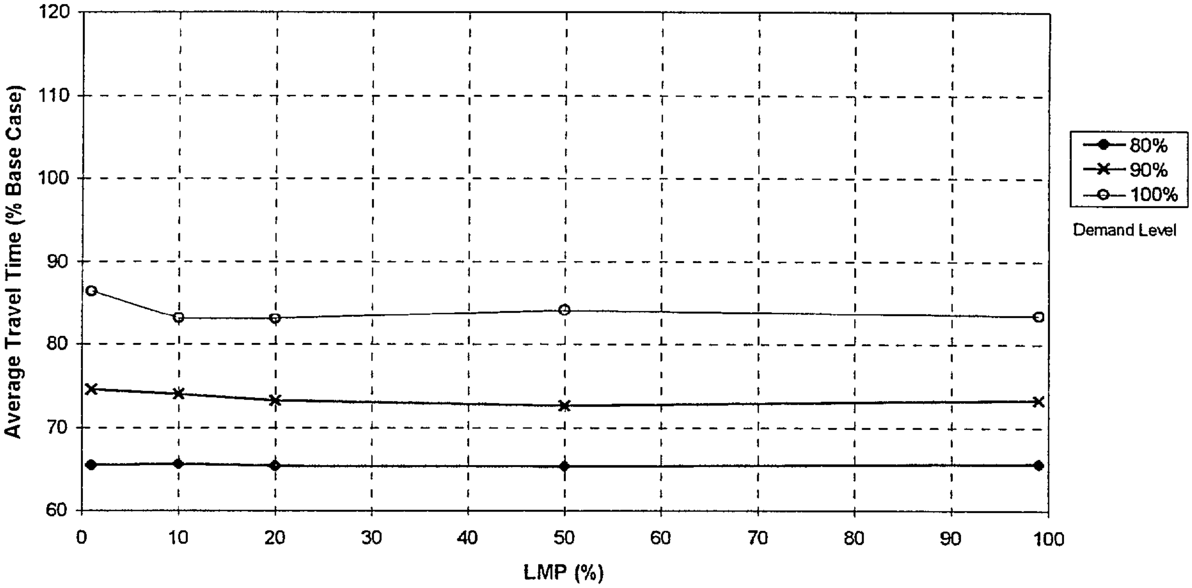

Figure D-2. Variation in average trip time of Genesis equipped vehicles as a function of LMP and demand level (0.5-lane blockage)

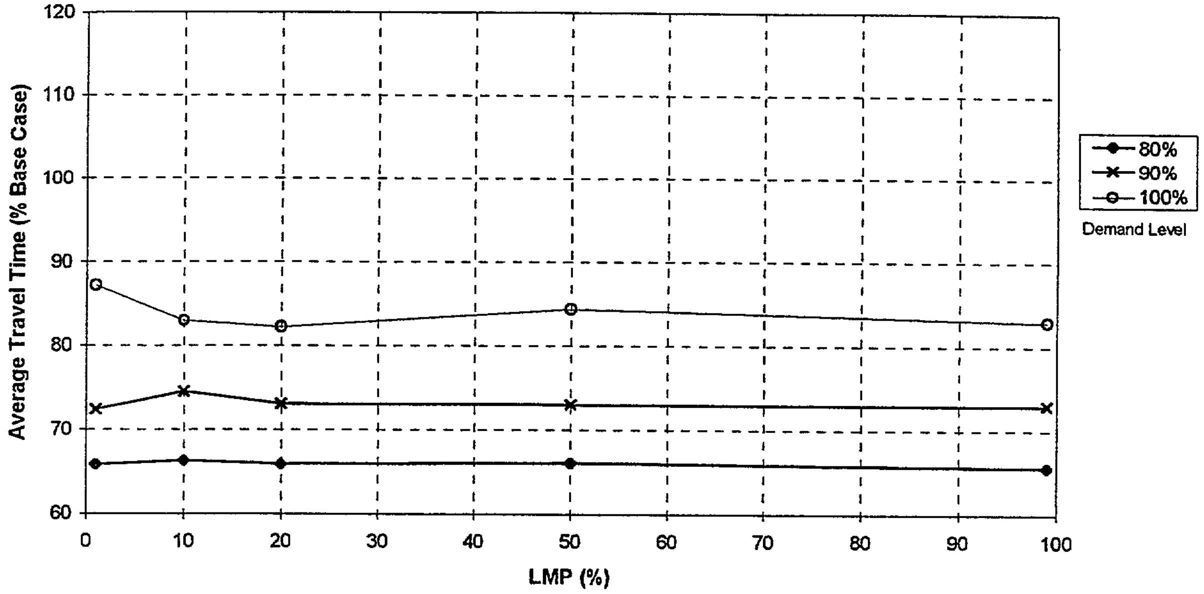

Figure D-3. Variation in average trip time of Genesis equipped vehicles as a function of LMP and demand level (1-lane blockage)

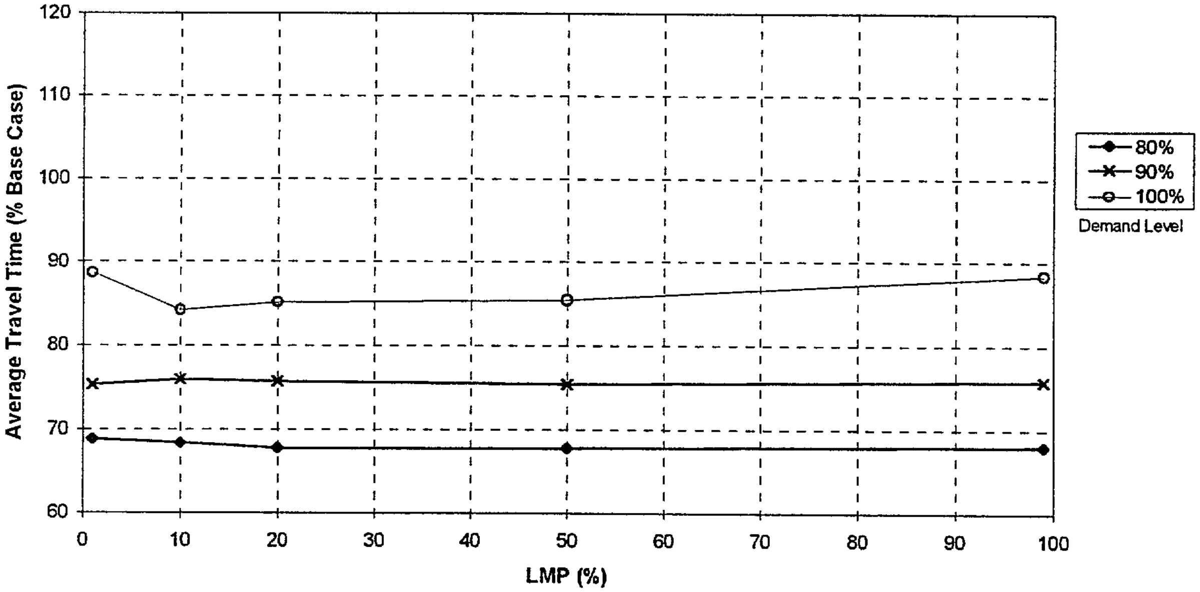

Figure D-4. Variation in average trip time of Genesis equipped vehicles as a function of LMP and demand level (2-lane blockage)

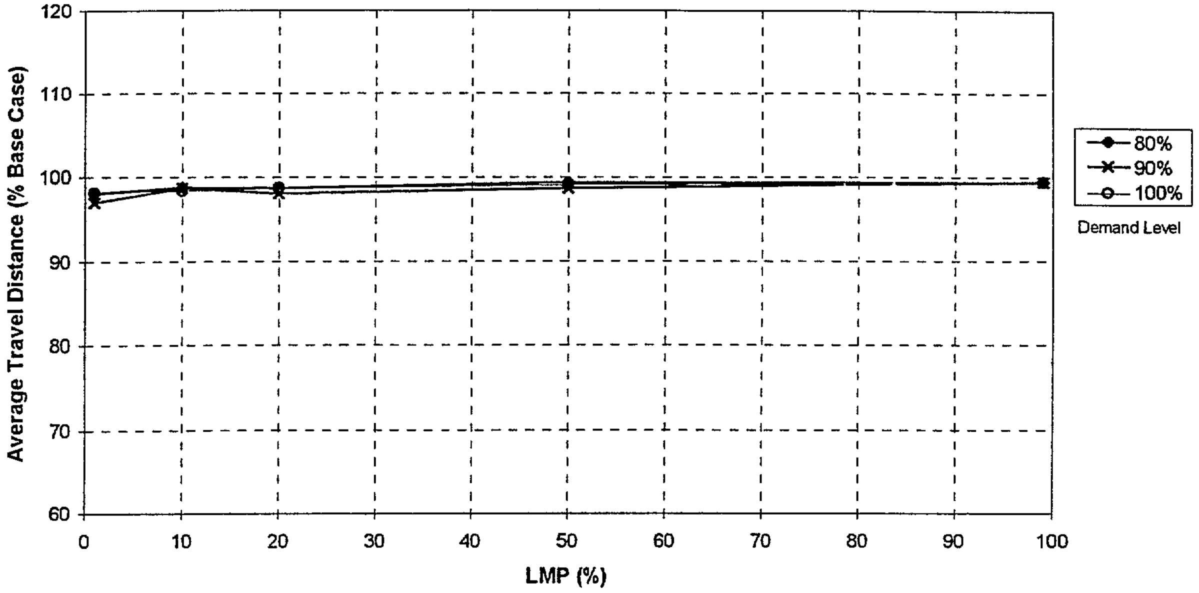

Figure D-5. Variation in average trip length of Genesis equipped vehicles as a function of LMP and demand level (No incident)

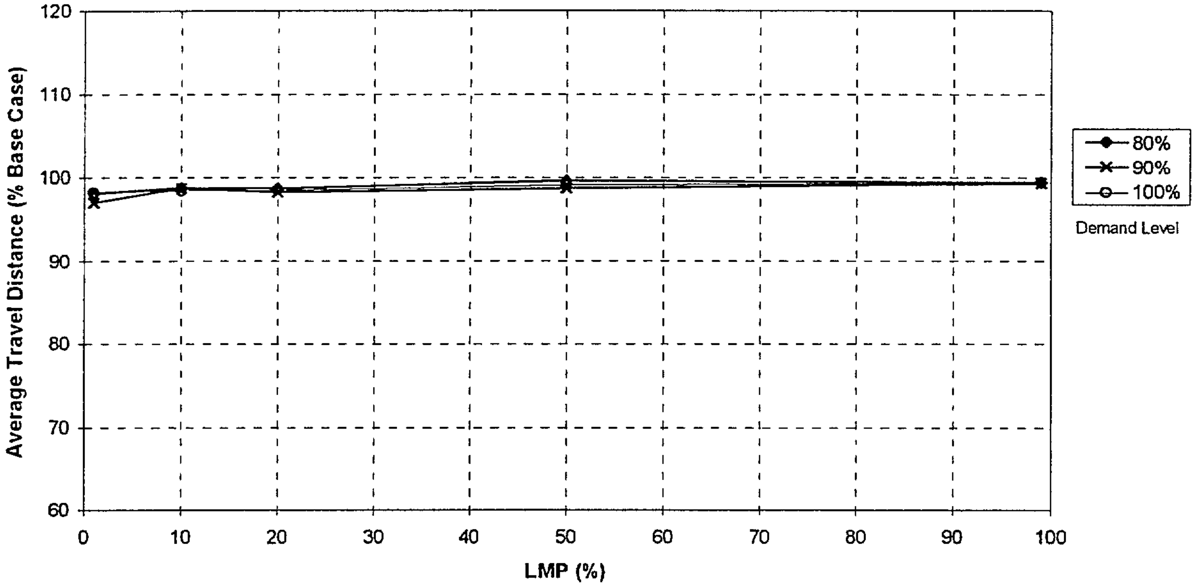

Figure D-6. Variation in average trip length of Genesis equipped vehicles as a function of LMP and demand level (0.5-lane blockage)

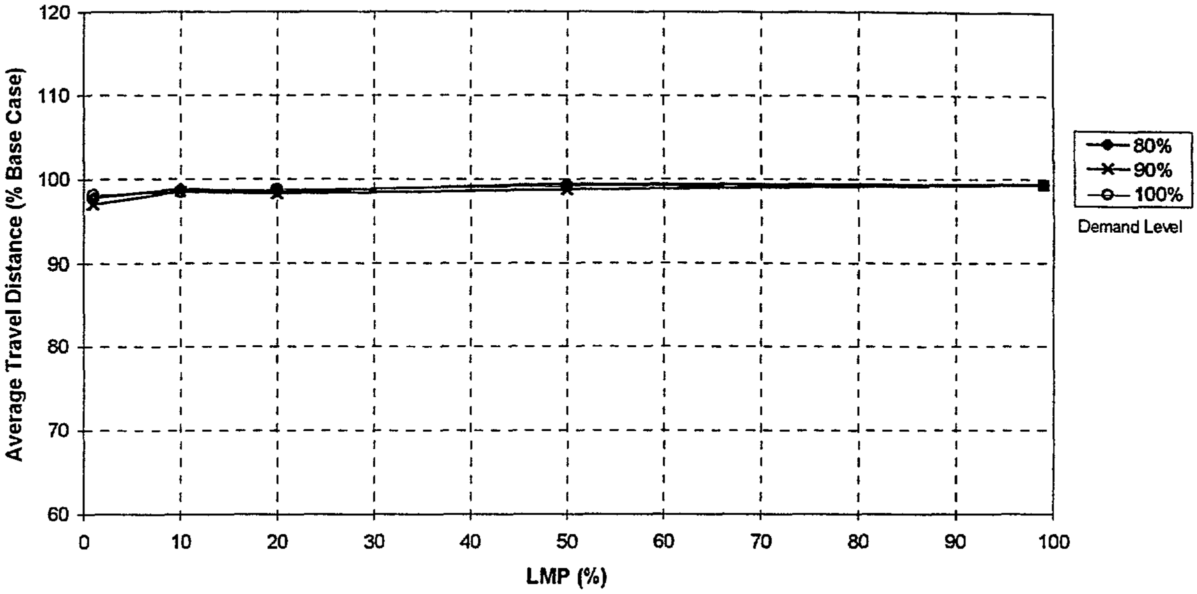

Figure D-7. Variation in average trip length of Genesis equipped vehicles as a function of LMP and demand level (1-lane blockage)

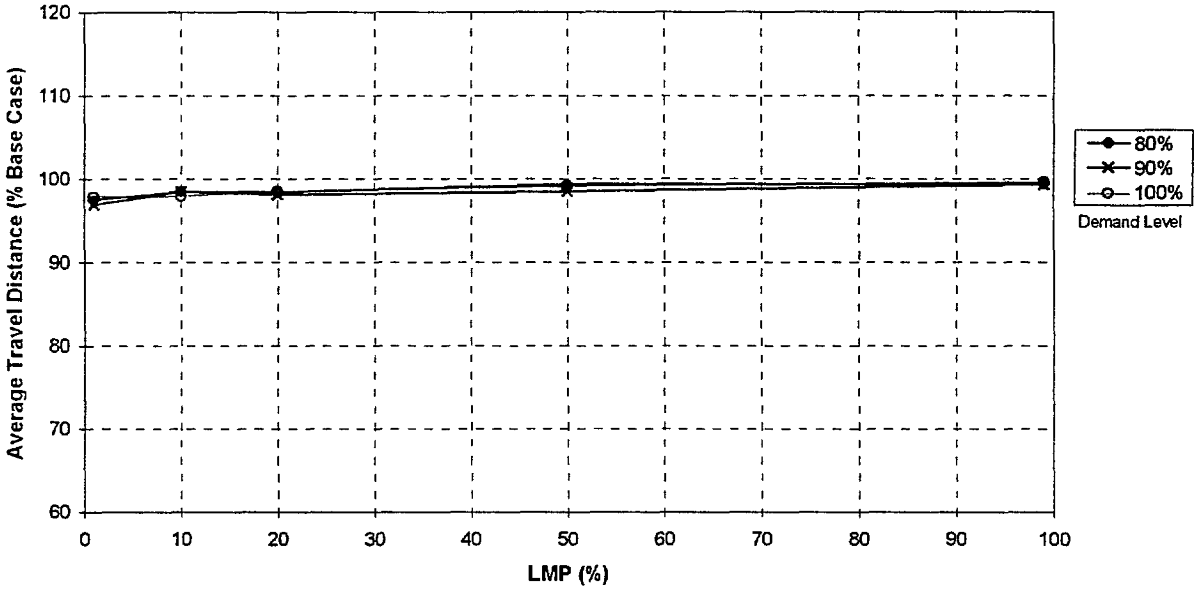

Figure D-8. Variation in average trip length of Genesis equipped vehicles as a function of LMP and demand level (2-lane blockage)

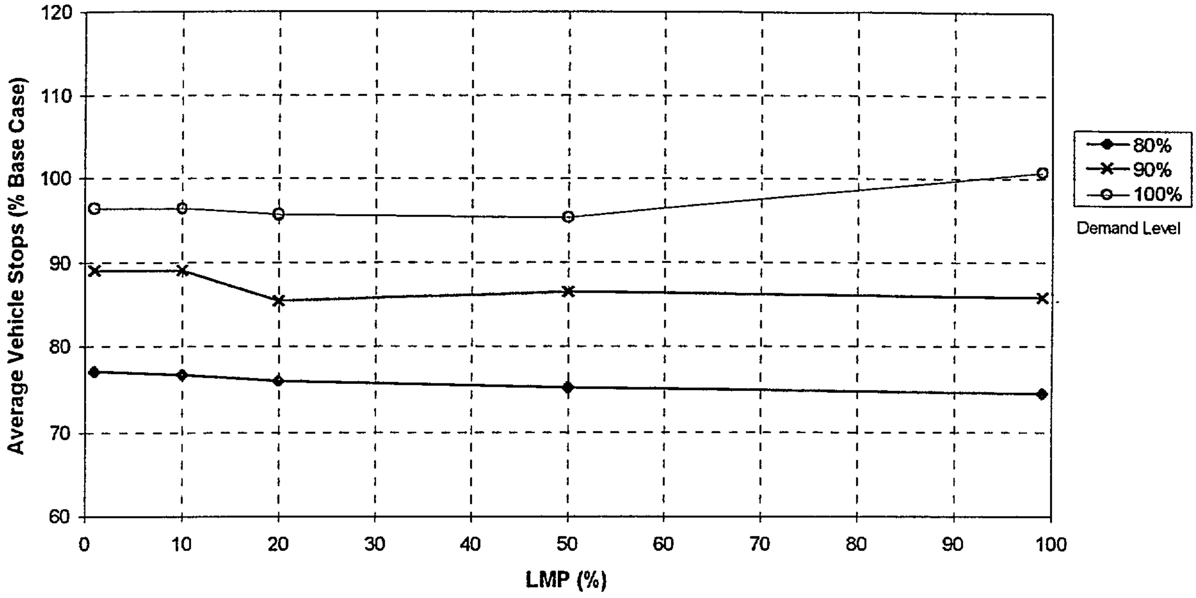

Figure D-9. Variation in average vehicle stops of Genesis equipped vehicles as a function of LMP and demand level (No incident)

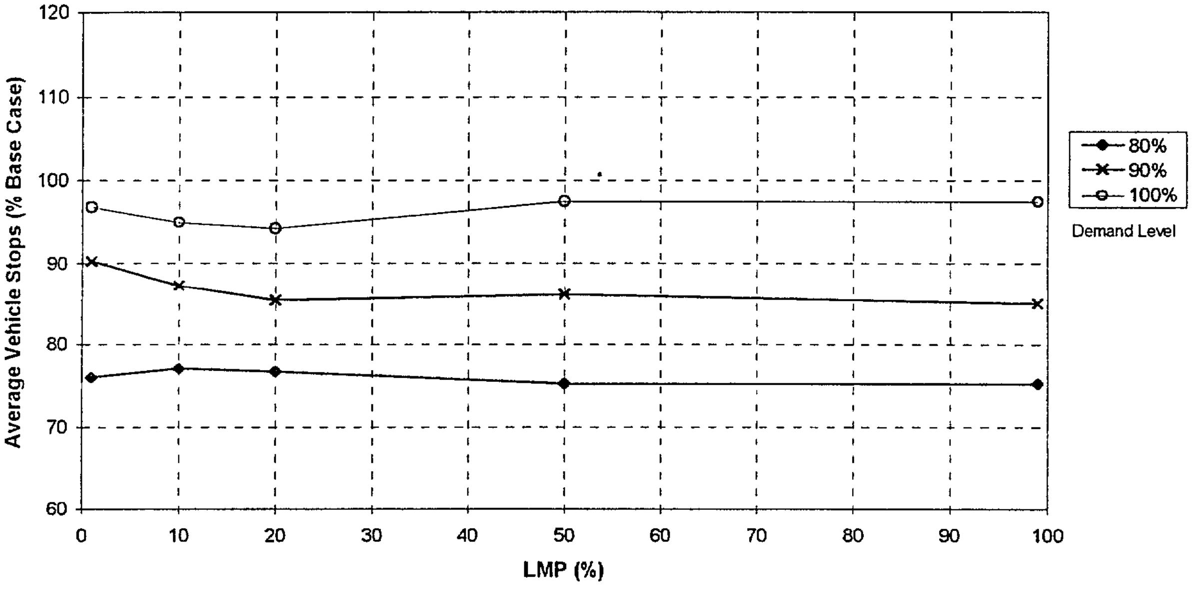

Figure D-10. Variation in average vehicle stops of Genesis equipped vehicles as a function of LMP and demand level (0.5-lane blockage)

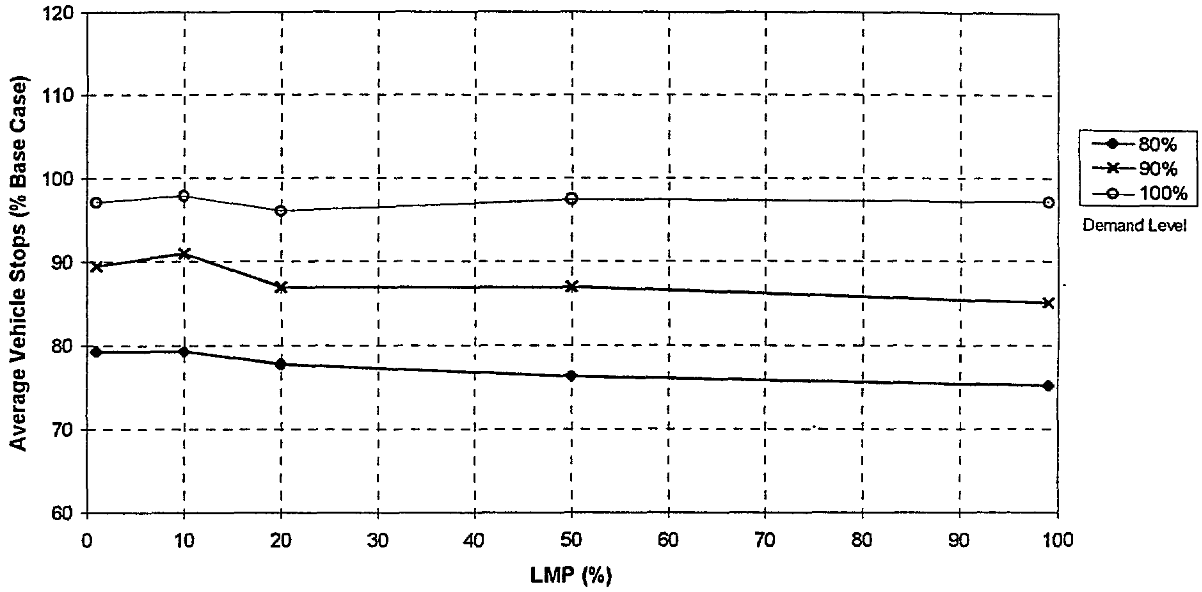

Figure D-11. Variation in average vehicle stops of Genesis equipped vehicles as a function of LMP and demand level (1-lane blockage)

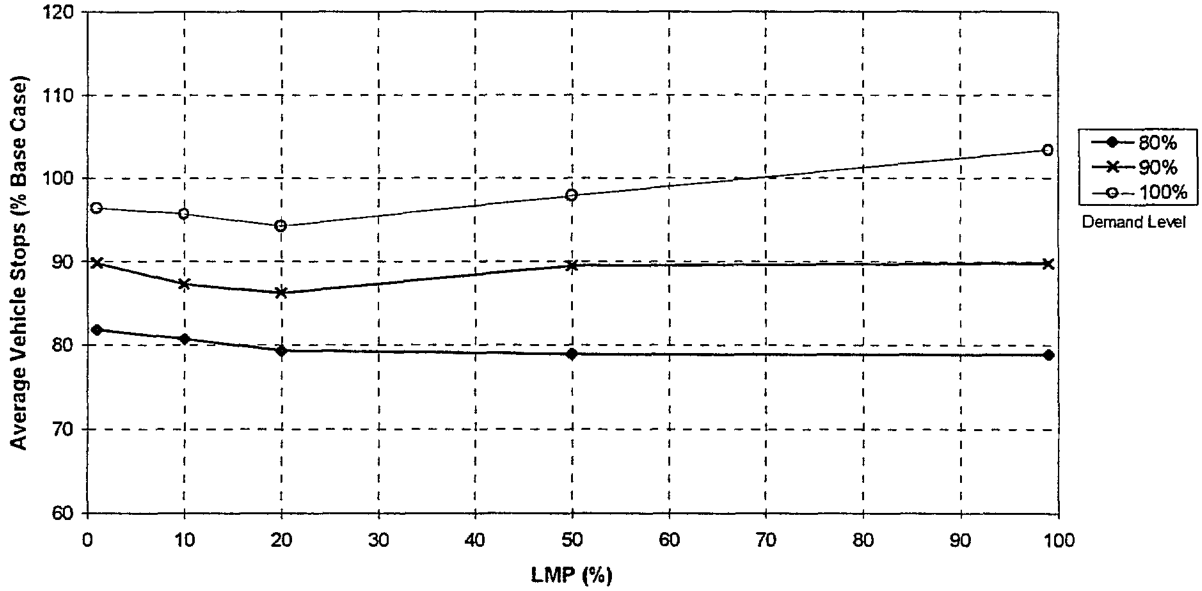

Figure D-12. Variation in average vehicle stops of Genesis equipped vehicles as a function of LMP and demand level (2-lane blockage)

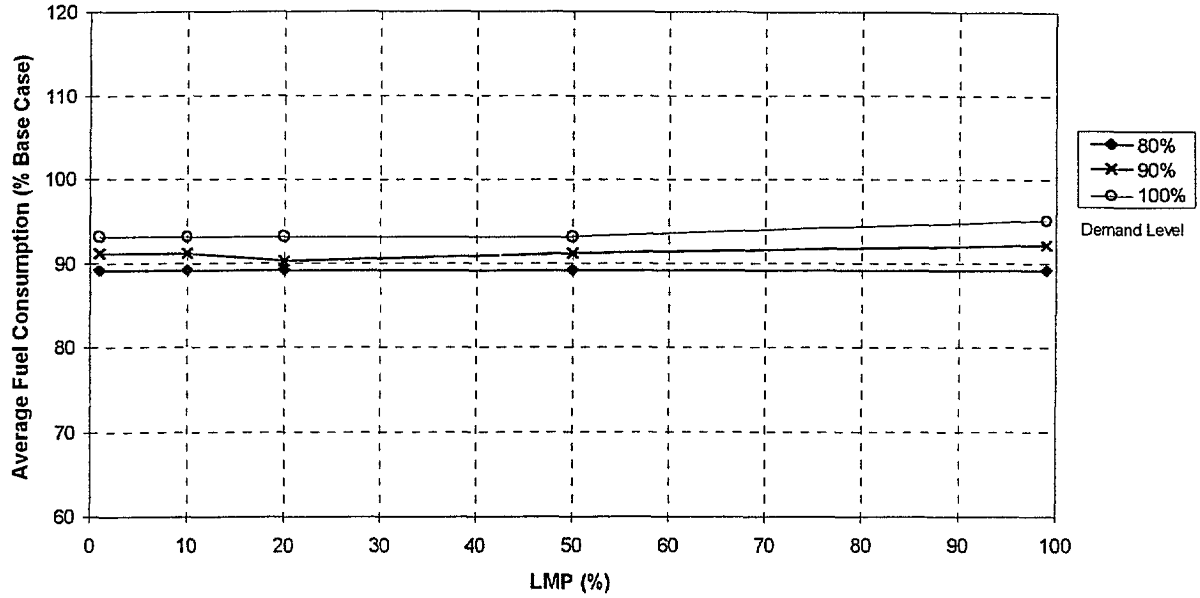

Figure D-13. Variation in average fuel consumption of Genesis equipped vehicles as a function of LMP and demand level (No incident)

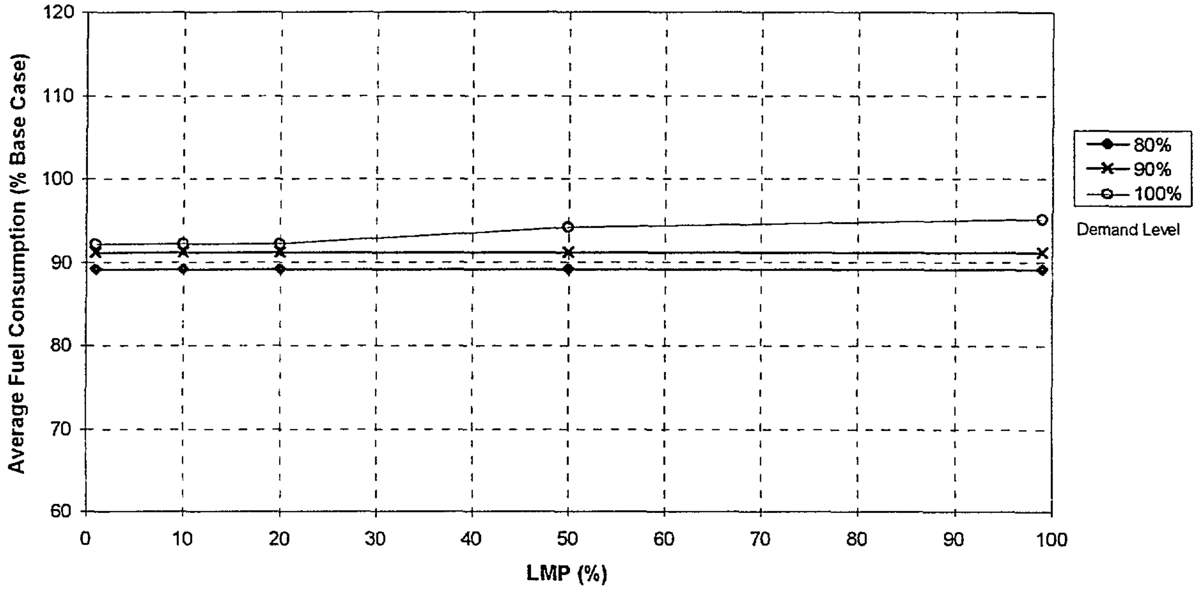

Figure D-14. Variation in average fuel consumption of Genesis equipped vehicles as a function of LMP and demand level (0.5-lane blockage)

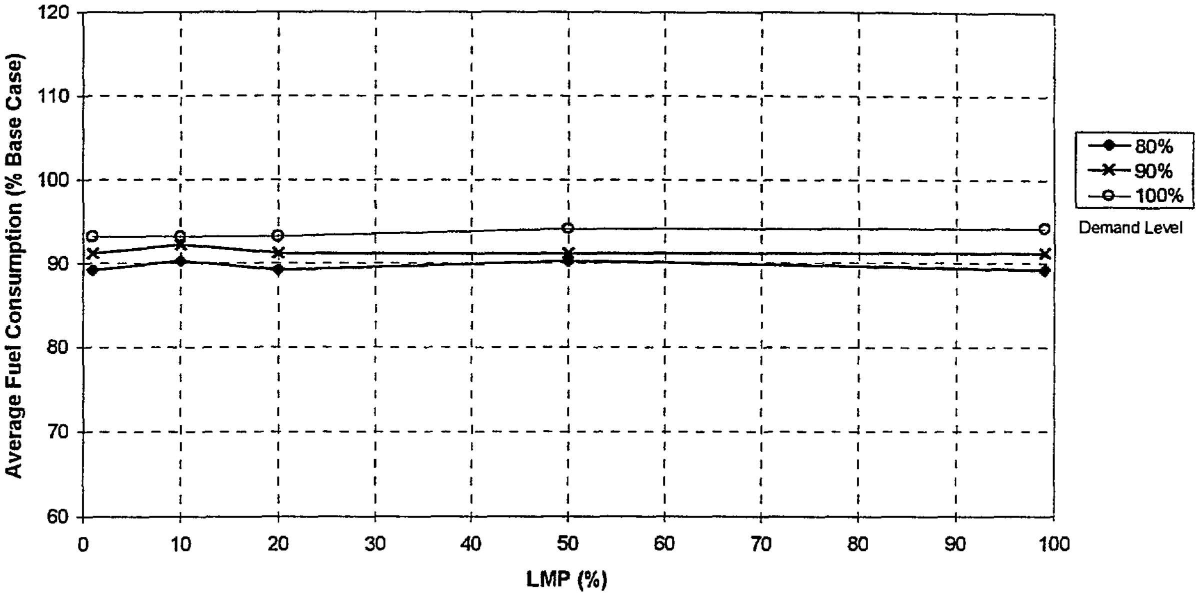

Figure D-15. Variation in average fuel consumption of Genesis equipped vehicles as a function of LMP and demand level (1-lane blockage)

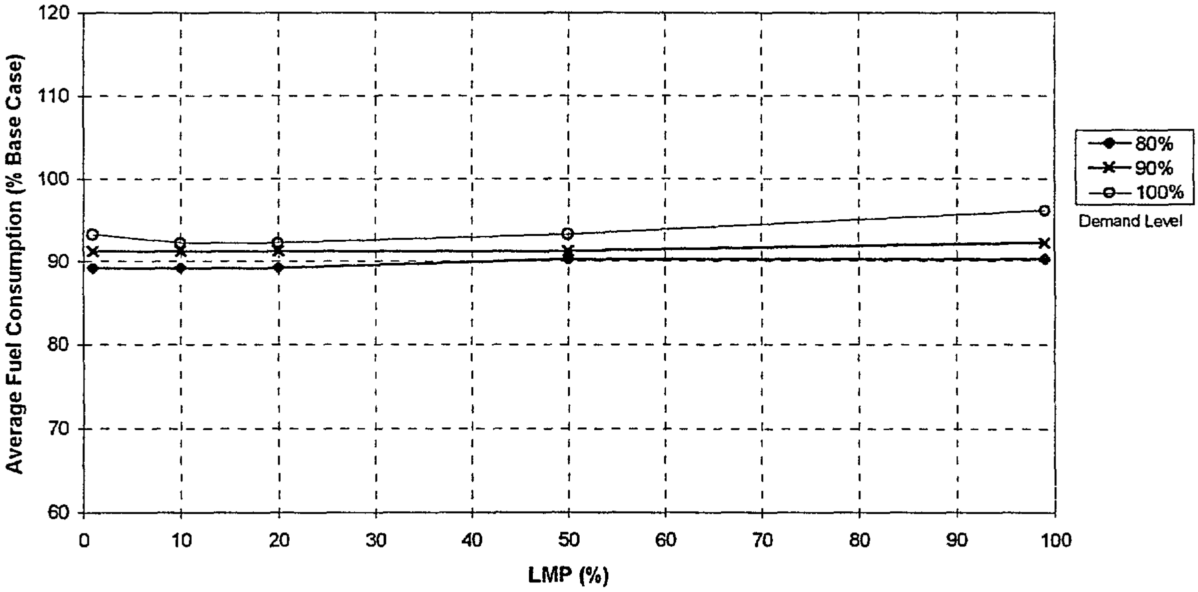

Figure D-16. Variation in average fuel consumption of Genesis equipped vehicles as a function of LMP and demand level (2-lane blockage)

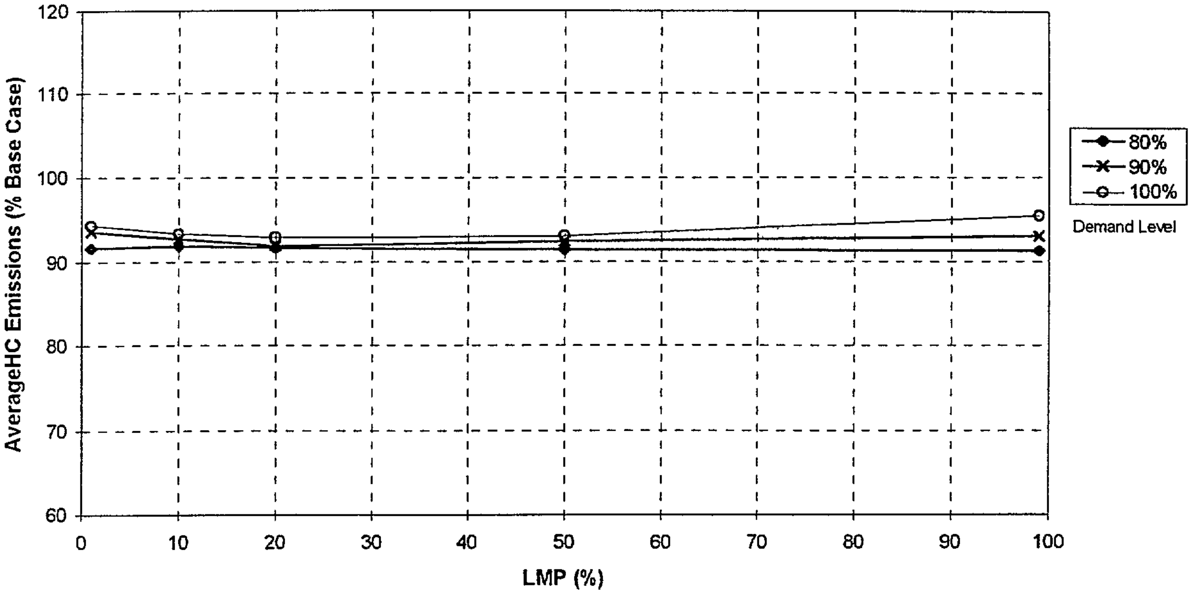

Figure D-17. Variation in average HC emissions of Genesis equipped vehicles as a function of LMP and demand level (No incident)

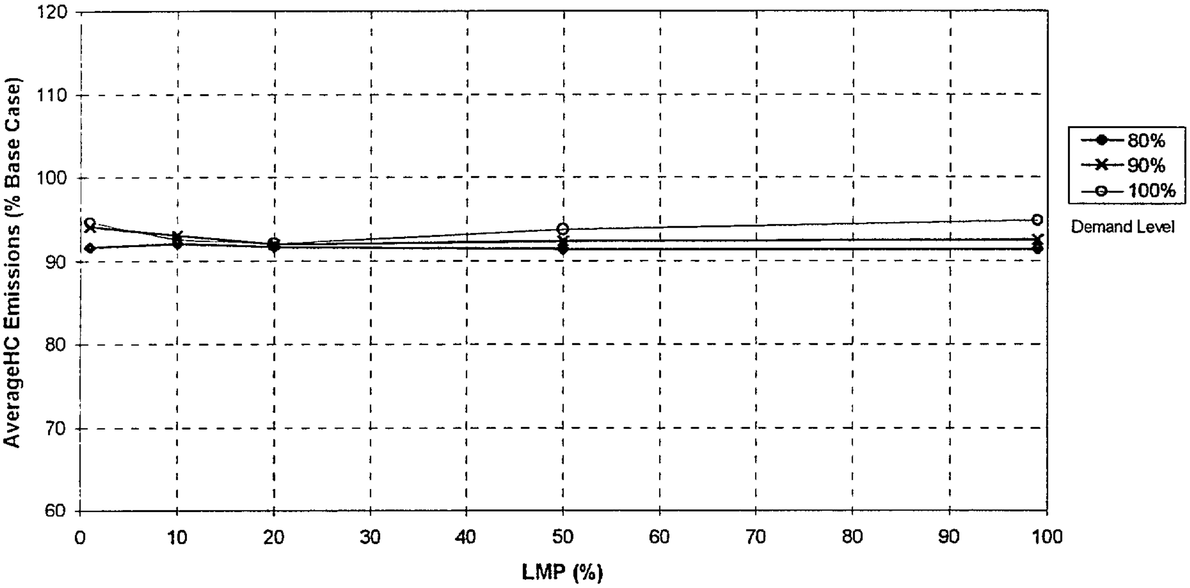

Figure D-18. Variation in average HC emissions of Genesis equipped vehicles as a function of LMP and demand level (0.5-lane blockage)

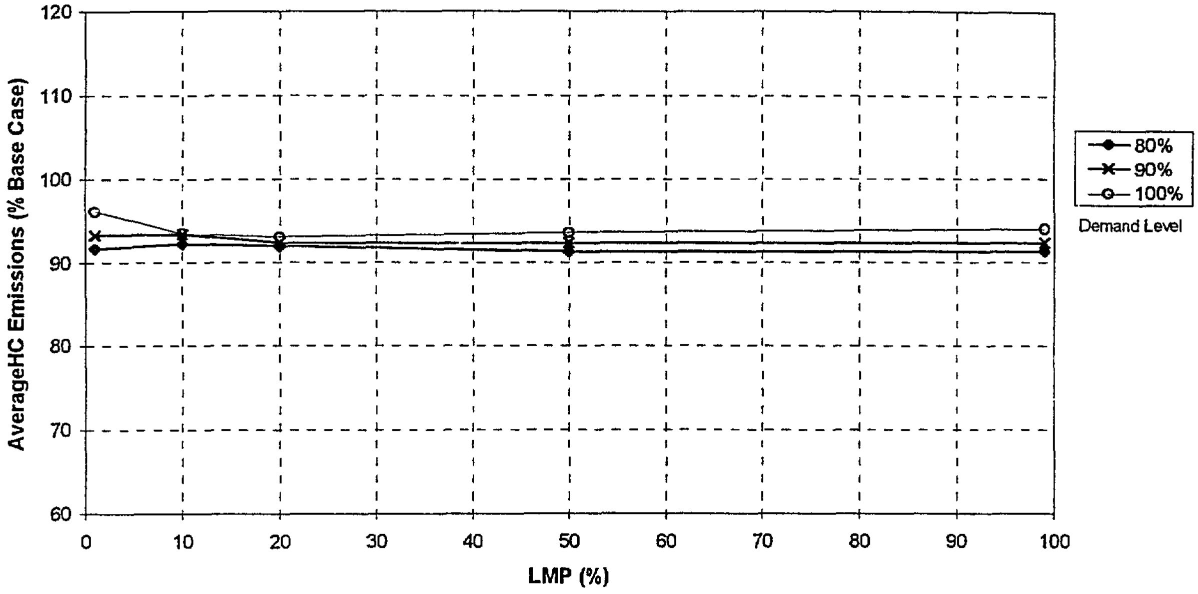

Figure D-19. Variation in average HC emissions of Genesis equipped vehicles as a function of LMP and demand level (1-lane blockage)

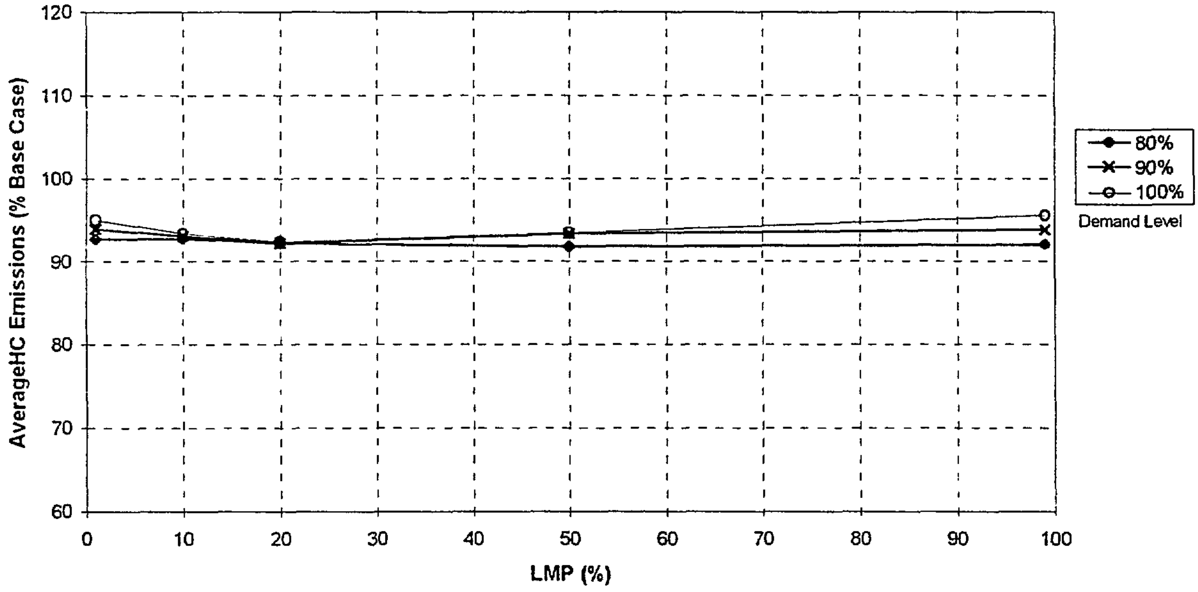

Figure D-20. Variation in average HC emissions of Genesis equipped vehicles as a function of LMP and demand level (2-lane blockage)

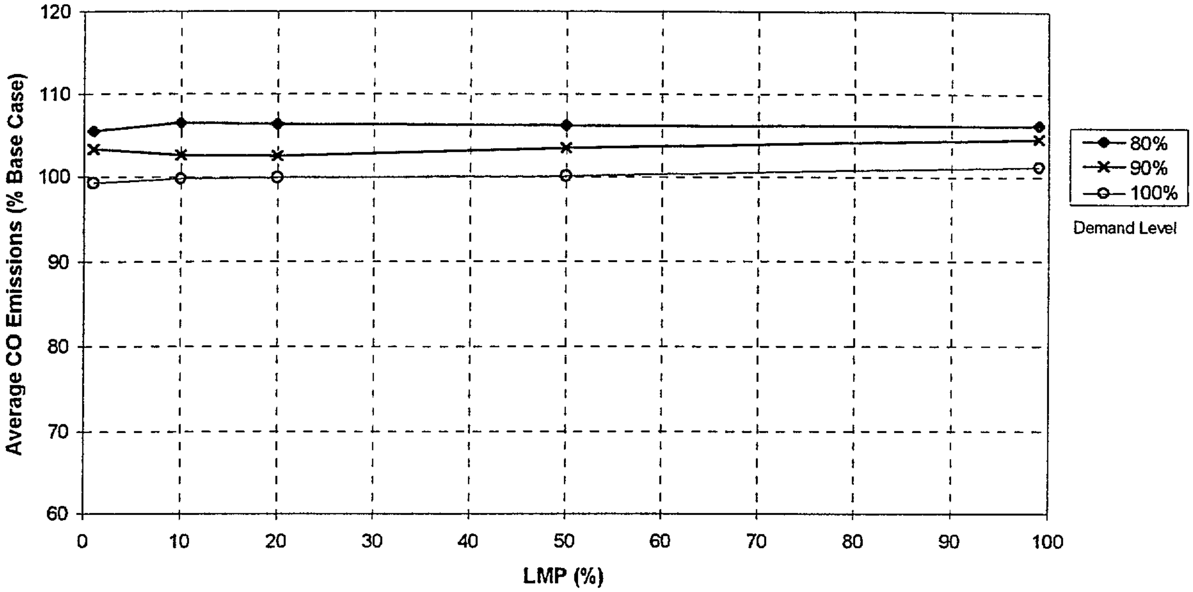

Figure D-21. Variation in average CO emissions of Genesis equipped vehicles as a function of LMP and demand level (No incident)

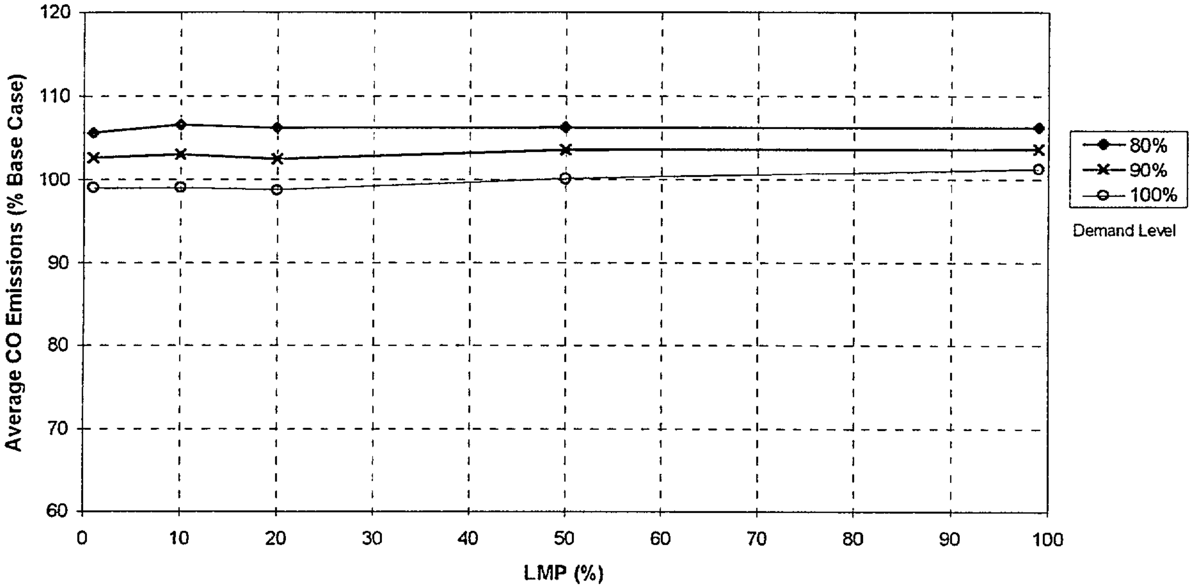

Figure D-22. Variation in average CO emissions of Genesis equipped vehicles as a function of LMP and demand level (0.5-lane blockage)

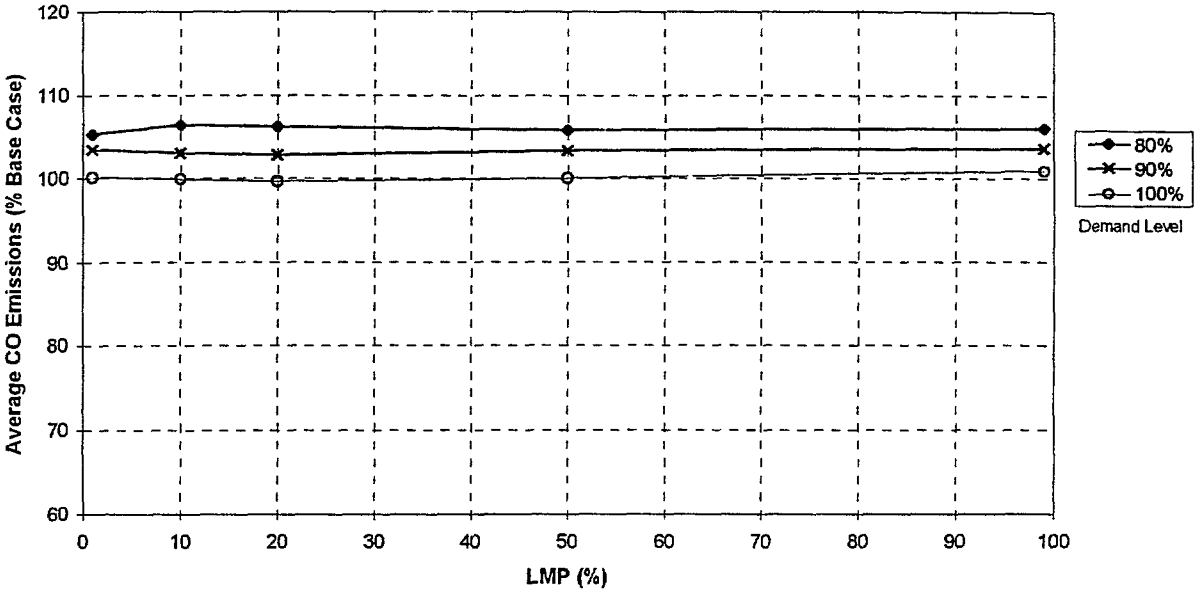

Figure D-23. Variation in average CO emissions of Genesis equipped vehicles as a function of LMP and demand level (1-lane blockage)

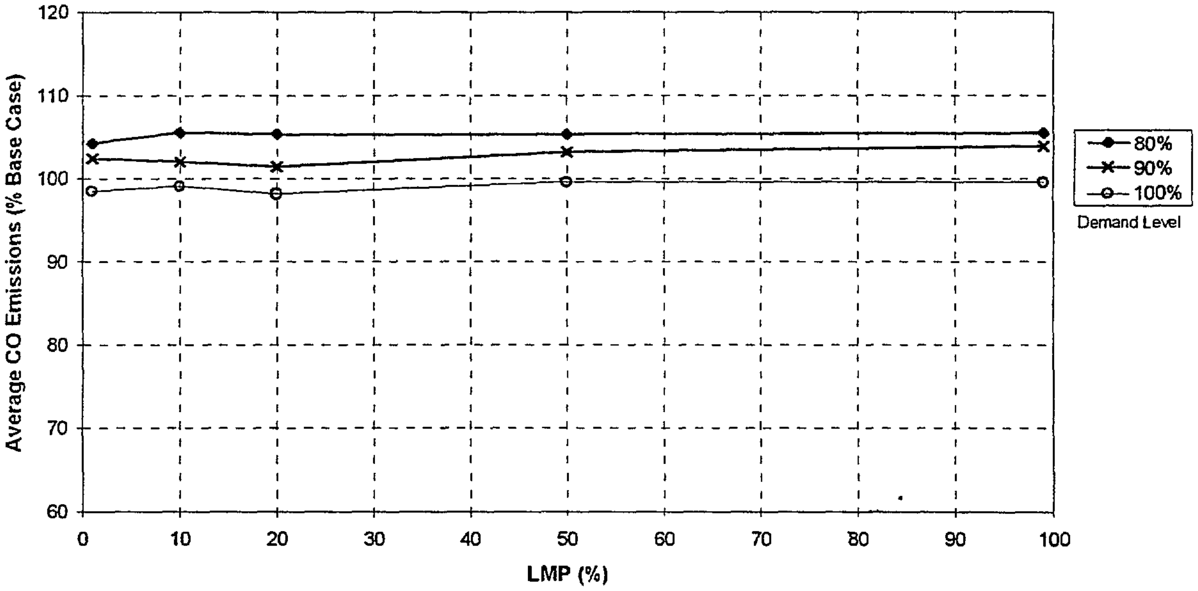

Figure D-24. Variation in average CO emissions of Genesis equipped vehicles as a function of LMP and demand level (2-lane blockage)

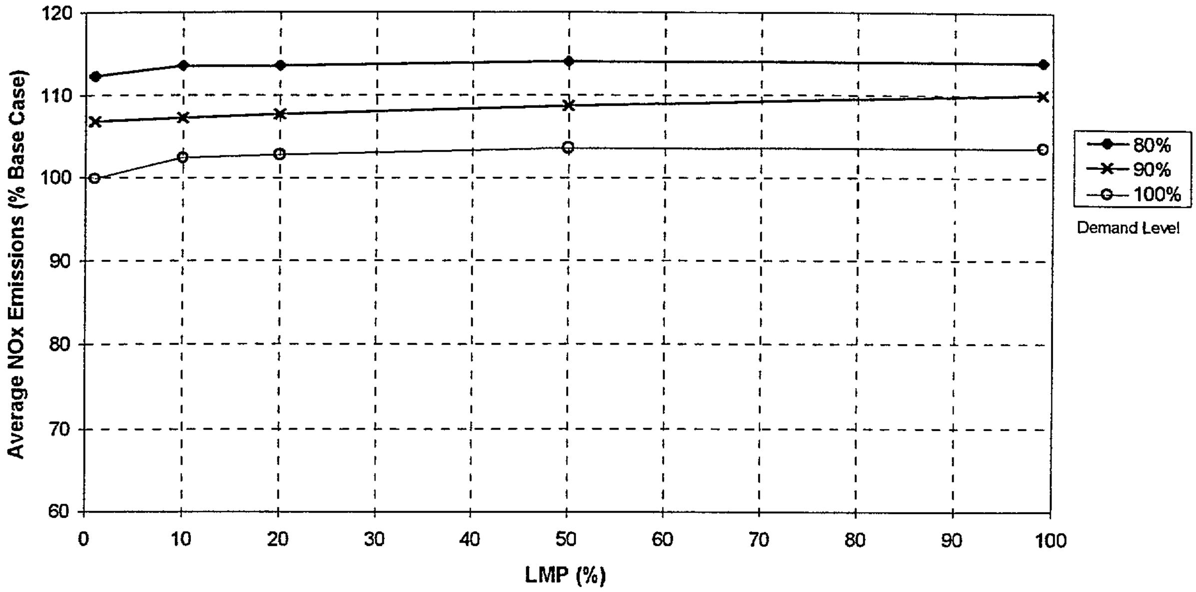

Figure D-25. Variation in average NO_x emissions of Genesis equipped vehicles as a function of LMP and demand level (No incident)

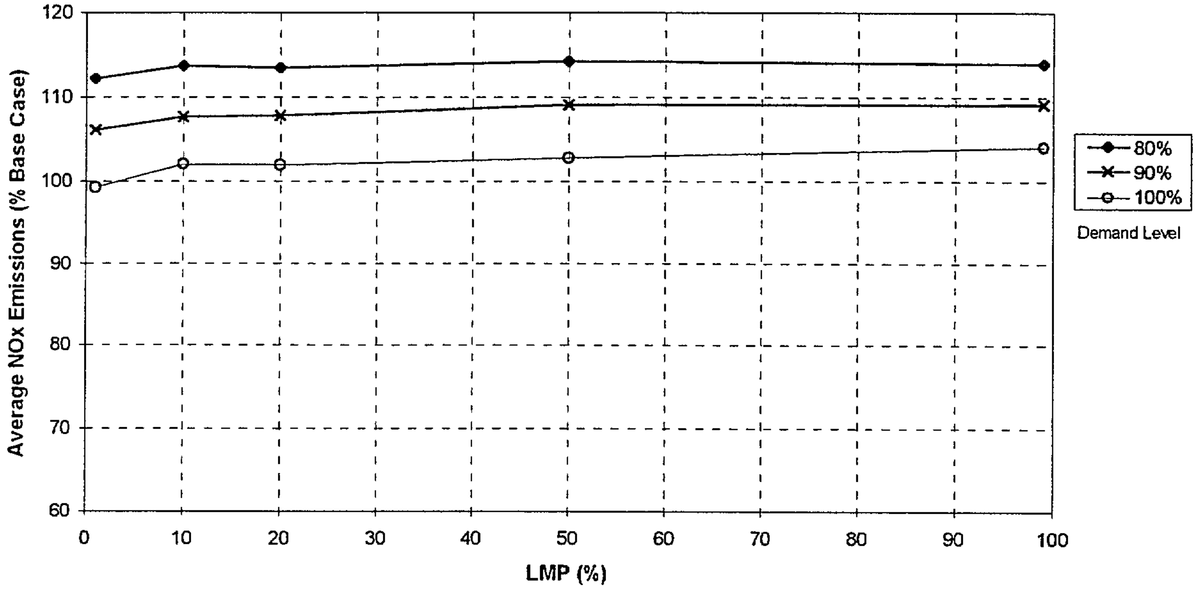

Figure D-26. Variation in average NO_x emissions of Genesis equipped vehicles as a function of LMP and demand level (0.5-lane blockage)

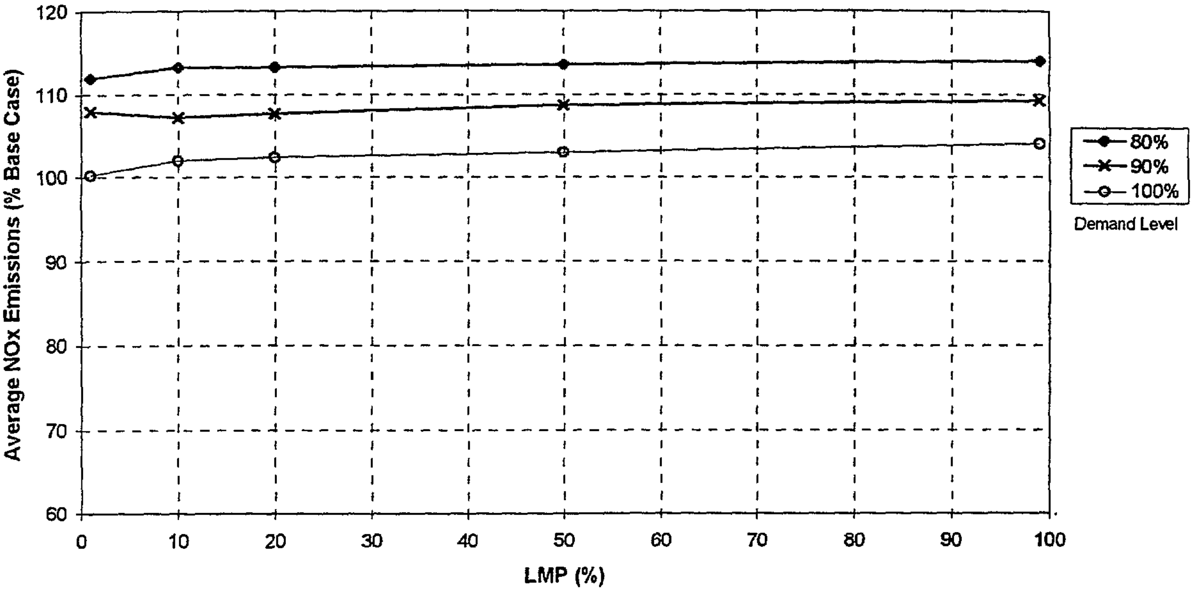

Figure D-27. Variation in average NO_x emissions of Genesis equipped vehicles as a function of LMP and demand level (1-lane blockage)

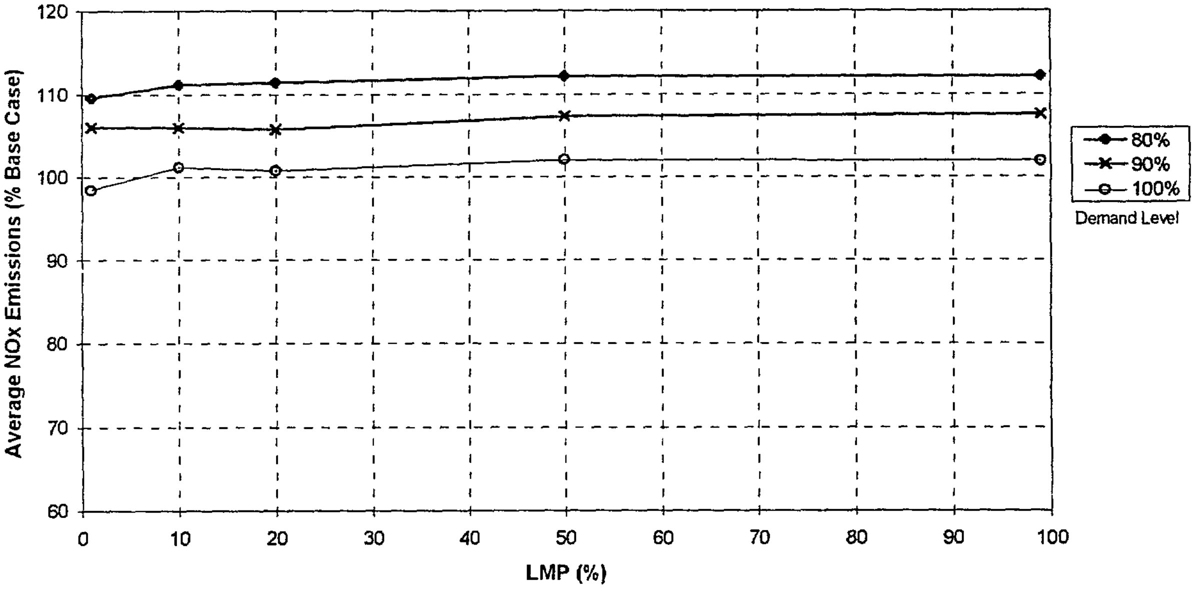

Figure D-28. Variation in average NO_x emissions of Genesis equipped vehicles as a function of LMP and demand level (2-lane blockage)

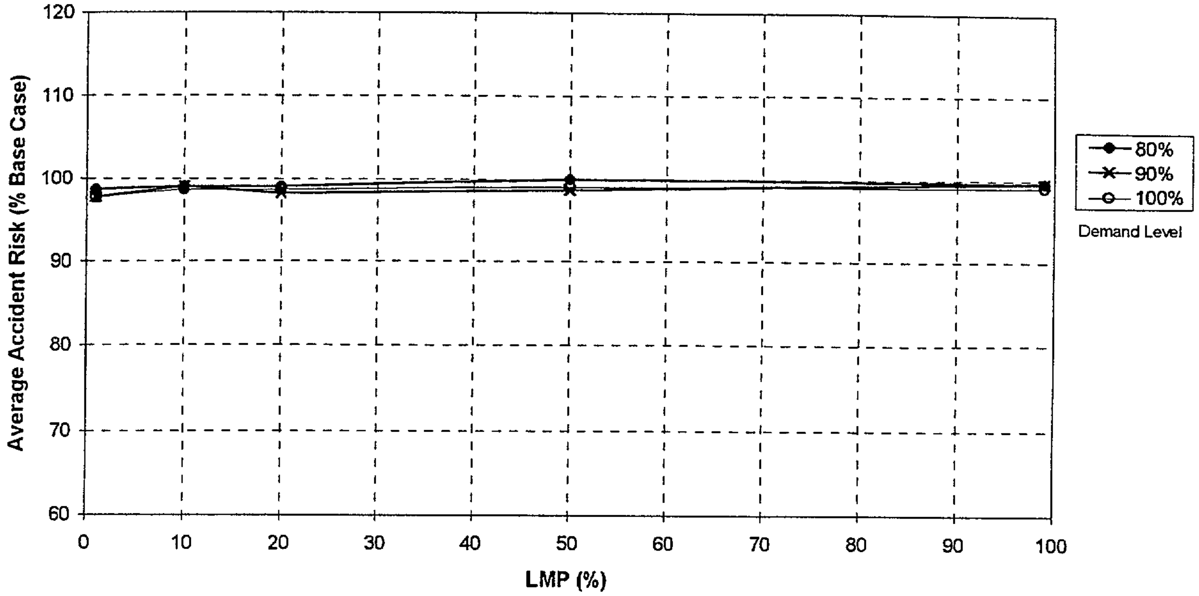

Figure D-29. Variation in average accident risk of Genesis equipped vehicles as a function of LMP and demand level (No incident)

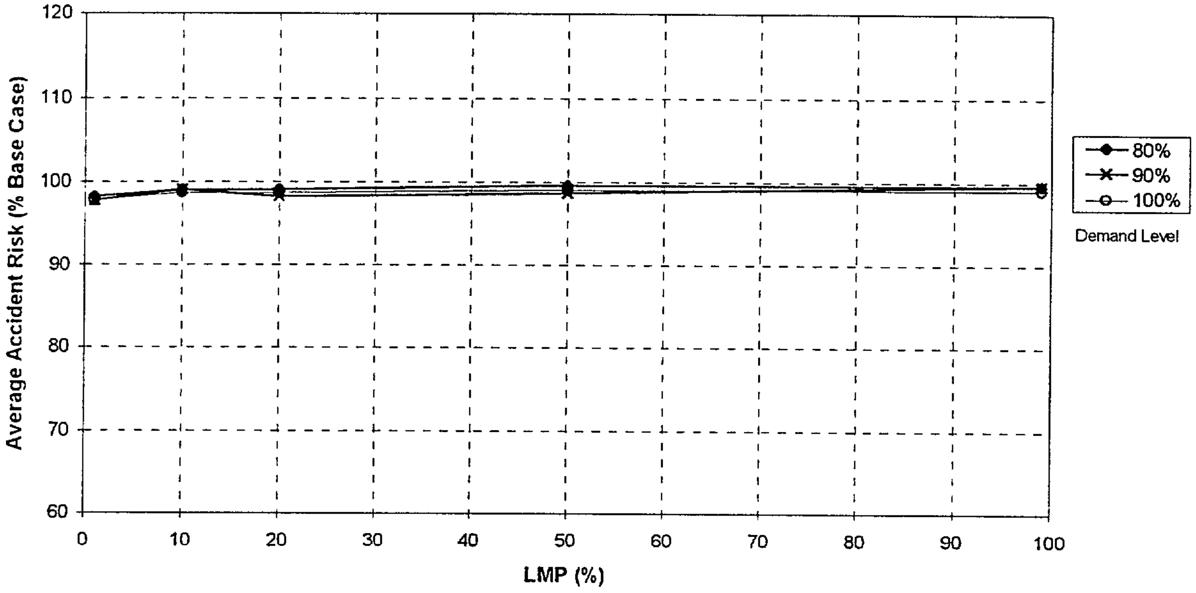

Figure D-30. Variation in average accident risk of Genesis equipped vehicles as a function of LMP and demand level (0.5-lane blockage)

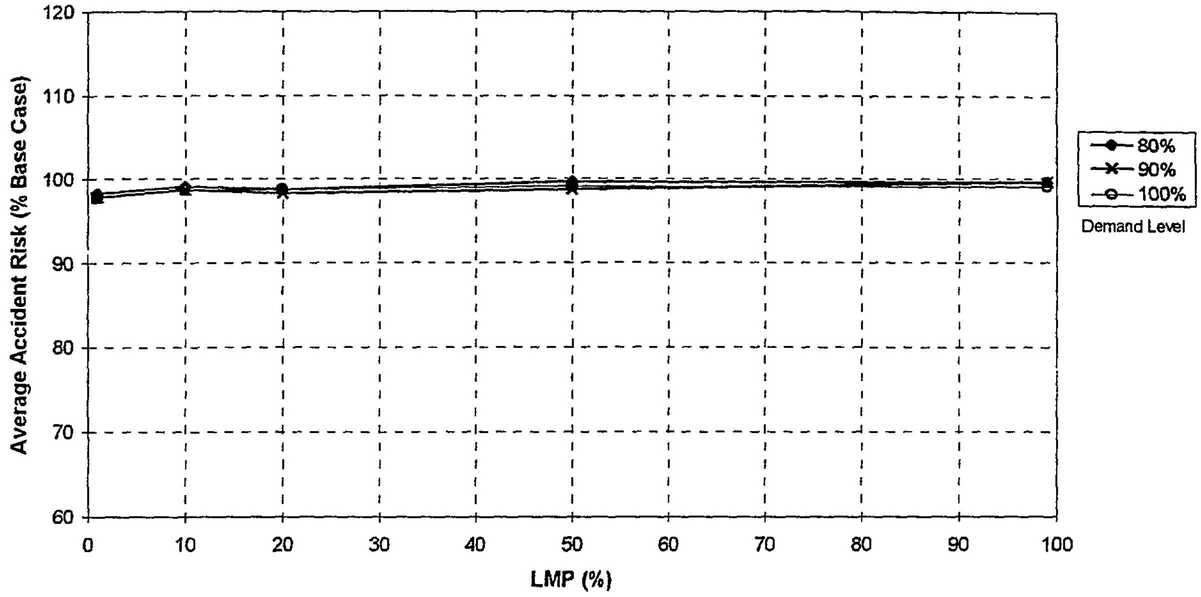

Figure D-31. Variation in average accident risk of Genesis equipped vehicles as a function of LMP and demand level (1-lane blockage)

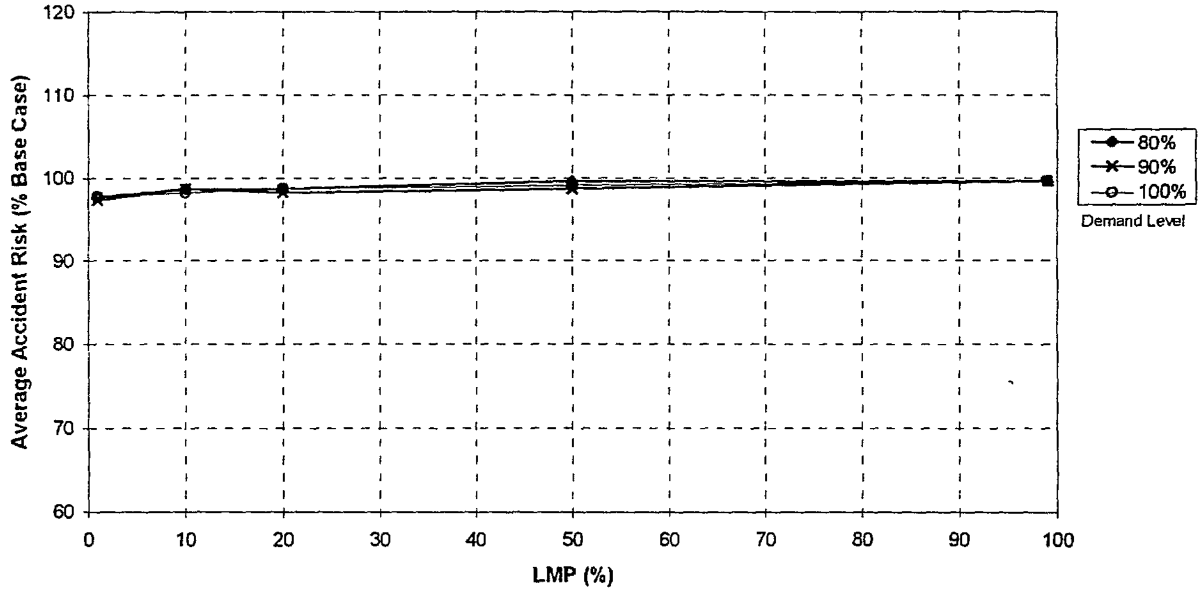

Figure D-32. Variation in average accident risk of Genesis equipped vehicles as a function of LMP and demand level (2-lane blockage)