Chapter 15

ADVANCED TRAFFIC MANAGEMENT SYSTEM DATA

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With the implementation of Intelligent Transportation Systems (ITS) for system management purposes, there is now the ability to extract archived data that can be used to evaluate the implementation of new operational strategies. In recognition of the need to provide feedback to decision-makers, efforts are underway to provide rigorous documentation of ITS benefits and costs. The objective of this paper is to describe how Advanced Traffic Management System (ATMS) data are being used to contribute toward these evaluations. Case examples are described in the areas of freeway management, incident management, arterial management, and transit management. Building a complete ITS system requires collaboration in time, funding, and institutional arrangements. ITS components that are integrated can result in synergistic effects when considered as an entire system. It is shown that in some cases it is possible to build upon national level statistics describing ITS benefits by using data collected from the systems themselves. It is hoped that further efforts to integrate transportation planning with evaluation methodologies will incorporate the necessary empirical results from a wide variety of studies. In this way, better databases can be developed, and heightened accountability will be more pervasive in the evaluation of ITS improvements.

1. INTRODUCTION

In 1997 in the U.S., automobiles traveled 1.4 trillion vehicle miles (2.3 trillion vehicle kilometers) and households spent an average of 19 percent of their income on transportation—less than housing but more than food

(Northeast-Midwest Institute, 2002). Further, drivers in the 68 largest urban areas in the U.S. experienced an increase in traffic delays due to congestion from 11 hours per year in 1982, to 36 hours per year in 1999 (Schrank and Lomax, 2002). The estimated cost of traffic congestion in these 68 areas totaled $78 billion, representing a cost of 4.5 million extra hours of travel and 6.8 billion gallons (25.7 billion liters) of wasted fuel (Schrank and Lomax, 2002). The average rush-hour trip takes 32 percent more time than the same trip taken during non-rush-hour conditions. Congested travel periods (rush hours) in the nation's major cities have doubled in less than 20 years, increasing from nearly three hours (morning and evening combined) in 1982, to almost six hours in 1999 (Schrank and Lomax, 2002). Congestion is now found during almost half of the daylight hours on workdays (Schrank and Lomax, 2002).

Increasing traffic congestion coupled with improved technology, funding constraints, and increasing environmental consciousness has provided an impetus to develop cost effective systems aimed at improving the efficiency and effectiveness of the transportation system. Intelligent Transportation Systems (ITS) include a wide range of diverse technologies, including information processing, communications, control, and electronics. ITS have evolved with applications, including collision warning systems, ramp meters, advanced signal control systems, transit and emergency vehicle management systems, and others. The goals of ITS deployments include improving traveler safety, traveler mobility and system efficiency; increasing the productivity of transportation providers; and conserving energy while protecting the environment. The strain on the transportation system as a whole is thus eased through the application of modern information technology and communications. Some technologies provide more cost-effective benefits than others, and as technology evolves, the choices to deployers are bound to improve. These technologies are often combined into a single integrated system, providing benefits that exceed the benefits of any single technology (Proper and Maccubbin, 2000).

ITS aims to improve the safety and efficiency of the transportation system. ITS systems themselves offer opportunities for new methods of evaluation and continuing assessment. As an indication of the degree of commitment to ITS in the U.S., during the last decade, federal, state, and local governments have appropriated billions of dollars for ITS programs. In 1998, the Transportation Equity Act for the 21st Century (TEA-21) provided more than $1.2 billion in funding to support ITS through 2003. Of that, $603 million was targeted toward research and development. Another $679 million was intended for deployment of ITS projects (Sundeen, 2002). Further, the Intelligent Transportation Society of America (ITS America) estimates that more than $209 billion will be spent on ITS programs by 2011.

There has been recognition of the need to demonstrate the benefits of ITS, providing a necessary feedback loop to decision-makers. In order to facilitate evaluations of ITS investments, the USDOT through its ITS Joint Program Office (established in 1994) continues to collect information regarding the impacts of ITS projects on the operation of the surface transportation network. The results of most ITS related projects and model deployments have been perceived as promising and efforts continue toward defining the magnitude of their benefits (Proper and Maccubbin, 2000). The objective of this paper is to describe how advanced traffic management system (ATMS) data are being used to evaluate the benefits of ITS investments.

2. EVALUATION PERSPECTIVES

Transportation improvements have frequently been deployed in order to make the system more efficient by reducing travel time, the number of stops, and delay. In the past, data collection experiments would be designed for limited time periods to collect data at the precise points of interest. This process was often manual and costly, with many people required to collect a small amount of data. Bias was then introduced by temporally extrapolating these data collected from one or two days over an entire year. The data that were used to estimate the benefits of the improvement had limited temporal coverage but were collected from the precise spatial points of interest.

Many ITS deployments include surveillance systems that are used in the operation of the system. For example, ramp metering systems usually include inductive loop detectors on the freeway and on-ramps in order to detect the presence and traffic state of vehicles. This information is often used to set the ramp meter timing, but from an evaluation standpoint, it is not possible to "choose" the loop detector locations, and it is impossible to move the detectors. Despite the fact that the detectors may have been located specifically to operate the metering system, it is recognized that the surveillance system can also be used for incident detection and verification. It has also been shown (Bertini, Leal, and Lovell, 2001; Nee, Ishimaru, and Hallenbeck, 2001; Ishimaru, Hallenbeck, and Nee 2001; Ishimaru and Hallenbeck, 1999) that these systems can be used to extract relevant performance characteristics for the transportation network and then tracked over time. In contrast to past evaluation efforts where an experiment could be designed and data could be sampled from "ideal" locations for short periods, ITS deployments have provided opportunities to sample data from "non-ideal" locations (established for traffic management purposes) over very long periods. The bias that results originates from the need to extrapolate over space, rather than over time, since data can be collected indefinitely.

3. ITS BENEFITS OVERVIEW

Since December of 1994, the USDOT's Joint Program Office (JPO) for ITS has collected information describing the impact of ITS projects on the operation of the surface transportation system. Data collected as part of these efforts are available in the ITS Benefits Database on the JPO Web site (www.its.dot.gov). The JPO also collects information on ITS costs, and maintains this information in the ITS Unit Costs Database. The database is a central site for estimates of ITS costs data that the JPO can use for policy analyses and benefit-cost analyses. In addition, the database can be viewed and downloaded as a cost-estimating tool for those implementing ITS projects and programs at state and local levels.

The development and deployment of ITS technologies offer a wide variety of opportunities for local, regional, and state agencies to improve the capacity, reliability, and efficiency of their transportation systems. Due to many factors, the quantification of ITS benefits and costs has been difficult using traditional transportation planning and analysis methods because traditional transportation planning models lack necessary sensitivity to many benefits derived from ITS technologies, and because information on the impacts and costs of many ITS technologies is not yet well-understood.

The Federal Highway Administration (FHWA) and others have recognized this potential barrier to integrating ITS into the transportation planning process. In 1997, FHWA and its partners began development of the ITS Deployment Analysis System (IDAS), which is a tool designed to help planners better address these issues (Cambridge Systematics, 2002). Cambridge Systematics, Inc. led the development team and the software is now available for use. According to product documentation, IDAS is designed to assist public agencies and consultants in integrating ITS in the transportation planning process. IDAS offers the capability for a systematic assessment of ITS with one analysis tool and is used for determining the benefits and costs of various ITS deployments. IDAS provides users with the following capabilities:

- Comparison and screening of ITS alternatives;
- Estimation of impacts and traveler responses to ITS;
- Estimation of life-cycle costs;
- Inventory of ITS equipment, and identification of cost-sharing opportunities;
- Sensitivity and risk analysis;
- ITS deployment and operations/maintenance scheduling; and,
- Documentation for transition into design and implementation.

As with any model, IDAS is not without limitation. IDAS operates as a post-processor for travel demand model output, and incorporates benefit and cost information from many disparate studies, with data coming from different locations and from different timeframes. Thus it should be emphasized that IDAS is only a tool and should be used with care. More research is needed to quantify actual ITS deployment benefits, and the results of such research should be incorporated into future ITS evaluation activities.

4. ITS COMPONENTS

ITS deployments themselves typically include surveillance systems that enable a more comprehensive understanding of how the existing transportation system operates and facilitates proactive strategies for managing it more efficiently. ITS deployments have benefited from advances in computer processing and miniaturization, communications technology, and enhanced institutional arrangements. Ten ITS systems will be introduced with some examples of how archived data have been used to provide evidence for the effectiveness of these systems. The ITS benefits and unit costs database has classified the benefits of implementing ITS into the following 10 program areas (USDOT, 2002a). Note that each program area includes different ITS applications and that there is some potential overlap:

- Freeway management
- Incident management
- Transit management
- Arterial management
- Emergency management
- Electronic payment
- Traveler information
- Crash prevention and safety
- Operations and maintenance
- Road weather management.

The ITS benefits and unit cost database also describes seven categories of benefits to be used for ITS deployment evaluations:

- Safety improvements
- Delay savings
- Throughput
- Customer satisfaction
- Cost savings
- Environmental
- Other.

In line with the scope of this chapter we concentrate on the benefits by program area and use some real examples used in the evaluation process. The examples are derived from past and ongoing efforts to evaluate specific systems using archived ATMS data.

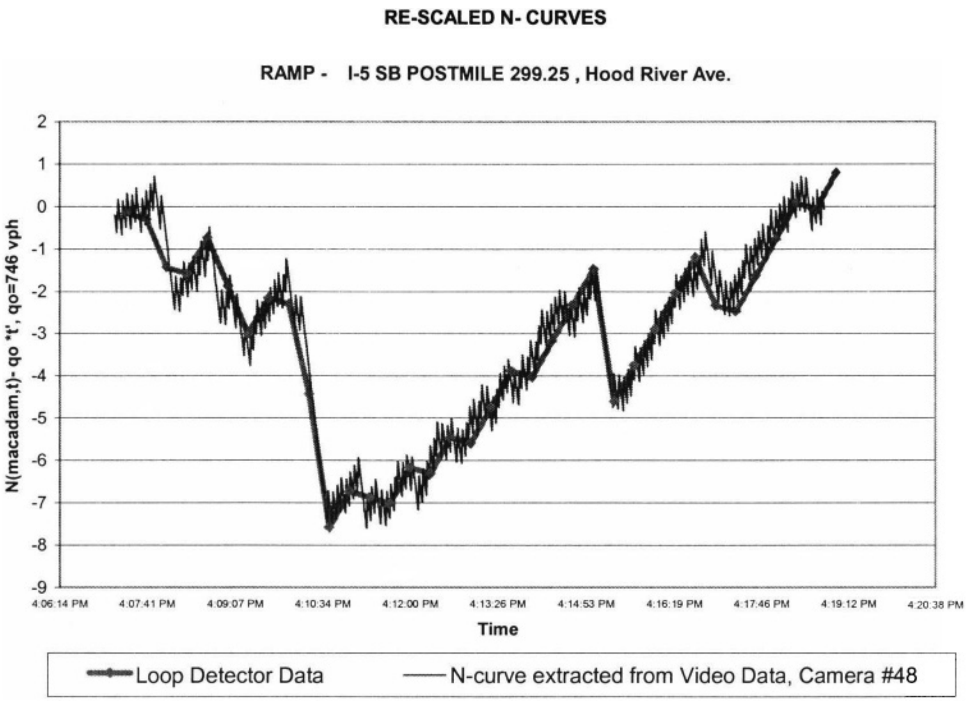
5. FREEWAY MANAGEMENT SYSTEMS

Three primary ITS functions make up freeway management systems: monitoring and surveillance, control of freeway operations, and the display or provision of information to motorists via dynamic message signs, highway advisory radio, in-vehicle navigation or information systems, or specialized information transmitted only to specific set of vehicles. Evaluations of freeway management system improvements such as ramp metering systems have demonstrated improvements in safety, reduction in travel time and delay, increased flows, and flow improvements (USDOT, 2002b).

Despite early efforts to deploy metering and management systems, actual traffic monitoring over a widespread area and real-time response is easier now due to advances in technology and greater system coverage. Typical traffic operations centers (TOCs) collect and process surveillance and monitoring data, most often from inductive loop detectors, and supplemented this with closed circuit television (CCTV) cameras that are also directly controlled from the TOC. The ability to collect data and reflect on it in real time has made a difference.

5.1 Interstate 5 Evaluations in Portland, Oregon

Presently, projects are underway by the authors to evaluate the performance of ramp metering and incident management in the Interstate 5 corridor in Portland, Oregon. The Oregon Department of Transportation (ODOT) has deployed a systemwide ramp metering program throughout the Portland metropolitan area. As part of the system itself, approximately 400 inductive loop detectors have been installed. Loops are included on each metered on ramp and in the freeway mainline lanes just upstream of each metered ramp. However, there are no detectors on off-ramps and there are few detectors at intermediate points (between interchanges) on the freeways. These detectors report speed, count, and occupancy every 20 seconds, but ODOT only archives data aggregated over 15-minute periods. Through special arrangement for the evaluation projects, the raw data are being archived. Thus far, the loop detector data has been validated with vehicle count data manually extracted from the video surveillance system. Figure 1 shows two sample validation curves, which include cumulative vehicle arrivals (plotted on oblique axes in order to magnify the details). The curves extracted from the loop detectors are aligned with the curves extracted from the surveillance video, indicating that the detectors are functioning reliably.



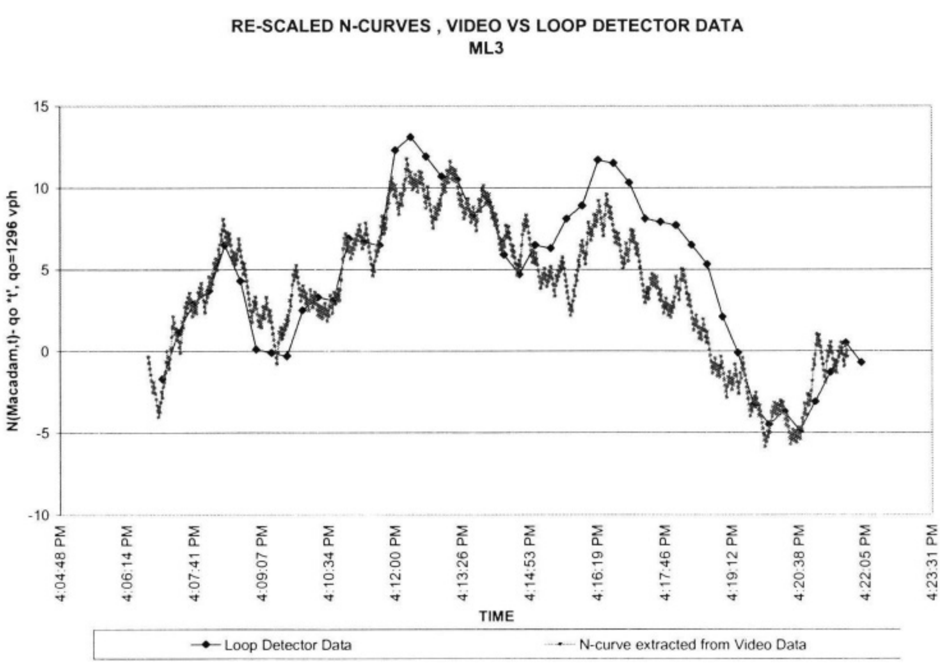


Figure 1. Validation of Loop Detector Data

The ramp metering evaluation will not include a true "before" and "after" component since ODOT is not able to shut down the meters. The project will include a comparison of actual ramp and freeway corridor performance using actual detailed counts and speeds extracted from the raw loop detector data. Using simulation tools, attempts will be made to evaluate different metering strategies and to create hypothetical performance characteristics "without" metering. It is recognized that relying on the fixed loop detector locations, with potentially large spacing, some bias will result in the analysis due to assumptions made about speeds over long freeway sections. As an example, Figure 3 shows a map of a section of Interstate 5 describing corridor speeds measured by loop detectors. When computing corridor performance, each detector is assigned to an influence area bounded by the midpoints between detectors. If the head or tail of a queue is present in the section, speed/travel time computation errors will be introduced which will in turn affect the calculation of performance measures such as vehicle miles (kilometers) traveled, delay, vehicle hours traveled, etc. Using a probe vehicle (at approximately the same time), Figure 2 shows the speed profile experienced by an actual vehicle traversing the section. Experiments are underway to examine the benefits of fusing the loop detector data with probe vehicle information (incident response vehicles and express buses are equipped with automatic vehicle location systems).

The incident management evaluation underway relies on the automatic vehicle location (AVL) system data provided by the incident response vehicles themselves, as well as an archived incident database that includes input from the incident responders, TOC dispatchers, and other emergency vehicle personnel.

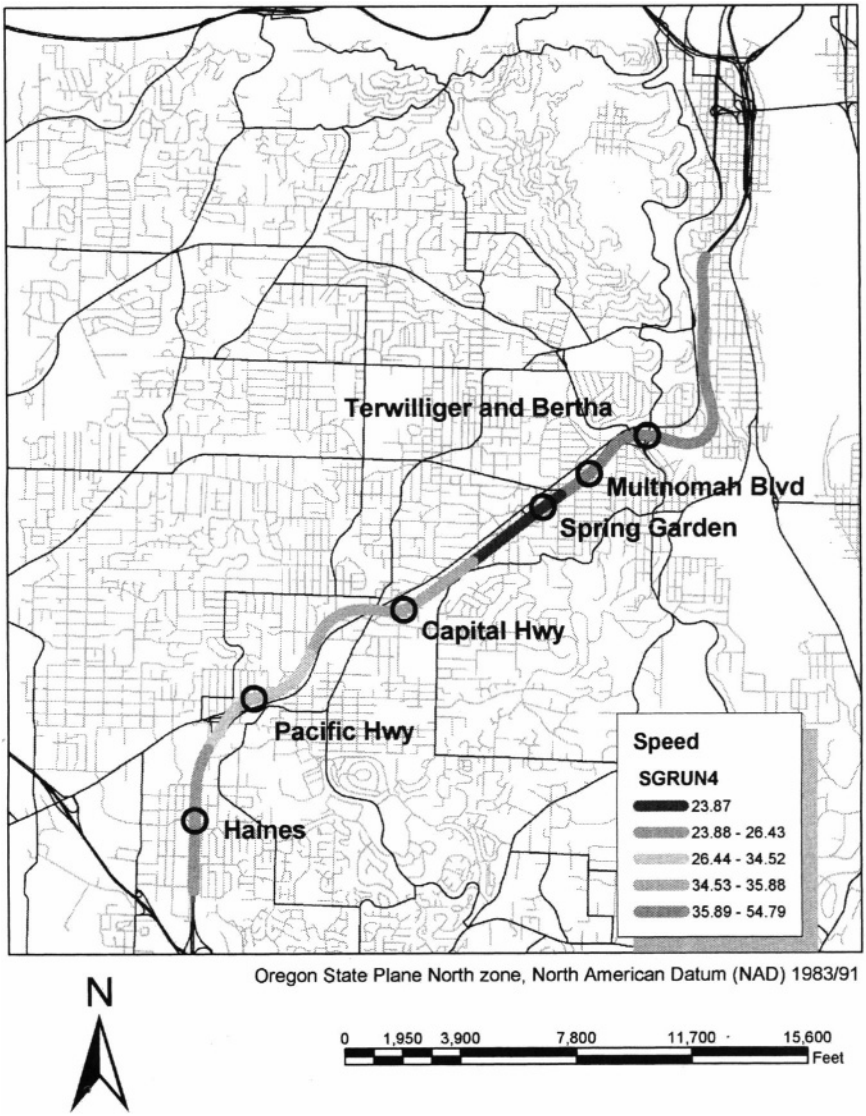


Figure 2. Speeds Extracted from Loop Detectors

5.2 Minnesota Ramp Metering System Evaluation

Recent public opposition threatened to abandon ramp control as a traffic management option in the Twin Cities of Minneapolis and St. Paul. In response to this, the Minnesota DOT was asked to produce tangible independent evidence of the effectiveness of ramp metering. A data collection procedure started with the ramp meters in operation, and continued with the meters shut down. A comparative study was conducted to compare before and after shutdown data (Cambridge Systematics, Inc., 2001; Levinson et al., 2002). In order to identify the temporal and spatial extents of congestion, occupancy contour plots were used (Bertini, Leal, and Lovell, 2002). Figure 4 shows two plots of occupancy with and without ramp meters along a 16-mile section of Minnesota Trunk Highway 169 (TH-169). Note the increase in occupancy (corresponding to increased travel times across the loop detectors) when the ramp meters were turned off compared to the occupancies measured with ramps turned on during another day. The before analysis indicated congestion somewhere between stations 17 and 18 while less congestion between stations 22 and 23 was reported in the after plot. Tables 1 and 2 summarize performance characteristics for a portion of TH-169. As shown, the speed dropped by nearly 18 percent after the shut down of the ramp metering system. Table 2 shows that the vehicle miles traveled (VMT) decreased by approximately 9.4 percent after the metering system was shut down.

The analysis performed by Cambridge Systematics, Inc. (2001) indicated that ramp metering is a cost-effective investment for the Twin Cities area, finding that after the meters were turned off, there was an average nine percent traffic volume reduction on freeways and no significant traffic volume change on parallel arterials included in the study. During peak traffic conditions, freeway mainline throughput declined by 14 percent in the un-metered condition. It was also estimated that the ramp metering contributed to an annual savings of more than 1,000 crashes or approximately four crashes per day. From an environmental perspective, ramp metering results in a net annual savings of 1,160 tons (1,052 metric tons) of emissions.

In parallel to the above study, a microsimulation analysis (Hourdakis and Michalopoulos, 2002) computed nearly the same benefits gained from applying ramp metering technology. The main result of the simulation process was that it has developed a prototype validated by empirical analysis under the relatively unique circumstances of a shutdown. See Chapter 9 of this book by Zhang and Levinson for another evaluation of the Twin Cities ramp metering shut-off.

Table 1. Minnesota TH-169 Average Speed

Stations	Before Shutdown Speed (mph)		After Shut Down Speed (mph)		Percentage Decrease Speed (mph)	
	Cumulative	Average	Cumulative	Average	Cumulative	Average
16	190,000	65	130,000	48	32	26
17	170,000	57	140,000	47	18	18
18	210,000	75	185,000	65	12	14
19	185,000	66	145,000	53	22	20
20	180,000	63	160,000	56	11	11
21	180,000	62	150,000	52	17	16
22	190,000	67	160,000	55	16	20
Average Speed Reduction from Station 16 to 22 =						18%

Table 2. Minnesota TH-169 Vehicle Miles Traveled

Station	Miles	VMT Veh-miles Before	VMT Veh-miles After	VMT Veh-miles Before - After	% Difference VMT Before - After
15	0.098	4637	4183	453	9.8
16	0.17	11478	10355	1122	9.8
17	0.26	13387	12027	1359	10.2
18	0.37	18667	16760	1907	10.2
19	0.50	24065	21699	2366	9.8
20	0.45	22381	20312	2069	9.2
21	0.42	19436	17770	1665	8.6
22	0.45	20214	18560	1653	8.2
Total		34268	21670	12597	9.4

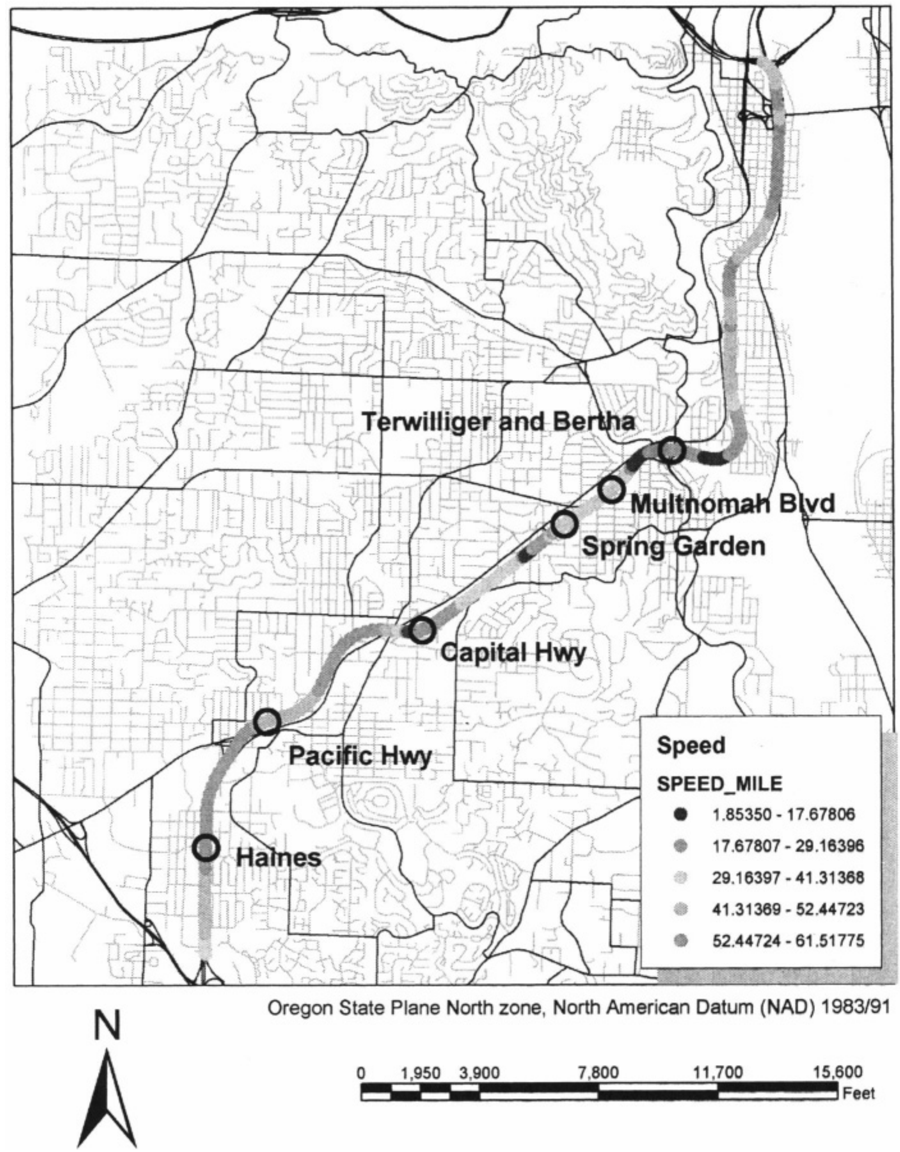


Figure 3. Speeds From Probe Vehicle

5.3 Incident Management Systems

Incidents are defined as crashes, breakdowns, and other random events that occur on our highway system. Congestion caused by incidents are serious problems that face any transportation agency. Incidents are known to cause more than 50 percent of urban congestion and lead to economic losses, air pollution, and human pain and suffering. Many urban areas have developed quick response incident management systems, recognizing that transporting victims to trauma centers within the "golden hour" can save lives. Further, through coordination among highway operations, law enforcement, and emergency personnel, secondary crashes can be prevented and responder safety can be enhanced (El-Geneidy and Bertini, 2003). So incident management systems are coordinated, preplanned, and/or real-time use of human resources to reduce the duration of incidents (Zografos, Androutsopoulos, and Vasilakis, 2001). Incident management systems contain components such as incident detection, incident verification, response to the incidents, clearance of the incidents, and traffic management at the incident locations. In many locations, incident data are archived on a regular basis to identify locations of high incident frequency. These locations can be used in planning the responders' routes on the highway and for identification of reasons for incident causation in an effort to improve the existing roadway characteristics to avoid future incidents at the same location. Numerous studies have been conducted to evaluate the implementation of incident management programs. Most of these studies came to the same findings that incident management programs have a substantial effect on delay time. (Chapter 11 of this book by Parthasarathi, Levinson, and Gillen also examines driver's willingness to pay for freeway service patrols).

5.4 Bay Area Freeway Service Patrol Evaluation

Incident management programs have been very popular additions to the transportation system. In many ways, the Bay Area Freeway Service Patrol Evaluation (Skabardonis et al., 1995) set the standard for comprehensive evaluations of incident management systems since it was a true before-and-after analysis. The study collected 276 hours of field data on one nine-mile (14.5 kilometer) freeway section, for 24 weekdays before and 22 weekdays after the freeway service patrol (FSP) was implemented. Field data included incident observations, probe vehicle travel times and speeds, flows, and occupancies extracted from archived loop detector data. The loop detectors were spaced at approximately 1/3 mile (0.5 kilometer) increments on the freeway mainline (and on-ramps) and the probe vehicles traveled at seven-minute headways during peak periods. Based on estimated savings in incident delay and fuel consumption, the study found that the FSP was cost effective for that particular freeway segment. It may have been tempting to try to extrapolate the results of the analysis to other freeway sections in the Bay Area or in other area. However, the researchers emphasized that the results would only be applicable "to sites with traffic and incident characteristics similar to the ones in the study area" (Skabardonis et al, 1995).

5.5 Los Angeles Freeway Service Patrol Evaluation

The Los Angeles Freeway Service Patrol Evaluation (Skabardonis et al., 1998), a true "before-and-after" analysis, measured the effectiveness of the FSP on a 7.8-mile (12.6 kilometer) section of the I-10 freeway in Los Angeles. An evaluation methodology was developed to estimate incident delays based on field data from loop detectors and probe vehicles, and to derive estimates of savings in performance measures in the absence of data for "before" FSP conditions. The methodology required the application of response time (and thus incident duration) savings due to the presence of the FSP on the freeway. Field data were collected in the corridor for 32 weekdays, for a total of six hours each day. This 192-hour database includes detailed descriptions for 1,560 incidents, probe vehicle travel time runs at 5.7-minute headways, and archived flow, occupancy and speed data from 240 loop detectors. This study found that the FSP program was also effective for the corridor studied.

5.6 Oregon Region 2 Incident Response Evaluation

In Oregon, an evaluation of the rural Region 2 Incident Response (IR) program (Bertini et al., 2001) involved a statistical analysis of archived incident data, estimation of reductions in fuel consumption and delay, calculation of program costs, and development of a decision-making tool for design/expansion of the incident management program on future corridors. The methodology consisted of a quantitative analysis of archived incident data during two distinct phases since the IR program's inception. The study focused on a 51-mile (82 kilometer) corridor on Oregon Highway 18 and a 41-mile (66 kilometer) corridor on Interstate 5 in Lane County. As shown in Figure 5, Phase 1 covered the period between February 1995–March 1997 and Phase 2 covered the period from March 1997–December 2000. Figure 5 also shows the total amount of IR resources deployed. As shown, during Phase 1 on Highway 18, IR personnel invested approximately 36 hours per month, while during Phase 2 (continuing today), there is one full-time IR staff member deployed (173 hours per month). Figure 5 also indicates that the staffing level has increased over time on Interstate 5. It was not possible to conduct a true "before-and-after" study, since it is the IR staff themselves who are the roving data collectors. Thus, the numbers of reported incidents (rather than the actual number of incidents) has increased because the IR personnel are physically monitoring the status of the roadways. Figure 6 is a tree that displays the number of incidents observed during the two phases. This illustrates that potential bias that can be introduced when using a data collection system that relies on the incident response personnel themselves.

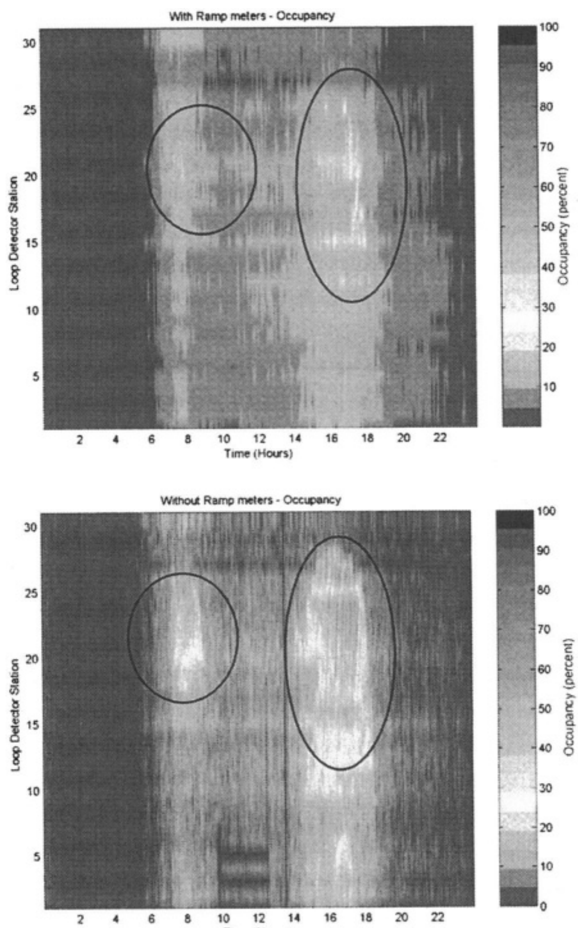


Figure 4. Before and After Occupancy (Percent) Plots from Minnesota

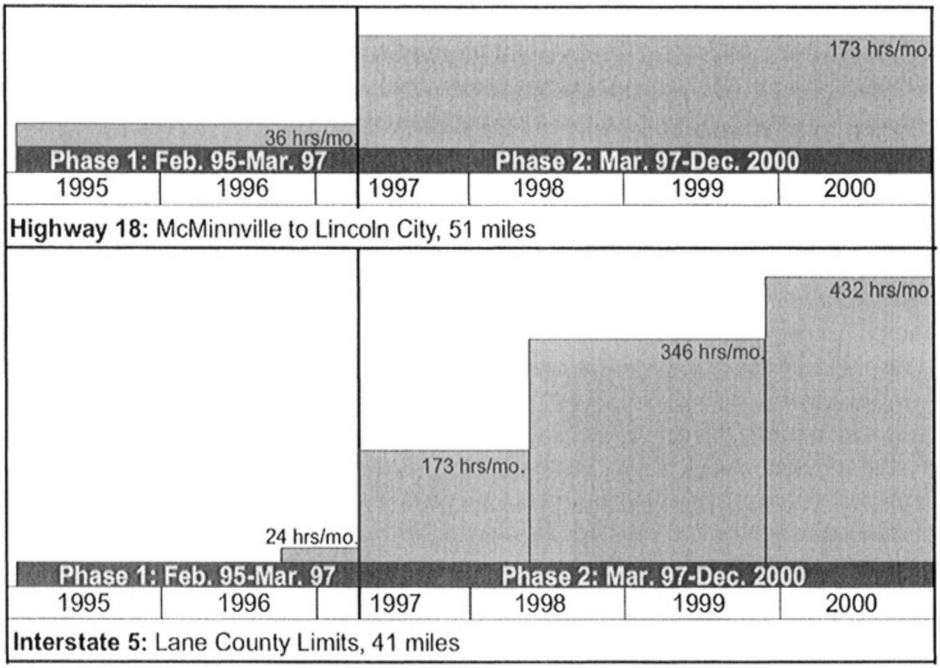


Figure 5. Incident Response Phases

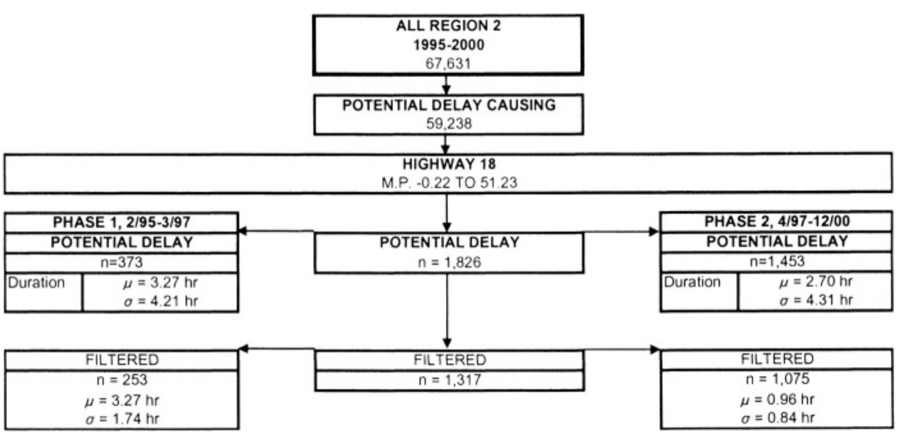


Figure 6. Incident Response Data Collection

5.7 Transit Management Systems

Transit management systems are concerned with increasing operational efficiency of all transit modes and increasing ridership by making the transit system more reliable. (McQueen and McQueen, 1999) The emergence of the global positioning systems (GPS) and the increase in its accuracy has helped this field substantially. Several transit agencies have equipped their vehicles with GPS to create automatic vehicle location (AVL). AVL technology has been widely implemented in North America and Europe. In the year 2000 about 35 bus systems had AVL technology implemented in the U.S., in both light-rail and bus systems (APTA, 2001).

The Tri-County Metropolitan Transportation District of Oregon (TriMet) operates 97 bus routes and a 38-mile light rail line within the tri-county Portland metropolitan region. TriMet's bus lines carry approximately 200,000 trips per day, serving a total population of 1.3 million persons within an area of 590 square miles (1,530 square kilometers). TriMet is considered as one of the leading ITS deployers in the U.S. TriMet has implemented a Bus Dispatch System (BDS) as a part of its overall operation and monitoring control system. (Strathman et al., 2002; Strathman et al., 2000; Strathman et al., 1999) The main components of the BDS include:

- Automatic vehicle location (AVL) based upon differential global positioning system (GPS) technology, supplemented by dead reckoning sensors;
- Voice and data communication system using radio and cellular digital packed data (CDPD) networks;
- On-board computer and control head displaying schedule adherence information to operators, detection, and reporting of schedule and route adherence to dispatchers;
- Automatic passenger counters (APCs) on front and rear doors of most vehicles (Kimpel, 2001); and
- Computer-aided dispatch (CAD) center (Strathman et al., 2001).

The implementation of the BDS in Portland, Oregon has resulted in substantial savings to the existing system and increased the service reliability in the region for both bus and light-rail (Strathman, et al., 2002). The total annual benefits derived from implementing the TriMet BDS system is estimated at $5.4 million dollars, and the present value imposing a 12-year expected life on the BDS is $47.8 million.

5.8 Arterial Management Systems

An arterial management system is used to manage traffic by employing various detection and control devices along arterial roadways. This includes surveillance and traffic signal control, and sometimes includes audio or visual information on arterial roadway conditions. Detectors collect basic traffic condition data (typically flow and speed information) and adaptive control systems can be used to coordinate traffic signal control across a metropolitan area by adjusting the lengths of signal phases and cycles. Without centralized control, vehicles would be delayed at intersections irrespective of actual traffic conditions as the vehicle progressed through the route. This caused undue vehicular delay to all vehicles including transit vehicles. Using knowledge of real-time traffic characteristics and coordination, arterial management systems have contributed to reductions in red light violations of 20–75 percent and reductions in fuel consumption by 2–13 percent in the studied areas (USDOT, 2002a). It was shown that St. Paul, Minnesota, traffic signal preemption systems reduced crashes for emergency vehicles by 71 percent in seven years (USDOT, 2002a). An arterial management system can be also monitored by the existing vehicles running on the system. For example several transit agencies have equipped their vehicles with GPS which reports the location of the vehicle back to a dispatch center every few seconds.

As an example, using some of TriMet archived data, a fusing process was developed as shown in Figure 7. This figure displays time-space diagrams for both TriMet buses and “ground truth” probe vehicles that were traveling on Powell Boulevard at the same time on the same day. The bus AVL data was extracted from archived data for Route 9 beginning at Front Avenue on the west side to the intersection of Powell Boulevard and SE 39th Ave. The probe vehicle data were collected with GPS installed on the vehicle. The bus AVL data were archived through BDS described above. A comparison between travel time for both the bus and the vehicle is shown in Table 3. The integration between these two systems can also be compared using vector analysis in Geographic Information Systems (GIS). Figure 8 shows an interpolated surface comparing a bus speed “surface” with a “surface” constructed from probe vehicle speeds. The surface was created using 20 runs collected by the GPS installed on the probe vehicles. The surface was interpolated using a krigging method in the ArcGIS software. Another vector surface was created for 20 bus trips using the same method and during the same period of time. Both the probe vehicles and buses had the same origin and destination. Looking in depth at the comparison, the bus has behaved in the same way as the probe vehicle yet the percentage of drop in speed at some locations were not similar. These differences are due to the variations in speed between the two modes during free flow travel time. Statistical relations between the probe vehicle and bus performance can be developed for reporting arterial performance to travelers and to quantify improvements to arterial management systems.

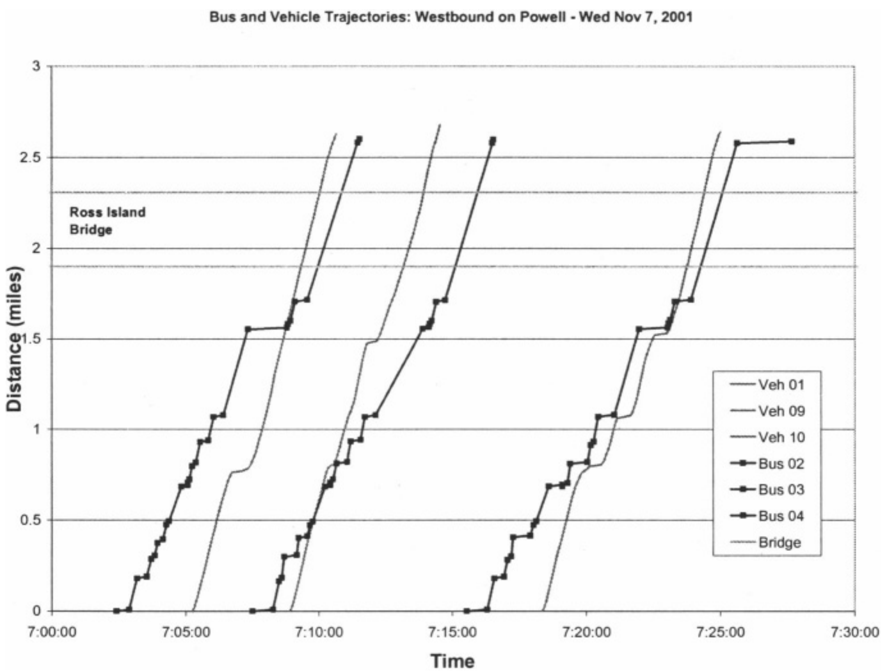


Figure 7. Time Space Diagram Fusing AVL Data

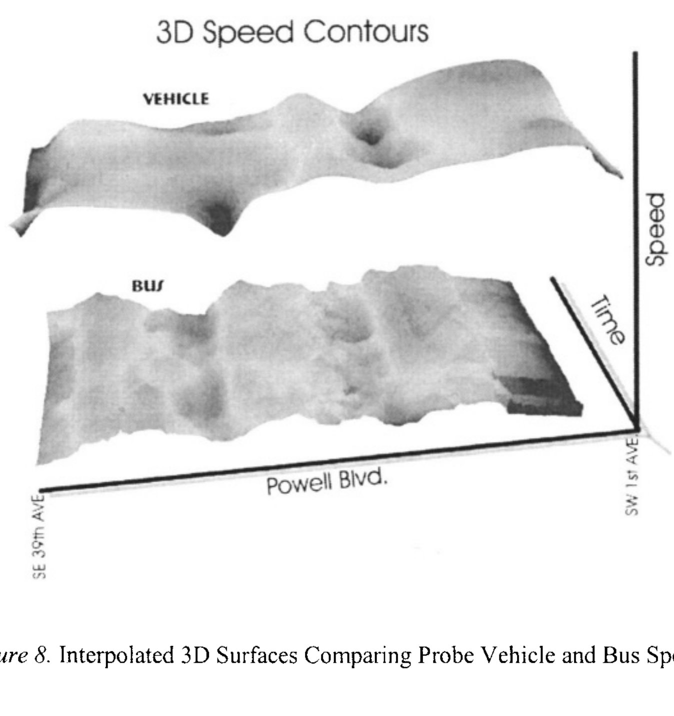


Figure 8. Interpolated 3D Surfaces Comparing Probe Vehicle and Bus Speeds

5.9 Emergency Management Systems

Emergency management systems are used by fire departments, police departments, ambulance services, and freeway service patrols. These systems respond to emergencies and direct the various departments to the incident location through the shortest path in order to clear the incident or save a life. These systems include traffic signal priority to give the right of way to the departments' vehicle. The emergency management systems use the AVL technology in order to locate the nearest vehicle and direct it to the incident. This system is managed by a transportation management center. The delivery of emergency service to the communities is an important responsibility that should be met when any person is facing an emergency.

A study of the Minnesota Highway Helper Program found that the program reduced the duration of a stall by eight minutes. Based upon representative numbers, annual benefits through reduced delay totaled $1.4 million for a program that cost $600,000 to operate. While in another pilot study looking at the Courtesy Patrol Program in Denver, Colorado, the estimates concluded a reduction cost in traffic delay by $0.8–$1.0 million for the morning period and by $0.90–$0.95 million in the evening. The study assumed a time value of $10 per hour. Program costs varied between the tow truck operators between $29 to $38 per truck-hour, which results in a benefit-to-cost ratio of 10.5:1 to 16.9:1 (USDOT, 2002a).

Table 3. **Travel Time Comparison Between Bus and Probe Vehicle**

Vehicle		Bus	
Departure Time	Travel Time	Departure Time	Actual Travel Time
7:05:15	0:42	7:00:22	0:58
7:08:54	0:46	7:02:52	0:53
7:18:21	0:38	7:08:16	0:49
7:32:48	0:35	7:16:18	0:49
7:38:06	0:43	7:23:04	0:50
7:56:15	0:35	7:30:24	1:02
7:59:45	0:41	7:35:06	0:54
8:22:12	0:32	7:49:10	0:47
8:44:03	0:42	7:54:22	1:07
8:49:30	0:34	8:05:20	1:05
9:01:03	0:48	8:21:00	0:44
9:07:54	0:32	8:23:04	0:49
9:18:30	0:37	8:48:14	0:55
9:22:03	0:33	9:10:24	0:49
9:35:00	0:34	9:20:24	0:45
9:36:21	0:33	9:35:06	0:46
9:49:42	0:39	9:52:06	0:46
9:50:30	0:31		
Mean	0:38		0:52
Variance	0.007		0.014
SD	0.085		0.119

5.10 Electronic Payment

Electronic payment systems are present on many of the highways in the U.S. Several DOTs are turning to toll collection in order to finance new roads and maintain existing highways. The congestion caused upstream of toll booths began to be a problem so the idea of electronic payments has emerged as an important response. Typically, drivers subscribe to an electronic payment system and are given radio frequency (RF) transponders that communicate with the toll collection system. Vehicles passing through the toll facility entrance and/or exit are not required to stop as their payment is automatically deducted from their accounts (Klein, 2001). Electronic payment is also used for collecting transit fares and commercial vehicle operating fees where the transponder can be used in various ways and it is linked to a bank account or credit card line. A typical manual toll lane might process 350 vehicles per hour while applying electronic payment on all lanes will result in about 1,200 vehicles per hour (ITE, 2000). If the toll plaza was eliminated the rate could be 2,000 vehicles per hour per lane. This application will save on both toll booth construction and administration fees.

5.11 Traveler Information

Traveler information systems are used to inform travelers regarding road conditions via broadcast media. The system collects data regarding the current status of the transportation network and broadcasts it to travelers via communication channels and media (McQueen et al., 1999) The objective is to provide travelers with current information so they can avoid congested routes. This kind of system tries to avoid the externalities caused by additional vehicles in the congested system. The communication system can be one-way or two-way where the vehicle will be equipped with GPS to identify the vehicle location and a traveler information center would direct the vehicle to an uncongested route. This system is known as a vehicle-motorist service information system (Hulse, Dingus, and Barfield, 1997). Several DOTs have started to apply similar systems and have begun to broadcast one-way communication to travelers via the radio and via the Internet. In Seattle, Washington, as shown in Figure 9, a Web-based traveler information system is available on the Internet (Washington Department of Transportation, 2002). The system is updated every minute. This kind of information system can also be implemented for transit. Several transit agencies have implemented Internet-based trip planners to transit riders. These trip planners save time and increase reliability to transit services.

5.12 Crash Prevention and Safety

In 1990, there were an estimated 16 million U.S. vehicle crashes. Forty-five thousand fatalities occurred during these crashes, along with 5.4 million nonfatal injuries and 28 million damaged vehicles. The average cost per crash is approximately $8,600. Crashes are mainly caused by human errors, including errors in recognition, decision, and performance. An ITS-based crash prevention and safety system will include an advisory crash avoidance system to alert the driver with a warning when the vehicle detects a crash is about to occur. This system can include an advisory system to indicate the optimum headway and the best speed (Dingus, et al., 1997). Vehicles can also be equipped with an in-vehicle safety and warning system where warnings of immediate hazards and road conditions affecting the roadway ahead of the driver are reported to the driver.

5.13 Operations and Maintenance

Operations and maintenance systems are created during the process of implementation of any ITS application to measure the success or the decline of the system. Operations and management systems are encouraged by the USDOT. The USDOT is responsible for monitoring 75 metropolitan areas in the U.S. that have deployed ITS and received federal funding for ITS investments. In addition, archived surveillance and performance data can be used later for generating various performance measures (Bertini and El-Geneidy, 2003; Bertini, Leal, and Lovell, 2002) and feeding performance data back into the planning process. Performance measures can lead to a better understanding of the existing system and the archived data can be used by various stakeholders in ways we cannot yet imagine. Collection of every single type of data needed for advanced traffic control for the entire traffic system is unrealistically costly and inefficient. Processing of disorderly and incomplete information reported from the field is usually complex and time consuming. (Klein, Yi, and Teng, 2002).

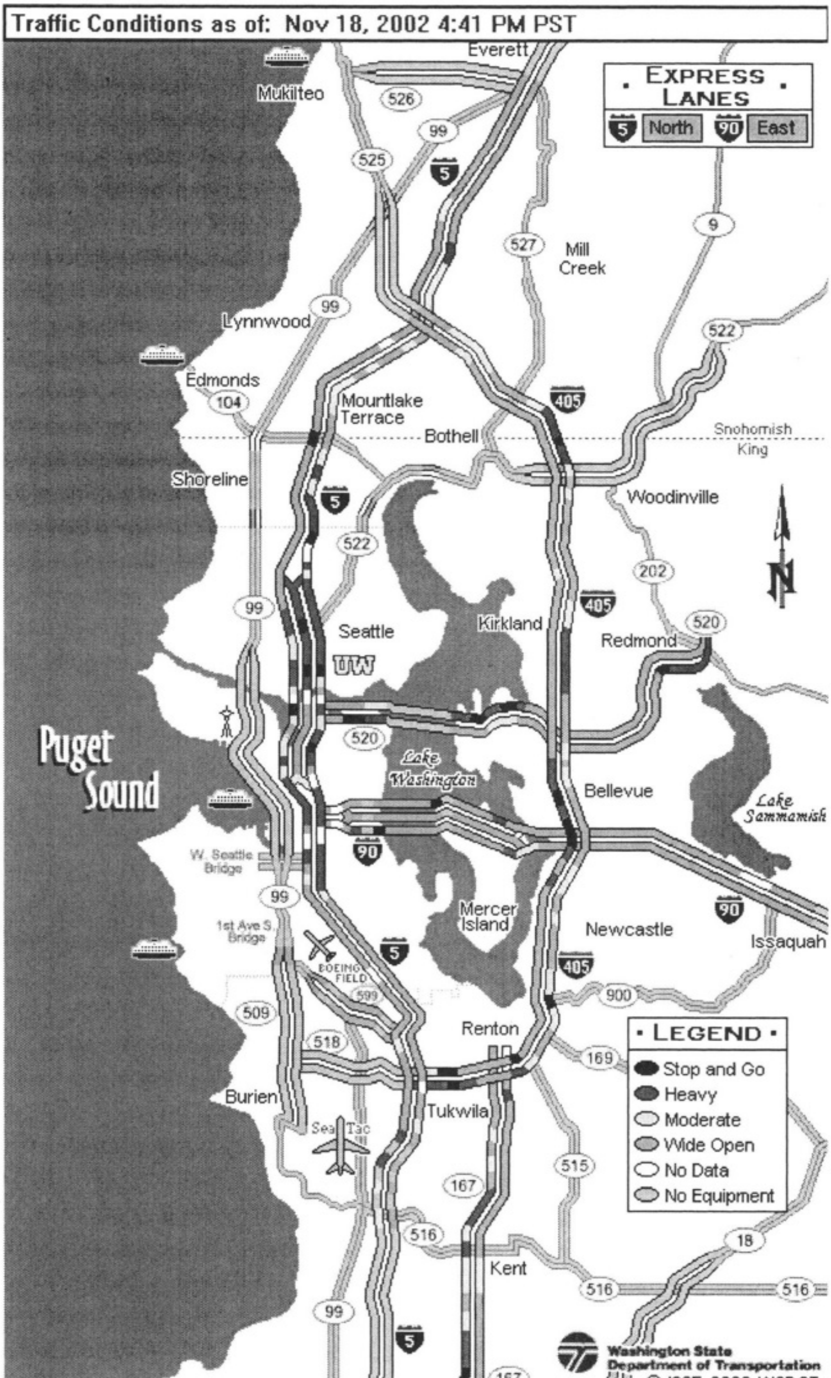


Figure 9. Seattle Online Freeway Condition Map

5.14 Road Weather Management

Weather impacts on transportation are pervasive. The weather can cause many incidents especially in the cold regions of the country. A study trying to quantify the benefits of an anti-icing program in seven different states in the United States was conducted in order to encourage the use of anti-icing/road weather information system technologies. The strategy of anti-icing involves the use of chemical freeze point depressants to prevent a bond from forming between pavement and snow or ice. NCHRP Project 20-7, Task 117 was initiated to address these needs and quantify the benefits (Boselly, 2001). The study concluded that the anti-icing program can reduce costs of providing a defined level of service by 10–20 percent, while the snow and ice control costs per lane mile can be reduced up to 50 percent.

6. CONCLUSIONS

After considering the 10 different ITS component systems it is clear that each system cannot be deployed to stand alone in the overall transportation system. Building a complete ITS system requires collaboration in time, funding, and institutional arrangements. ITS components that are integrated can result in synergistic effects when considered as an entire system. It is shown that in some cases it is possible to build upon national level statistics describing ITS benefits by using data collected from the systems themselves. Thus far, the quantification of ITS benefits has not been statistically sophisticated. Often, benefits are expressed as being "certain," when this is far from the truth. For example, the measurement of any reduction in mean travel time as a result of an ITS deployment involves bias; thus any benefit should be expressed along with its associated variance. In addition, there is no guarantee that travel time reduction due to the installation of ramp metering in one city will result in similar benefits in another city—particularly if the nature of system integration and institutional cooperation is widely different. It is hoped that further efforts to integrate transportation planning with evaluation tools such as IDAS and microsimulation will incorporate the necessary empirical results from a wide variety of studies. In this way, better databases can be developed, and heightened accountability will be more pervasive in the evaluation of ITS improvements.

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