Title

Inter-technology Effects in Intelligent Transportation Systems

Permalink

https://escholarship.org/uc/item/93x392jw

Authors

Levinson, David M.
Kanchi, Seshasai
Gillen, David

Publication Date

2002-05-01

CALIFORNIA PATH PROGRAM
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY

Inter-Technology Effects in Intelligent Transportation Systems

David M. Levinson
Seshasai Kanchi
David Gillen

California PATH Research Report
UCB-ITS-PRR-2002-19

This work was performed as part of the California PATH Program of the University of California, in cooperation with the State of California Business, Transportation, and Housing Agency, Department of Transportation; and the United States Department of Transportation, Federal Highway Administration.

Report for TO 4119

May 2002

ISSN 1055-1425

Inter-technology Effects in Intelligent Transportation Systems

Prepared for California PATH, Institute of Transportation Studies,
University of California, Berkeley
May 2002
By

David M Levinson, Seshasai Kanchi and David Gillen

David M Levinson (*)
Assistant Professor
Department of Civil Engineering
University of Minnesota,
500 Pillsbury Drive, SE
Minneapolis, MN 55455 USA
levin031@tc.umn.edu

+1-612-625-6354

Seshasai Kanchi
Associate, ICF Consulting
Fairfax, VA

David Gillen
Institute of Transportation Studies
Department of Civil Engineering
University of California at Berkeley

Abstract

This project examines the expected benefits of varying combinations of ITS applications: Freeway Service Patrol, Changeable Message Signs, and Ramp Metering. The research analyzes the simulated results of a stylized network in a microscopic traffic simulator. The traffic network includes parallel roadways, ramp meters and changeable message signs. We have tested these technologies in various combinations. We measure effectiveness and define a measure of inter-technology economies. In brief, it is found that additional technologies are sub-additive, and more benefits come from each technology in isolation than when it is bundled with other technologies.

Keywords: Transportation System Management, Inter-technology Economies, Freeway Service Patrol, Changeable Message Signs, Ramp Metering, Intelligent Transportation Systems, Evaluation

Introduction

There has been recent interest in understanding the economic viability of Intelligent Transportation Systems (ITS) technologies, such as route guidance, freeway service patrols, traveler information and traffic control, to determine their ability to substitute for physical infrastructure investment. Incident management programs are one of the key elements of ITS. The goal of such programs is to clear incidents and return traffic flow on the roadway to normal as soon as possible. Incident management programs have been introduced in many places to help reduce the time to detect and the duration of incidents. They make use of ITS services and coordinate among the various operating agencies to meet the goals of reduction in the detection and clearance of incidents.

Highway assistance services, also called freeway service patrols (FSPs), are one of the main approaches used by incident management programs. These services use vehicles to patrol heavily traveled segments and congested sections of freeways that are prone to incidents (Freeway Operations Section 2000). The main goals of the Freeway Service Patrols are to help identify incident locations, reduce the duration of incidents, restore full freeway capacity, and diminish the risks of secondary accidents to the motorists (Fenno and Ogden 1998). The role of the patrols is to clear the majority of incidents without any assistance from other agencies. In case of major incidents, the patrols help assess the equipment and manpower needed to clear the incidents, coordinate with the other agencies involved, provide the needed traffic control and act as a buffer between the workers and traffic. They also help detect and verify incidents like major accidents and pass on the required information to the transportation management centers (TMCs).

Changeable Message Signs (CMS) (also called Variable Message Signs) give information and recommendations to drivers, making them aware of upcoming traffic conditions along their trip. These dynamic messages inform drivers about unexpected incidents and congestion and suggest alternative routes so that delay is minimized.

Ramp metering programs (RMP), aimed primarily at recurring congestion, have been applied in numerous cities in the United States as well as throughout the world. Ramp metering aims to limit the number of vehicles entering the freeway from entrance ramps at specific periods of time so that freeway flow can be maintained at a desired service level. Excess demand is forced to wait at the entrance ramp. The intention of ramp metering is, therefore, to maintain uninterrupted, non-congested flow on the freeway as long as possible by transferring delay from the freeway to the entrance ramp. The diversion of traffic to alternative routes in the corridor, less congested departure times or even different modes of transportation is an anticipated consequence of ramp metering.

This project aims to evaluate the benefits associated with various combinations of these three ITS applications (FSP, CMS, and RMP). The results obtained from each case are analyzed and the optimal use of ITS technologies has been determined. The methodology adopted is described in the form of a flowchart (Figure 1).

This paper begins with a brief description of the methodology used for traffic simulation. The assumptions and details regarding the traffic network are described in the next section. The subsequent sections delve into modeling the traffic network and describing our measure of effectiveness. A summary of study results and conclusions are then provided.

Input Characteristics and Assumptions

The input flow characteristics of the system are shown in Figure 2. The free flow speed of vehicles is taken as 88 km/hr on freeways and 60 km/hr on entrance ramps. The flow distribution is assumed to be uniform with traffic comprising all cars. The initial warm up time for the simulation is set at 15 minutes for an overall 120 minutes of the simulation run. The input traffic demand consists of three states 1, 2 and 3. The states 1 and 3 correspond to base flow rates of 8000 vehicles / hour, while state 2 carries a flow of 10,000 vehicles / hour in the entrance section. All the ramps allow 600 vehicles / hour into the freeway for all the three states. State 1 lasts from 0 to 45 minutes, state 2 from 45 to 75 minutes and state 3 from 75 to 120 minutes as shown Figure 2. The traffic incidents are activated after 30 minutes of simulation run at a specific fixed location with varying rates of clearance. Optimal ramp metering rates were determined from initial simulations. However, it is assumed that the optimal ramp metering rates remain unaltered even during incidents in the downstream of the ramp meters.

The network includes parallel roadways, ramp meters and changeable message signs. We analyzed multiple or group ramp meters. Figure 3 illustrates the test scenario. A downstream bottleneck on a freeway has two upstream ramp meters with a CMS at the diverge point where the freeway with three lanes splits into two freeway sections each of two lanes. The location of the incident is after the second ramp downstream bottleneck as illustrated in the Figure 3.

The four ramps are tested under both metered and unmetered scenarios. To maintain simplicity for analysis, we restrict ourselves to one type of meter control. We employ Changeable Message Signs for some scenarios. We specify the proportion of traffic that receives the message and the probability of acting on it at the traffic intersection. The evaluation is made for different proportions of people receiving and acting on the message and see how savings change as a result of these different proportions. We assume that CMS informs 100% of drivers, but the percent who act based on the message varies from 0 to 100%. When analyzing CMS, we consider the optimal switching rate for that case. Using different actions, each corresponding to a specific CMS, the turning probability is altered. We believe that with an appropriate severity of message and some experience, turning probabilities can be tuned. FSP is not directly included in the simulator, but can be modeled by injecting an incident and accelerating the clearance rate. The blockage effects 1 or 2 lanes and the clearance rate of the incident can be changed.

Modeling

This research employs the AIMSUN2 (Advanced Interactive Microscopic Simulator for Urban and Non-urban networks) microscopic traffic simulator. AIMSUN2 continuously models the behavior of each vehicle in the network, using car following and lane changing models. The traffic links or sections in the traffic simulator are represented in the form of channels of pipes for freeways and ramps. The simulator allows users to vary percentages of different vehicles like cars, trucks and buses. The input traffic demand is specified by the means of a result container, which comprises different states, varying traffic flow demands based on time of the day (morning, afternoon and evening). Ramp metering control is performed by loading a control plan, which contains the details about the traffic flow from the ramps onto the freeway (ramp metering rate). The modeling system allows adaptive, fixed and uncontrolled ramp metering with user defined minimum, initial and maximum flow metering values. Changeable message signs (CMS), which dictate splitting percentages at junctions, can also be modeled directly in AIMSUN by inputting the percentage of drivers who will respond based on a given message. The optimal CMS splitting percentages for different scenarios is determined by compiling alternative splitting percentages between two paths at the CMS and then choosing the rate that maximizes the overall measure of effectiveness. Freeway service patrols (FSP) are simulated by generating a traffic incident in the network which gets cleared after a given time interval determined by the user to reflect the level of service of FSP. The simulator allows creating incidents on single or multiple lanes depending on the time when they are activated, duration (size) and location in a section of the network.

The ramp metering rate optimization process involves comparison of downstream bottleneck sections for each of two ramps by performing a number of simulations. Each simulation varies the traffic demands and metering rates for the ramps without any incident, and thus no need for CMS or FSP. The bottleneck sections were compared using basic traffic characteristics of flow, speed and density for each of the cases and the results of the analysis are shown in Table 1. The optimal case that corresponds to maximum flow is selected as metered flow rates for the ramps. These metered flows are entered as inputs for the next stage of the analysis. We selected test G (shown in **bold** in Table 1) because it resulted in more flow than all of its other counterparts, which is consistent with many ramp metering strategies. In the analysis shown in Table 1, section 12 denotes the downstream bottleneck section for first ramp meter while section 13 denotes the downstream bottleneck for second ramp meter. Due to complexity of the traffic simulation modeling and time constraints we used a constant optimal metering rate of 600 vehicles per hour for all scenarios. Such an assumption would lead to some under-estimating of positive impacts of using adaptive ramp metering instead of a constant metering rate. Once the optimal traffic demands with metering rates are determined, the final simulation runs are performed with the integration of CMS and FSP with (or without) optimal ramp metering rates. We designed on ramps long enough to allow the total inflow of vehicles entering the network during the simulation cycle at all times and thus accounted for different on ramp delays for different scenarios.

Measures of Effectiveness

Once the fixed ramp metering rates are obtained, these values are fed into the microscopic traffic simulator and the analysis is performed with different combinations of CMS turning flow percentages at the diverge point and with different incident durations. To determine the efficiency of our test traffic network, we measure the expected net benefits of some combination of ITS applications.

Inspired by the notion of consumer's surplus, our approach defines a Measure of Effectiveness (MOE) as in equation (1), illustrated in Figure 4. Figure 4 depicts that with the increase in output flow Q_s to Q_i, the travel time decreases from T_s to T_i. The figure represents two sets of conditions, both with fixed demand D, one with S_s and the other with supply S_i. The shaded block in the figure represents the change in benefit (DB) in vehicle hour units, which is approximated by equation (1), which sums up benefit on all links (including ramps) on the network.

$$\Delta B_{is} = \sum_{j=1}^{J} {}^{1}\!/_{2}\left(Q_{sj} + Q_{ij}\right)\left(T_{sj} - T_{ij}\right) \qquad (1)$$

T_{sj} and Q_{sj} are the fixed section travel time and outflow characteristics corresponding to a standard base case (one or two lane incident blockage and an equal split of mainline traffic between the top and bottom roads) for both metering and non-metering tests on section 'j'.T_{ij} and Q_{ij} are the sectional travel and flow characteristics for a varying incident duration and turning flow percentages for each section 'j'. In the above equation, 'J' represents the number of sections in the system. ˇB_{is} represents how much the system 'i' is better or worse off than system 's' in terms of vehicle hours for all sections, both freeway and ramp sections are included in this analysis. While the loaded traffic onto each ramp is fixed, the traffic on each section is not, due to queuing and capacity restrictions associated with incidents.

Inter-technology Economies

The primary objective of the paper is to test whether inter-technology economies are present between FSP, CMS and RMP. Inter-technology economies exist whenever the benefits of all technologies together exceed the sum of benefits of each technology individually. In other words, inter-technology economies are present if the individual benefit of consuming the outputs jointly is greater than the sum of the benefit of consuming the products separately. Thus, if A, B and C are benefits in units of vehicle hours corresponding to FSP, CMS and RMP in isolation and D represents over all benefits for consuming all the technologies simultaneously, then an inter-technology economy implies $A + B + C < D$, a case we call super-additive. Otherwise (if $A + B + C > D$) there is an inter-technology diseconomy, a case we call sub-additive. Using this definition we examine how the MOE changes when we add additional ITS technologies for different incident clearance intervals with one and two lane blockages.

Results

First we test the change in benefit in the presence of ramp metering. As noted before, the actual demand on ramps is set as 630 vehicles/hour, while the optimal metering flow rate is 600 vehicles / hour. Table 2 shows how the benefit changes with additional ITS technologies indicating whether the system has a particular ITS technology for one-lane and two-lane blockage. In the case with no CMS, a standard 50 % split between the two routes is assumed, and for the cases with no FSP, a standard incident clearance rate of 20 minutes is assumed. Similarly, in the cases with FSP and CMS, the MOE corresponding to 10 minutes incident clearance rate and optimal splitting rates are considered.

In this first case, the change in benefit (in vehicle hours) for each case in one and two lane blockage is measured with respect to a standard base case with an incident, but no early clearance (i.e. no FSP), no diversion (50-50%) and standard metering rate of 600 vehicles/hour. Table 2 shows the change in benefit for a system with various combinations of FSP, CMS, and RMP for one and two-lane incident blockage. Table 2 also shows the change in benefit for one lane blockage are lower than two lane blockage, showing that the traffic conditions are more severe and worse in the latter case.

In order, to determine whether Freeway Service Patrols and Changeable Message Signs are super-additive or sub-additive, we have to compare the savings attained from each of them separately and together. In order words, we need to find whether:

$$Benefits(FSP,0) + Benefits(0,CMS) \lessgtr Benefits(FSP,CMS) \qquad (2)$$

where,

- Benefits(FSP, 0) denotes benefits attained only due to FSP, which is the difference between Benefits(with FSP, without CMS) and Benefits(without FSP, without CMS)
- Benefits(0, CMS) denotes benefits attained only due to CMS, which is the difference between Benefits(with CMS, without FSP) and Benefits(without CMS, without FSP)
- Benefits(FSP, CMS) denotes benefits attained by both FSP and CMS together, which is the difference between Benefits(with CMS, with FSP) and Benefits(without FSP, without CMS)

Putting the values for savings in (2), we see from Table 3 that we get [Benefits (FSP, 0) + Benefits (0,CMS)] > Benefits (FSP, CMS), (65+212=277 > 247) which demonstrates that the two technologies are sub-additive. Similarly, we can perform the analysis in the case of two-lane blockages with ramp metering. Table 4 summarizes the analysis of inter-technology economies with and without freeway service patrols, changeable message signs, and ramp metering for one and two-lane blockages. The results obtained are for a 20 minute incident that is cleared in 10 minutes if there is a Freeway Service Patrol operating. The change in benefit obtained for cases without each technology are lower than with that technology which suggests that all of these technologies have positive benefits in congested prone networks. Also, the results illustrate that the impact of technology is greater for two-lane blockages than one-lane blockages since the individual benefits from FSP and CMS are higher for the former case. The results show that for both one and two-lane blockages the ITS technologies are generally sub-additive, generating more benefits separately than together. For the one-lane blockage case, CMS and RMP are sub-additive but for two-lane blockage they are super-additive. This one case of super-additivity may be because there is more mainline congestion during a two-lane blockage.

Conclusions

This research identifies and develops a method for measuring the benefits associated with bundles of technologies. This novel analysis of what we call inter-technology economies provides insights into how recurring and non-recurring traffic congestion can be alleviated with ITS technologies. It suggests that most of the gains can be obtained from whatever technology is deployed first, and that successive gains from additional technologies are smaller than the first application. It is observed that all but one of the cases we modeled demonstrated sub-additive benefits. This does not mean that multiple ITS technologies should not be pursued, but that the benefit claims of ITS when measured separately must not simply be added together. The more severe the incident, the more useful the ITS technology, either separate or together. For non-recurring congestion, Freeway Service Patrols are found to generate significantly more gains than either Changeable Message Sign or Ramp Metering applications. While many of the benefits may be sub-additive, there may be cost savings associated with deploying multiple technologies that should also be considered in any complete evaluation.

ACKNOWLEDGEMENTS

The authors of this paper would like to thank the California Department of Transportation and the California PATH program at the University of California at Berkeley for providing support as a part of the project Measuring Network Effects in ITS and the University of Minnesota. The authors would like to thank Pavithra Kandadai Parthasarathi for help in analyzing Freeway Service Patrols. The authors of this paper would also like to thank Panos Michalopoulos, John Hourdakis and Koka Muralidhar for their helping us perform efficient traffic simulations with AIMSUN2.

REFERENCES

Abdulhai, B., Sheu, J., & Recker, W., (1999). *Simulation of ITS on the Irvine FOT Area Using Paramics 1.5 Scalable Microscopic Traffic Simulator: Phase I: Model Calibration and Validation*, California Path Research Report, (UCB-ITS-PRR-99-12)

Barcel, J., Ferrer J.L. and Grau R., (1996) "Microscopic Traffic Simulation for ATT Systems Analysis". Research Report, Departament de Estadstica e Investigacin Operativa, Universitat Politecnica de Catalunya.

Fenno, D., & Odgen, M., (1998). "Freeway Service Patrols A State of the Practice" *Transportation Research Record*, no.1634, pp.28-38.

Freeway Operations Section (2000). *Highway Helper Summary Report* Minnesota Department of Transportation.

Gillen, D., & Haynes, M., (2000). *Measuring the Aggregate Productivity Benefits from ITS Applications: The California Experience*, California PATH Draft Report: Berkeley CA: Institute of Transportation Studies, University of California at Berkeley.

FIGURE 1: TRAFFIC SIMULATION METHODOLOGY

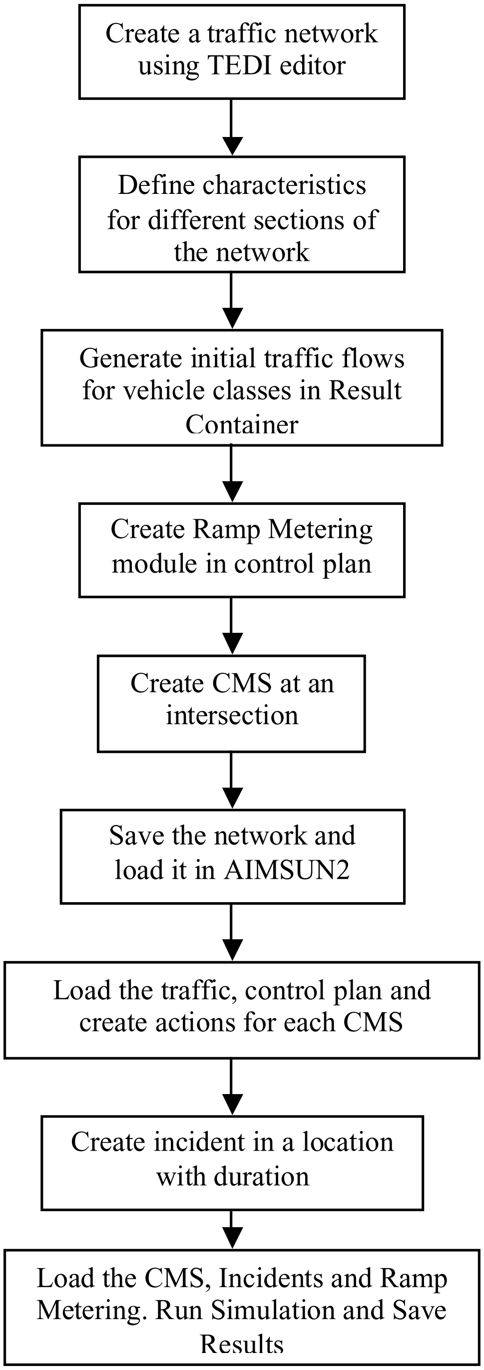


Figure 2: Flow Characteristic Diagram

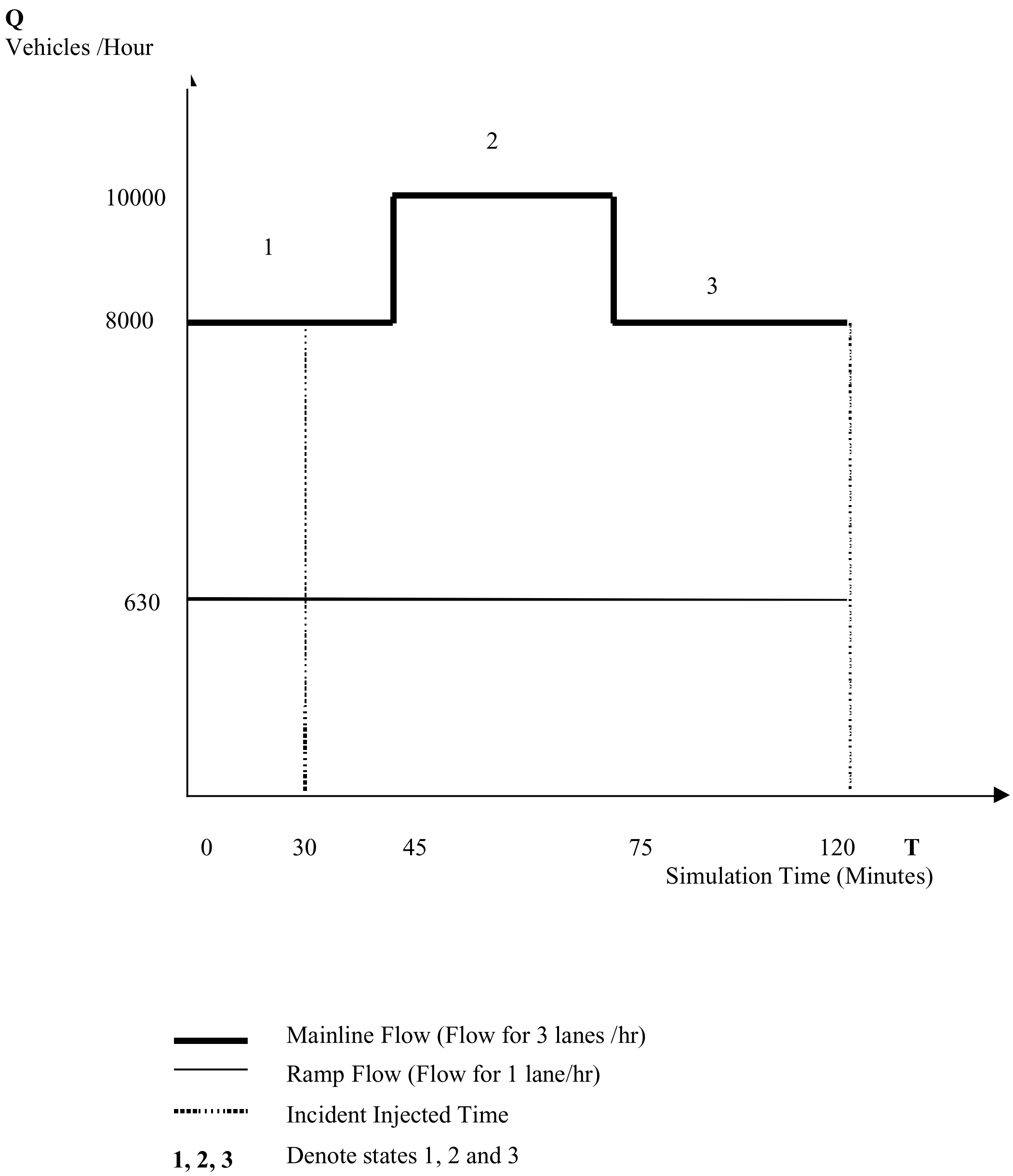


Figure 3: Test Network

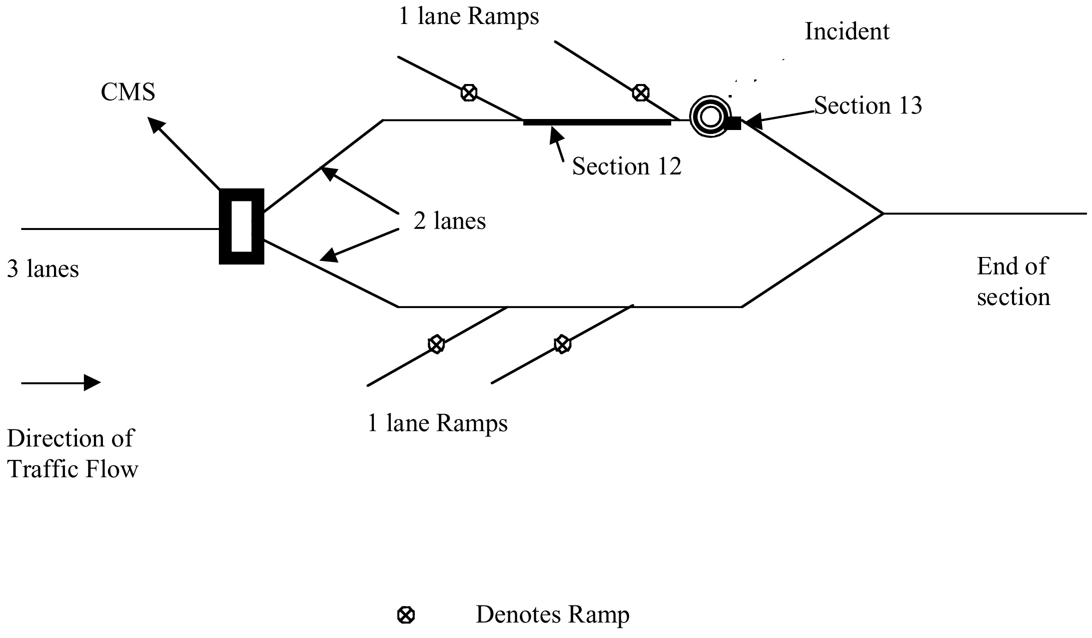
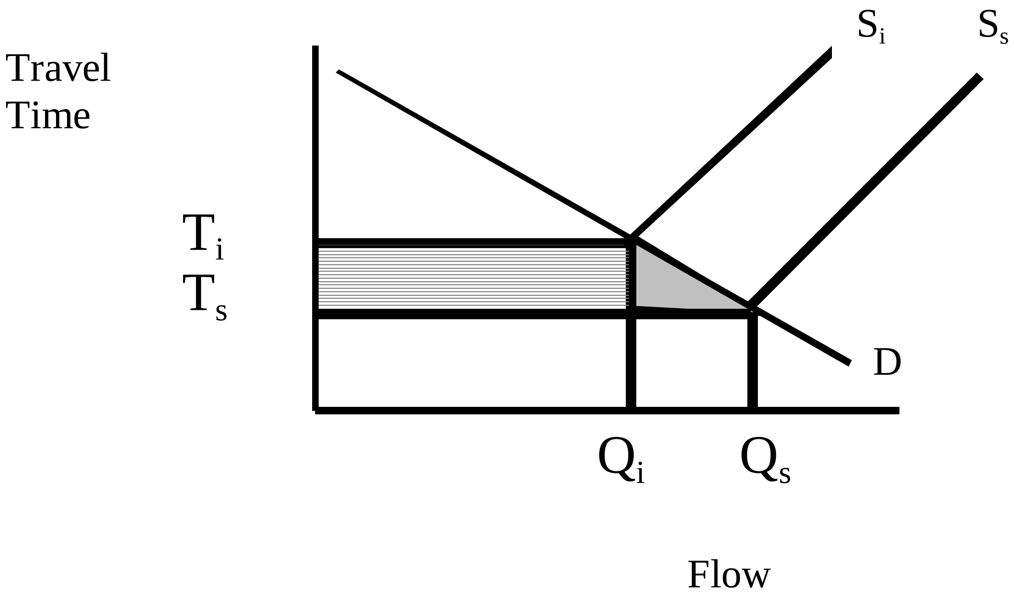


Figure 4: Benefit Measurement



TABLES

TABLE 1: Sectional Characteristics of Traffic Flow for Sections 12 and 13 By Varying Ramp Metering Flow

		SYSTEM			SECTION 12			SECTION 13		
Case	veh/hr Ramp Flow	veh/hr Total Flow	veh/km Average Density	km/hr Speed	veh/hr Total Flow	veh/km Average Density	km/hr Speed	veh/hr Total Flow	veh/km Average Density	km/hr Speed
A	0	5823	21.13	59.38	2980	16.59	79.50	2976	14.35	79.98
B	100	6208	22.93	59.22	3075	17.83	77.73	3171	16.78	77.25
C	200	6613	24.92	58.90	3195	19.57	75.00	3402	19.95	73.55
D	300	7000	26.91	58.42	3287	21.13	72.10	3576	22.18	71.13
E	400	7373	28.89	57.78	3342	22.99	68.56	3727	24.54	68.08
F	500	7725	33.43	54.07	3445	36.16	52.14	3946	30.38	61.16
G	**600**	**7978**	**44.74**	**44.58**	**3423**	**49.96**	**39.91**	**4021**	**33.74**	**57.78**
H	700	7923	47.53	42.81	3356	52.38	38.30	3976	35.29	56.01
I	800	7911	49.83	42.00	3341	53.13	38.46	3982	34.73	56.01

TABLE 2: Summary Results From Simulation Runs

	Blockage:	1 Lane		2 Lane	
Cases		With Metering	Without Metering	With Metering	Without Metering
1	No FSP, No CMS	284	0	523	0
2	FSP, No CMS	348	140	568	402
3	No FSP, CMS	496	242	716	129
4	FSP, CMS	531	257	734	485

Note: Change in benefit in vehicle hours

TABLE 3: Illustrative Inter-technology Economy Matrix (FSP, CMS, RMP) for 1 Lane Blockage

	With CMS	Without CMS	Savings
With FSP	*531*	348	182
Without FSP	496	*284*	**212**
Savings	35	**64**	*247*

212+64=276 > *247=531-(284)*

Note: Change in benefit in vehicle hours compared to baseline case of no ramp metering with one lane blockage.

TABLE 4: Inter-technology economy (FSP, CMS, RMP) For One and Two Lane Blockage

	1 Lane Blockage		2 Lane Blockage	
Technologies	CS	Result	CS	Result
FSP,0,RMP		Sub-additive		Sub-additive
Benefits(FSP,0,0)	140		402	
Benefits(0,0,RMP)	284		523	
Benefits(FSP,0,RMP)	348		568	
0,CMS,RMP		Sub-additive		Super-additive
Benefits(0,CMS,0)	242		129	
Benefits(0,0,RMP)	284		523	
Benefits(0,CMS,RMP)	496		716	
FSP,CMS,0		Sub-additive		Sub-additive
Benefits(FSP ,0, 0)	141		401	
Benefits(0,CMS, 0)	242		128	
Benefits(FSP, CMS,0)	257		484	
FSP,CMS,RMP		Sub-additive		Sub-additive
Benefits(FSP, CMS ,0)	257		485	
Benefits(0,0,RMP)	284		523	
Benefits(FSP, CMS,RMP) (baseline: metering off)	531		734	
FSP,CMS,**RMP**		Sub-additive		Sub-additive
Benefits(FSP ,0, RMP)	64		45	
Benefits(0,CMS, RMP)	212		148	
Benefits(FSP, CMS,RMP) (baseline: metering on)	247		166	

Note: Change in Benefit in Vehicle Hours. All cases except last assume baseline with all technologies off (0,0,0) with one or two lane blockage respectively. Final case assumes baseline with metering on (0,0,1) Benefits are calculated from Table 2. Incidents 20 minutes without FSP, 10 minutes with FSP.