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Abstract

SIRIUS (Systeme d'Information Routiere Intelligible aux Usagers) is the largest urban field operational test of the advanced traveler information and automated traffic management system in Europe. With variable message signs, **SIRIUS** has been in operation in the Paris region since December 1992. This study is a preliminary investigation of the effectiveness of the SIRIUS system in traffic management. The concern of the paper is the extent to which drivers respond to real-time traffic information and the consequential changes in link flow under SIRIUS. Time-series traffic data were analyzed to measure changes in mean flow rates at a selected link. The study indicates that variable message signs do influence drivers to choose lesser congested routes when provided with real-time information. Graphical analysis using cumulative arrival curves suggests that diversion behavior is closely associated with information pertaining to the level of congestion. The results of the study indicate that as congestion becomes heavier, drivers are more likely to respond to variable message signs.

Executive Summary

A real-time traffic information system called **SIRIUS** (Systeme d'Information Routiere Intelligible aux Usagers) using variable message signs (VMS) has been in operation in the Paris region since December 1992. Part of the DRIVE II program and the largest urban pilot project of its kind in Europe, **SIRIUS** provides real-time traffic information via 200 remotely controlled VMSs operated from a centralized data processing center. **SIRIUS,** which is based on an expert system, includes video cameras at selected sites and 5,000 loop detectors within half of the 600 kilometer freeway network in and around the eastern region of Paris. This study is a preliminary investigation of the effectiveness of the **SIRIUS** system, the extent to which VMSs affect motorists' route choices and whether drivers respond differently to different types of messages. The first link of the network selected for the study is an access ramp connecting Autoroute 86 (A86) with Department Road 45 (D45). A VMS displaying traffic conditions on A86 is located on D45 upstream of the A86 access ramp. When A86 is congested downstream of the access ramp, drivers receive information on the length of the queue and may choose to stay on D45 to avoid congestion. This working paper reports on the findings of the data analysis on this link.

The objective of the study is to identify the effects of real-time traffic information via VMSs on link flow and route choice; the degree to which route choice is affected by real-time traffic information. Data on the number of vehicles, density, and speed collected over a three month period from February to April 1993 provided a sample of 86 observations at this study site. The conjecture was that the link flow on the access ramp will decrease as the VMS indicates an increasing queue length on A86 because some drivers will elect to remain on D45 in order to avoid congestion on A86.

The null hypothesis was that there is no difference in traffic flow on the access ramp before and after message changes. This hypothesis was tested using differences in means tests using traffic volume data 5 minutes before and 5 minutes after message changes. The test indicated that traffic flow decreased on the access ramp by 3.68% when the VMS message changed to indicate increasing congestion on A86. The t-test showed statistical evidence of a significant variation in means at a 90% confidence interval when the VMS indicated increasing congestion. When the VMS indicated decreasing

congestion, traffic flow remained constant; no statistically significant variation in means was found. The constant amval rate in this case could mean that the increased number of vehicles wanting to take **A86** in response to the message displayed is approximately equal to the decreased number of vehicles arriving at the ramp due to reduced demand after the maximum peak time. The arrival rate of vehicles on the ramp decreased as the queue on **A86** vanished. The study also suggests that route choice is a function of the congestion level of the alternative route as indicated on the VMS. **A** queue length of **3** kilometers on the alternative route seems to be the threshold at which diverting strategies become most evident.

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1. Introduction

The 600-kilometer freeway network within a 30-kilometer radius around Paris handles nearly one half of the regional traffic. To increase its operational efficiency, this network is now managed by a single authority, Service Interdepartmental d'Exploitation Routiere (SIER), a regional highway operations division of the French National Department of Transportation. Within this new institutional framework, an expert system called SIRIUS (System d'Information Routiere Intelligible aux Usager) has been in operation since December 1992. The largest urban field operational test (FOT) project of its kind in Europe, SIRIUS provides real-time traffic information via 200 remotely controlled variable message signs (VMS) operated from regional Traffic Management Centers (TMC) with a centralized database. Over the past few years, SIER has placed video cameras at selected sites and has installed 5,000 loop detectors on the freeway network in and around the eastern region of Paris.

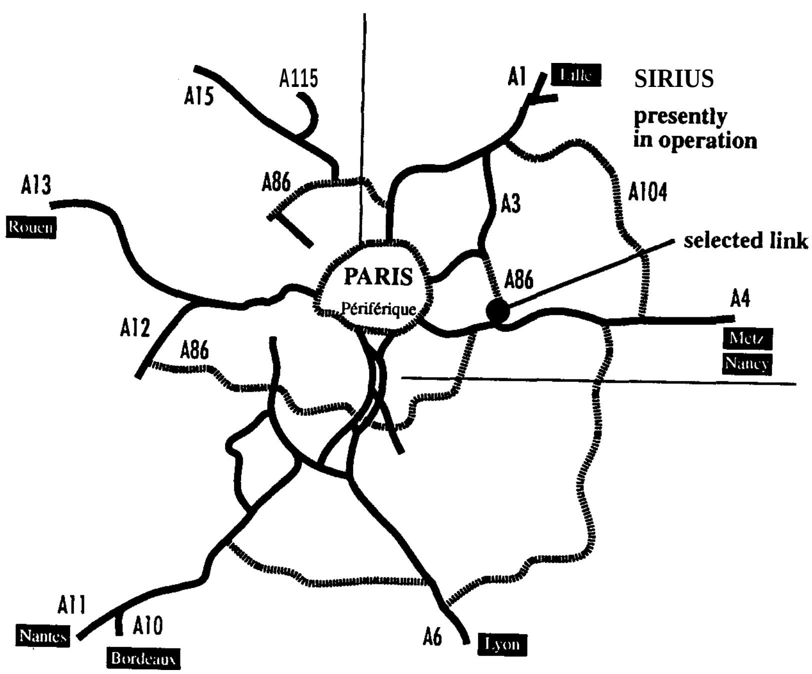
The SIRIUS evaluation project is aimed at demonstrating the effectiveness of the advanced traffic management and traveler information systems using VMSs. As part of the CITIES (Cooperation for Integrated Traffic Management Information Exchange Service) project under the DRIVE II program, SIRIUS will be evaluated in three phases over the next three years (Commission of the European Communities, 1992). The Phase I study will measure changes in individual link flow using traffic data. The Phase II study will measure changes in travel behavior of those motorists who are equipped with in-vehicle communication devices such as CARMINAT. The Phase III study will measure changes in system level performance for the overall regional network traffic (Durand-Raucher, 1992).

Within the framework of the Phase I evaluation plan, the objective of the present study is to assess the effects of VMSs on individual link flow. This paper is concerned with the extent to which SIRIUS influences route choice so that existing freeways can operate more efficiently. The broad research issues were whether the link flow rates with VMSs under SIRIUS are significantly different from the flow rates without VMSs and to what extent VMSs affect motorists' route choices. More specific issues were: 1) whether there is a significant change in link flow following a message change; 2) whether motorists respond differently to various types of messages; and 3) whether traffic stream flow data on a single link can be utilized to detect driver response to VMSs. This paper reports on the results of the traffic flow data analysis for a selected link addressing the above issues.

The selected link for performance evaluation was the access ramp connecting Department Road 45 (D45) to Autoroute 86 (A86). A86 is the second ring road which wraps around the suburbs of Paris (Figure 1.1) and D45 is the frontage road serving the residential and industrial districts along A86. A VMS was placed along the slow lane of D45 approximately 300 meters upstream of the A86 access ramp. The sign displays traffic conditions on A86 at all times including *free flow* conditions. When A86 is congested downstream of the access ramp, drivers receive traffic information as to queue length via the VMS.

The paper begins with a discussion of the **SIRIUS** project in Section **2,** followed by an overview of VMS studies in Section **3.** Methods used for data analyses are presented in Section 4 and the results of the data analyses are reported in Section 5. Conclusions are presented in Section 6.

Figure 1.1 The Study Site in Relation to the Regional Network
(Source: French National Department **of** Transportation, **1992)**



2. Background

This section provides background information on the **SIRIUS** program regarding the new institutional arrangement and the congestion problems with the regional freeway network. The SIRIUS program is a region-wide traffic management system which is designed to improve the operational efficiency of the roadway network by providing real-time traveler information via variable message signs. To increase the efficiency of the traffic management system, significant changes were made in the roadway network management and operation system under **SIRIUS.**

2.1 New Institutional Arrangement

Until recently, the managerial and operational responsibility of the roadway network in the City of Paris and its surrounding regions ***(Ile de France)*** was under local and regional jurisdictions, each city and suburban community managed and operated its own transportation network. Under the **SIRIUS** program, this decentralized institutional arrangement was restructured into a highly centralized system in which regional freeways and city arterials are now managed by a single authority, the Regional Route Operations Division of the French National Department of Transportation (DOT). This jurisdictional reform was an important step towards institutional cooperation between regional and local agencies, especially between the City of Pans and the federal government.

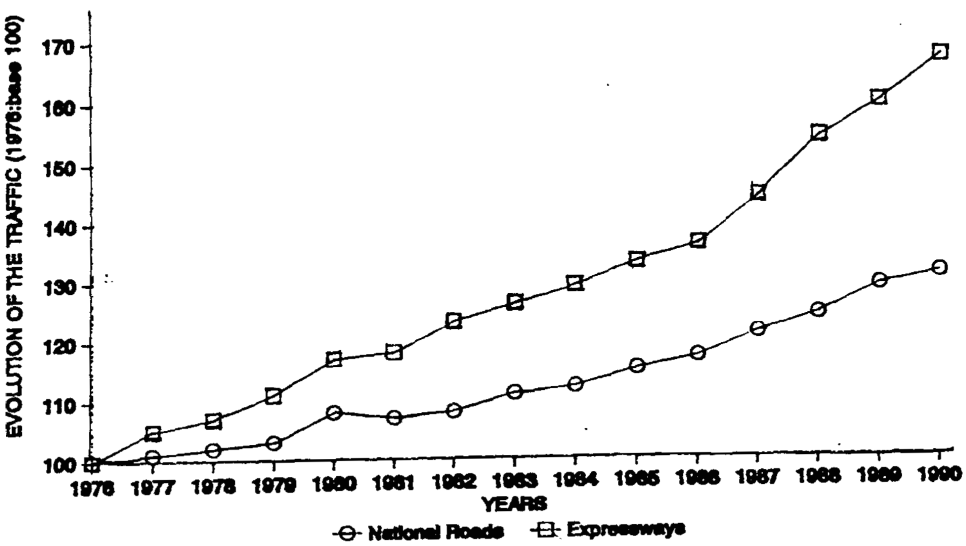
The newly formed regional transportation division is responsible for collection of traffic data, coordination with the highway patrol and maintenance and operations of freeways. In addition, the regional authority is responsible for providing engineering work for highway construction and alterations and modifications to the existing infi-astructure for improved operational efficiency and traffic safety.

Since SIRIUS has been in operation, the French DOT's concern has been whether the VMSs would actually be able to redirect traffic and ultimately reduce travel time of the overall roadway network. The capital investment of the **SIRIUS** system was substantial and it is important to understand the extent to which **SIRIUS** VMSs help to reduce congestion and increase traffic safety. The French DOT is currently collecting traffic data using loop detectors at selected freeway intersections to measure the changes in link flow under SIRIUS.

2.2 *Re de France* Freeway System

The *Ile de* ***France*** freeway system is subdivided into four geographical divisions. Each division has its own Traffic Management Center **(TMC).** Each TMC receives all necessary traffic information and responds to inquiries from other TMCs. These TMCs are connected to a centralized database for data processing and retrieval with common communications links. In the Paris region, **7%** of the freeway system handles 40% of the total regional traffic. During the last four years, **traffic** has grown at a rate of **4** to *6%* per year on the network, twice as fast as traffic growth on the major arterial roads in France (Figure 2.1). Congestion is estimated to cause approximately 100 million hours of delay annually. The near-term goal of the French DOT is to improve traffic safety and driving conditions using real-time traveler information, namely **SIRIUS,** to modify individual drivers' behavior so that existing roadways can be better utilized through the efficient distribution of traffic flow.

Figure 2.1 Traffic Increase in the Paris Region
(Source: **French** National DOT, **1992)**



The regional freeway network serving *Ile de France* consists of nine radial freeways and three beltways. The radial fieeways are extended out to the suburbs and the provinces from the core area of Paris. The first beltway which wraps around the city center is called *Boulevard Peripherique*; it is approximately **35** km long. The second beltway, **A86,** is about **5** to 10 km apart fiom the first beltway and is 80 km long, with a link missing in the western portion of the network. The third beltway, highway **A104,** is **10** to 20 **km** fiom the second beltway and connects the major radial freeways, A1 to Lille and **A6** to Lyon. Links between **Al** and **A10** of the **A104** network were not completed.

For the operational efficiency of the SIRIUS system, the radial system of the *Ile de France* freeway network is now developed into a spider-web pattern to provide motorists with more options to move conveniently from one route to another. While such a configuration offers a range of route options, it presents technical and operational problems in disseminating information. The major problem with VMS systems is the lack of available personalized traveler information that is needed to achieve the maximum efficiency of the roadway network. The French DOT hopes to resolve this problem with in-vehicle two-way communication devices using CARMINAT or similar products.

3. Previous Studies

While several urban corridors in various countries utilize variable message signs (VMSs) as a means of traffic advisory and incident management, little is known about the extent to which VMSs influence travel behavior. Recently, several studies have attempted to quantify the effects of VMSs on diversion behavior. The findings of such recent studies are summarized in this section.

3.1 Overview of Recent VMS Studies

SIRIUS is the most extensive deployment of VMSs in Europe, even though the City of Amsterdam and some parts of London are well equipped with roadside traveler information systems. In the U.S., the northern *36* miles of the New Jersey Turnpike has the most extensive application of VMSs. The system on the Santa Monica Freeway in Los Angeles is part of the Smart Corridor field operational test currently under evaluation. Other VMS projects are listed in Table **3.1.**

Studies of VMSs are generally grouped into four areas of research: 1) system characteristics; *2)* operational characteristics; 3) public opinion; and 4) travel behavior. Research on system characteristics deals generally with sign types, the number of messages, the physical characteristics of signs, the interconnection elements of signs, and the surveillance and control of signs. The operational aspects of the study include the information types, location of signs, and display of signs. **A** large body of literature exists on the system and operational characteristics of VMSs. **A** few studies have recently addressed public opinion concerns pertaining to the use of VMSs and to travel behavior. Table 1 in Appendix I summarizes the subjects covered in VMS research.

The INFORM evaluation study of the Long Island Expressway is one of the recent research efforts to deal with the impact VMSs on diversion behavior. Considering that many factors influence diversion choices, the study could not predict the precise number of vehicles diverted on a given day. The survey of motorists, however, indicated that one-half of the sample population responded to VMSs in order to avoid congestion. The study concluded that VMSs will definitely improve travel conditions on the

Long Island Freeway Corridor; even with low diversion percentages, it will be possible to increase throughput.

The earlier studies of the ADVICE system in Melbourne, Australia (Tryford, et al., 1988) and the Ontario system in Toronto, Canada (Smiley and Dewar, 1988) reached similar conclusions. Although the estimated benefits of VMS varied significantly among the studies conducted, the general consensus is that drivers respond to traffic advice and VMSs are effective in incident management and traffic advice. The studies of motorists in Melbourne indicated that drivers preferred road signs (54%) as opposed to radio (35%) or in-vehicle devices (11%). Over 70% of the respondents said that they modified their driving according to travel advice such as reducing speed according to speed advice or taking alternate routes to avoid congestion. Since the installation of ADVISE, the number of accidents has been reduced by 25% in the daytime and by 50% in the evening. Comparative findings of the previous studies are listed in Table **3.2.**

These studies also suggest that VMSs should be located upstream of bottlenecks and high accident areas to allow drivers to make diversion decisions in advance and messages should be displayed when unusual conditions occur (Dudek and Huchingson, 1986; Armstrong and Upchurch, 1990). All studies agreed that VMSs were favorably received by those who responded to the surveys. The public perception of VMSs **is** consistent among the motorists surveyed in Australia, Canada, France, and the U.S. The opinion is that the roadside advisory information will assist drivers in avoiding congestion and thus in reducing travel time.

However, the benefits of roadside advisory information varied widely among the studies. The ADVISE project in Australia estimated that VMSs would result in a benefit-to-cost ratio of 20 to 1; the accident rate would be reduced by 25% and the project would result in an annual operating cost savings of $750 million. The INFORM project in the **U.S.** is estimated to result in a benefit-to-cost ratio of **3** to 1, a 5% reduction in accidents, and an annual operating cost savings of $4.5 million. The disagreement between the research findings may be due to differences in culture, environment, lifestyle, and driving habits, **as** well as in the design of the VMSs, including the message content and comprehensibility.

Table 3.1 Freeways Using of Variable Message Signs

Location	Freeway
U.S.A.	
California	(Smart Corridor) Santa Monica Freeway
Colorado	1-70, US-36, I-25 (2 signs)
Minnesota	1-35
New Jersey	New Jersey Turnpike
New York	(INFORM) **Long** Island Expressway, 1-495 (72 signs)
Ohio	I-75, I-71 in Cincinnati (19 signs)
Pennsylvania	1-279 near Pittsburgh
Texas	Skillman Ave, N. Central Expressway in Dallas
CANADA	
Ontario	Highway 40 1 in Toronto
AUSTRALIA	
Melbourne	**(ADVISE)** Canterbury Road
FRANCE	
Paris	(SIRIUS) expressways **of** Ile de France (174 signs)

Table 3.2 Travel Behavior and Variable Message Signs

	ADVISE	INFORM	SIRIUS	Dallas	Ontario	Smart Corridor
Diversion behavior	49%	50%	70%	71-85%		
VMS favored:	77%		80%		69	
VMS use:						
Traffic information	77%					
Speed information	73%					
Distance information	**50%**					
Effectiveness:						
Benefit/cost	20:1	3:1				
Accidents	25-50%R	5%R				**17%R**
Delay savings		300vh/y/v				
Travel time		13-20%down				
Fuel savings	3-4%R					
Cost:capital		$35mil				
operating	$750mil/y	$4.5mil/y				

Legend:

R = reduction

vh/y/v = vehicle hour per year per vehicle

mil = million

mil/y = million per year

The above findings are based **on** motorists surveys. Note that the findings are stated responses.

3.2 Surveys of Motorists in the Paris Region

As stated earlier, the goal of **SIRIUS** is to modify individual drivers' behavior so that existing roadways can be utilized more efficiently. Previous studies demonstrated that not only **will** the accuracy of the information influence driver behavior, but the manner in which it is provided will also influence the way drivers respond to the information (Commission of the European Community Council, 1992). To understand the user requirements of the VMSs, the French National Department of Transportation (DOT) conducted traveler surveys in the Paris region. In May 1992, a mail survey was distributed among Paris area motorists for the sample size of 8,000. **A** follow-up telephone survey was conducted shortly thereafter with 100 participants. The surveys focused primarily on gathering information about the cognitive ability of motorists for comprehension and interpretation of roadside messages. Based on the findings of these surveys, VMSs were designed and installed at locations which allowed drivers to make diversion decisions in advance of reaching congestion areas.

The survey results considered for the design of the VMSs are as follows (Durand-Raucher, et al., 1993):

1) The majority of motorists can comprehend symbolized messages and 95% of the respondents were able to interpret messages adequately. The most difficult symbol to understand was "BP," which stands for Boulevard Peripherique, the beltway that wraps around the City of Paris.

2) The **high** mileage drivers who drove the Paris region frequently had fairly good cognitive understanding of the regional roadway network.

3) A strong correlation exists between the ability to comprehend messages and the perceived benefits to drivers in reduced travel time and improved driving conditions.

4) Motorists in the Paris region were well aware of the SIRIUS project. The vast majority of the follow-up survey participants (95%) indicated that they were aware of the system and 70% of those believe that roadside information would be "very useful." 80% said that they would be disappointed if the **SIRIUS** system were never implemented.

5) The survey suggests that motorists would respond to traveler information. Over 70% of the drivers surveyed indicated that they would divert if they learned about traffic congestion ahead of time. **35%** said that they actually change their itinerary "often" and 75% said that they change their itinerary "from time to time" to avoid congestion.

6) One third of the drivers who are accustomed to a given route had sufficient knowledge of the roadway network in the area where they travel and actually understood the messages correctly. These drivers **are** the primary target group of the SIRIUS program.

The surveys also suggest that VMSs would have a positive impact both on drivers who take alternate routes and also those who stick to their original itinerary. The motorists surveyed believed that they can benefit fiom **SIRIUS** in: 1) increased driving comfort; **2)** improved traffic conditions; and **3)** enhanced safety.

The most important finding of the surveys was that VMSs would influence diversion decisions. Performance evaluation of the **SIRIUS** project will be an on-going effort over the next three years. Further research includes a thorough quantitative analysis of traffic diversion patterns in the region and evaluations on the learning curve of both the technicians who operate the system and the drivers who become acquainted with the roadside information service. Credibility of the SIRIUS program, on which drivers will have to rely progressively, is essential to system performance; thus, driver response studies are scheduled to be completed over the duration of the field operational test. Based on the initial studies of driver response to VMSs, research on diversion behavior of drivers with in-vehicle two-way communication devices is planned. The traveler response study using **CARMINAT** was planned to be conducted in the early part of 1994 with a fleet of about 500 specially-equipped vehicles.

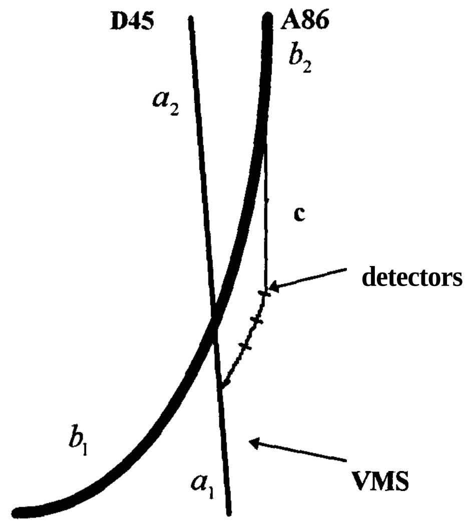
4. Methodology

Based on the traveler survey results, the French DOT estimates that the vast majority of motorists would **use** roadside traffic information and at least 50% of vehicles would divert given the choice between congested and free flowing links. Given the choice between two congested links, it is estimated that **3** to 5% of motorists would divert to the lesser congested link when comparative information was provided on these links. The research interest of the French DOT is to measure the revealed changes in link flow by using loop detector data. One of the technical challenges of the SIRIUS evaluation study is to estimate the actual number of vehicles which responded to VMSs using the minimal amount of traffic data which is available. **As** experienced in many European and North American cities, historical traffic data in the Paris region are generally unavailable for comparison of the ***before*** and ***after*** effects of VMSs. Even after the installation of VMSs, traffic data were taken at one link as opposed to being taken at all links affected by VMSs. In this paper, we explored several methods that can be employed to measure the shift of link flow using post VMS traffic data taken at a given location on a single link. This section presents the data analysis approach that was taken to estimate the traffic shift from **A86** to D45.

4.1 Geometric Configuration of the Selected Link

Under SIRIUS, VMSs are placed at locations where three types of diversion decisions can be made: a) from one freeway to another freeway; b) from a freeway to a local street via an egress ramp; and c) from a local street to a freeway via an access ramp. It is assumed that diversion behavior under these geometric configurations will differ and that each configuration will present different methodological problems for data analysis. The selected link for this study falls into the third category where motorists can make a choice either to stay on the arterial road D45 to avoid congestion or to take **A86** via the access ramp (Figure 4.1).

Figure 4.1 Roadway Configuration of the Study Site



With respect to the above configuration, the research interest was to understand the probability of those vehicles that responded to various types of messages displayed on the VMS. According to the stated preference shown in the motorist surveys of 1992 (Durand-Raucher, et al., 1993), the probability of drivers who would respond to VMSs is as high as 0.5; nonetheless, it is speculated that this figure is higher than the actual number of vehicles which would respond to VMSs. Previous studies showed that the revealed preference responses (drivers who actually took alternate routes with traffic information) were lower than the stated preference responses (drivers who said they would take alternate routes). In this paper, an attempt was made to estimate the proportion of those vehicles stayed on **D45** to avoid congestion on **A86** in responce to the **VMS.**

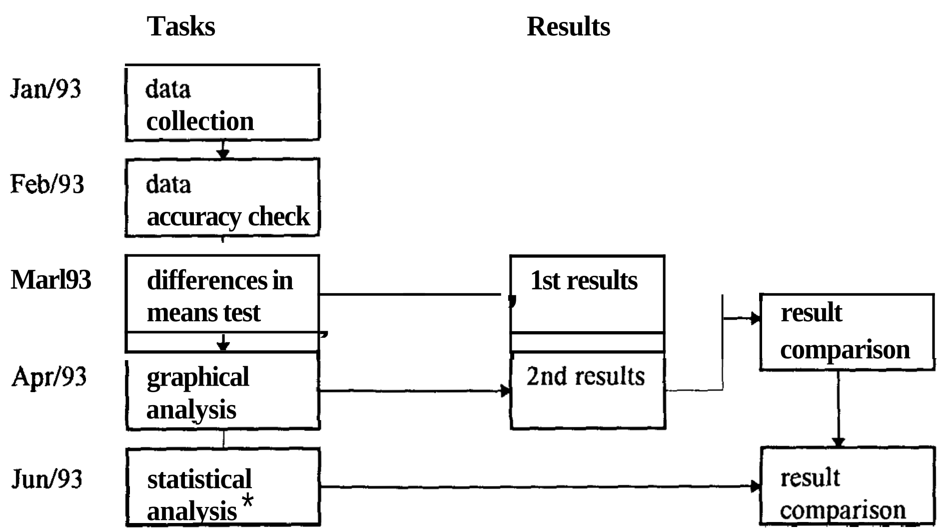
4.3 Method of Data Analysis

The traffic data available for conducting the SIRIUS evaluation at the study site were fi-om the access ramp connecting **D45** to A86. On this ramp, three loop detectors are placed 500 meters apart; the first and the third stations with a single loop detector and the second station with a double loop detector. The data on this ramp consist of vehicle counts, speed, and density recorded at 20-second intervals.

The results reported in this paper are derived from these loop detector data. The sample size of **86** observations were collected over a three-month period fi-om February to April 1993.

Two methods were employed for loop detector data analysis of the study site; a statistical method using the differences in means test and a graphical method using cumulative arrival curves (Figure **4.2).** The results of the data analysis using the statistical method were compared with the results obtained using the graphical method. These results were then compared with an independent experiment conducted by the French DOT using a new set of traffic data taken fi-om the same loop detectors by turning on the **VMS** for 5 minutes and then turning the **VMS** off for 5 minutes (Appendix 2). The sample size of this experiment was **74** observations.

Figure 4.2 Process of Data Analysis

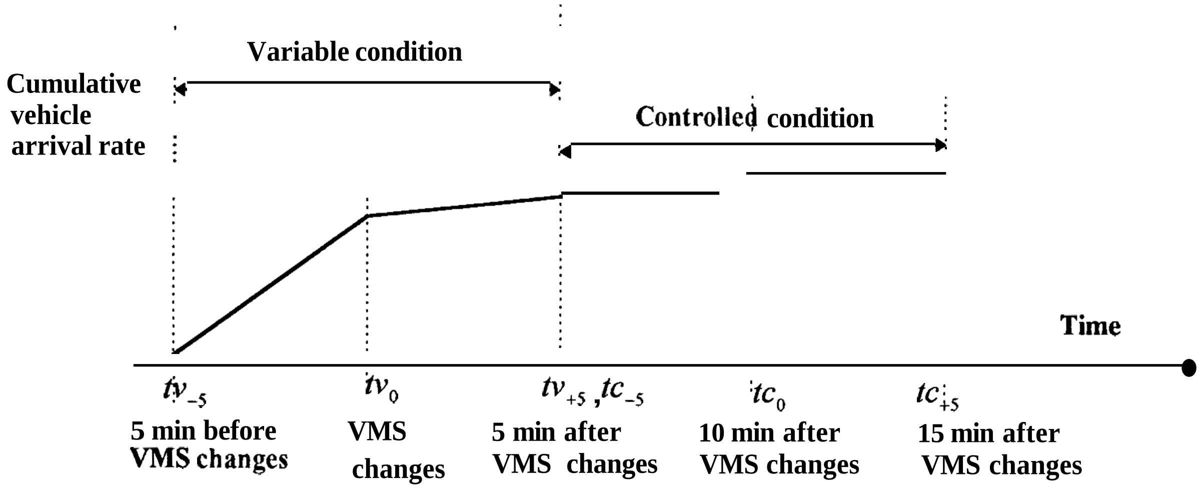


* **Analysis using data from the** VMS **on-and-off experiment**

For the statistical analysis, the data were examined under both short- and long-term conditions. The short-term condition refers to the evolution of traffic flow, either an increase or a decrease, which takes place during the ***5*** minute period after the message changes. This state of evolution was called 'Gariable condition." The long-term condition refers to the evolution of traffic flow, either an increase or a decrease, which takes place during a 10-minute period following the 5 minute period after the message changes. This state of evolution was called 'controlled condition." The purpose of examining data under these conditions is to detect the changes in link flow that might be precipitated by

VMSs under variable conditions. Examining data under controlled conditions, on the other hand, would provide information to detect variations in flow patterns that might be influenced by factors other than the **VMSs.**

Figure 4.3. Variable and Controlled Conditions



5. Results of Data Analysis

This section presents the results of the data analysis using both statistical and graphical methods. The results include the differences in means test and the analysis of vehicle arrival curves on the access ramp to **A86** under the different types of messages. The **VMS** at the study site displays queue length information, in one kilometer increments for the most part, to indicate the freeway level of congestion. In addition, this **VMS** provides information on the 0.5 km queue when it changes fiom ***free flow*** conditions to the initial increment of ***congestion.***

As stated earlier, our research questions were: 1) Is there a significant change in link flow after the messages change; ***2)*** Is there a variation in link flow under different messages because motorists respond differently to different types of messages; and *3)* What is the probability that traffic flow is influenced by VMSs under 1 km, 2 km, *3* km, and 4 km queue lengths? The differences in means test was employed to answer the first question and to partially answer the second question. The graphical method was used to answer the second and third question.

5.1. Statistical Analysis

The conjecture was that some drivers would stay on **D45** instead of taking **A86** in order to avoid traffic congestion on **A86.** Therefore, the traffic flow rate on the **A86** access ramp immediately after the message sign changed would be different fiom the flow rate before the message sign changed. If all things are equal, we would expect a decrease in flow rate on this access ramp immediately after the sign changed to indicate a greater level of congestion on **A86.** Conversely, we would also expect an increase in flow rate on the ramp when the sign changed to indicate a lesser degree of congestion on **A86.** That is to say that the changes in flow rate with the use of a **VMS** are statistically different fiom the changes typically shown under normative traffic flow conditions. Hence, two null hypotheses were constructed: the first (H_{0_1}) being that the mean traffic flow rate on the ramp during the five minutes before the message changes and the mean flow rate during the five minutes after the message changes are equal and the second $(H,)$ being that the mean traffic flow rate on the ramp between 5 to 10 minutes after the message changes is equal to the mean flow rate between 10 to 15 minutes after the message changes.

$H_{0_1}: \quad \bar{q}_{tv_{-5}} = \bar{q}_{tv_{+5}}, \qquad H_{0_2}: \quad \bar{q}_{tc_{-5}} = \bar{q}_{tc_{+5}}$

$$\bar{q}_{tv_{-5}} = \frac{N_{tv_{-5}}}{T}, \qquad \bar{q}_{tv_{+5}} = \frac{N_{tv_{+5}}}{T} \tag{5.1}$$

$$\bar{q}_{tc_{-5}} = \frac{N_{tc_{-5}}}{T}, \qquad \bar{q}_{tc_{+5}} = \frac{N_{tc_{+5}}}{T} \tag{5.2}$$

where

$\bar{q}_{tv_{-5}}$ = mean flow rate during **5** miutes before message changes
$\bar{q}_{tv_{+5}}$ = mean flow rate during **5** minutes after message changes
$\bar{q}_{tc_{-5}}$ = mean flow rate during **5** – 10minutes after message changes
$\bar{q}_{tc_{+5}}$ = mean flow rate during 10 – 15minutes after message changes
$N_{tv_{-5}}$ = the number of vehicles passed loop detectorsduring **5** minutes before message changes
$N_{tv_{+5}}$ = the number of vehicles passed loop detectors during **5** minutes after message changes
$N_{tc_{-5}}$ = the number of vehicles passed loop detectors during **5** – 10minutes after message changes
$N_{tc_{+5}}$ = the number of vehicles passed loop detectors during 10 – 15minutes after message changes
T_t = elapsed time, $\frac{1}{12}$ hour after message changes

a) Results of variable condition:

The differences in means test showed that when the message changed to indicate increased traffic congestion on A86 the mean flow rate on the ramp during the 5 minutes afier the message changed decreased by 3.68%. The t-test for paired samples using the mean traffic rate during the 5 minutes before and the 5 minutes after the message changed showed some statistical evidence of a significant variation in means at a 90% confidence interval. Therefore, the first null hypothesis (H_{0_1}) was rejected.

Table 5.1. Results of the Differences in Means Test Under Variable Conditions

Mean traffic flow rate 5 minutes before message changed	123.95 vehicles per 5 minutes
Mean traffic flow rate 5 minutes after message changed	119.38 vehicles per 5 minutes
Mean value of paired difference	- 4.57
t-value	-1.73
df	48
2-tail Significance	0.09

The differences in means test, however, showed that when the message changed to indicate a decreased level of congestion on A86, no significant difference in means existed before and after the message changed. This is largely due to the fact that the actual flow rate stabilized when the message changed to indicate a shift from heavy to light congestion. This suggests that the demand level on the ramp is relative to the demand level on A86; thus, the vehicle arrival rate at the ramp decreases as the queue on A86 vanishes.

The differences in means test showed that the level of decrease in flow rate on the access ramp is also a function of the freeway level of congestion indicated on the VMS. This is true in the case of increasing congestion and also in the case of decreasing congestion (Figures 5.1 and 5.2). A message indicating a queue length of 3 km or longer on A86 appears to significantly influence diversion decisions and a 3 km queue length seems to be a threshold where the diverting strategies become most evident.

b) Results of controlled condition:

Using the data under controlled conditions, the differences in means test was performed with two sub-groups; vehicles that passed the loop detectors between 5 to 10 minutes ($\bar{q}_{tc_{-5}}$) after the message changed and the vehicles that passed the loop detectors between 10 to 15 minutes ($\bar{q}_{tc_{+5}}$) after the message changed. The differences in means test showed that there was no significant differences in means between the two sets of data. When the message indicated increased congestion, the flow rate on the ramp also increased under the controlled condition. The flow rate on the ramp decreased when the message indicated a decrease in congestion under the controlled condition (Figures 5.3 and 5.4). Therefore, the second null hypothesis (H_{0_2}) was accepted.

Figure 5.1. Differences in Mean Flow Rate Under Variable Conditions when signs changed to indicate an increased level of congestion

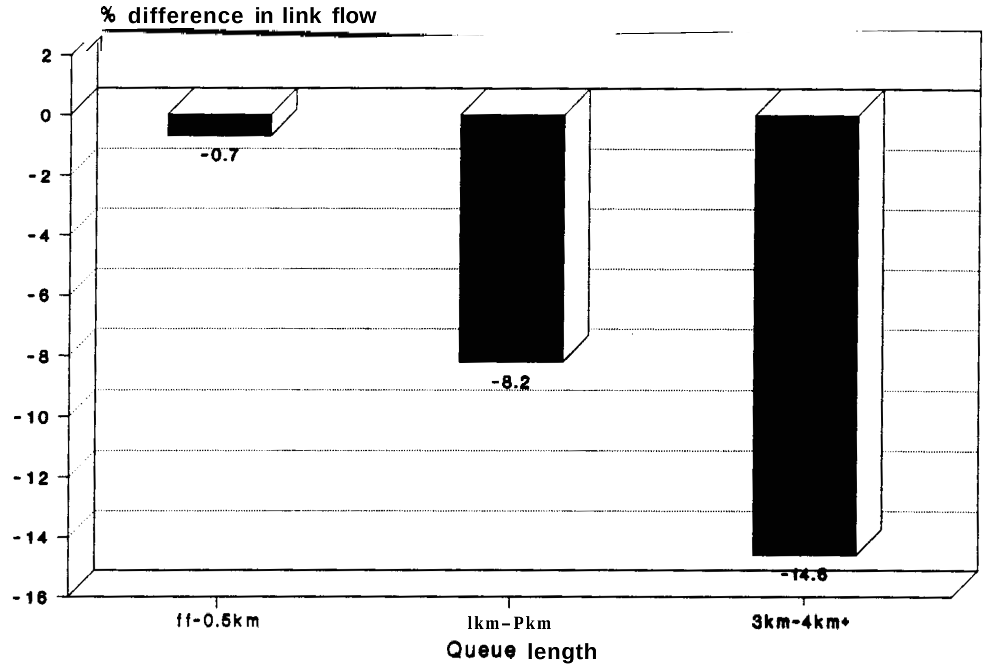


Figure 5.2. Differences in Mean Flow Rate Under Variable Conditions when signs changed to indicate a decreased level of congestion

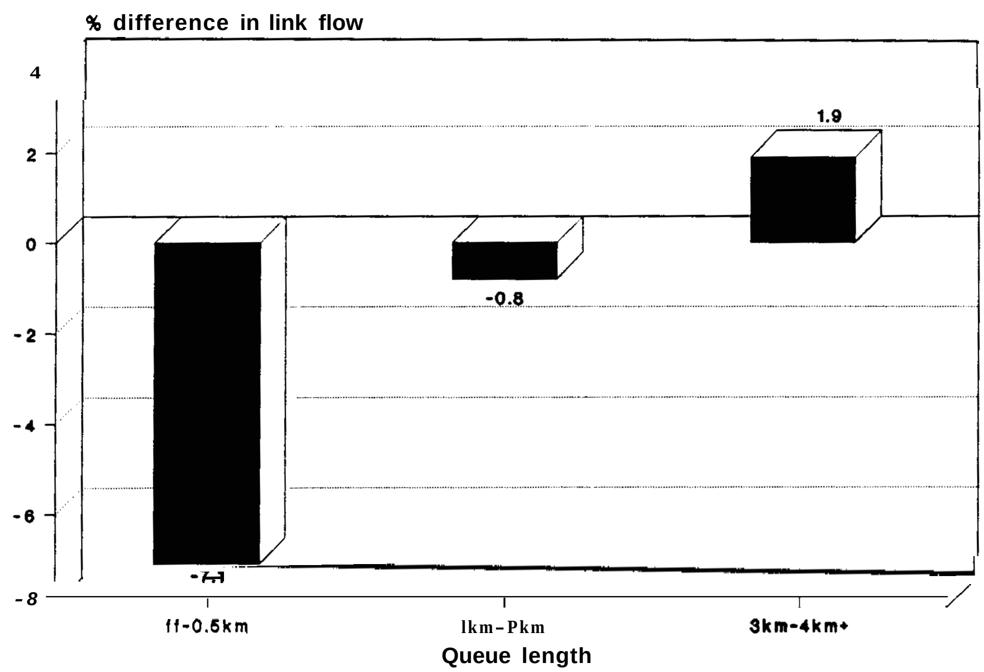


Figure 5.3. Differences in Mean Flow Rate Under Controlled Conditions when signs changed to indicated an increased level of congestion

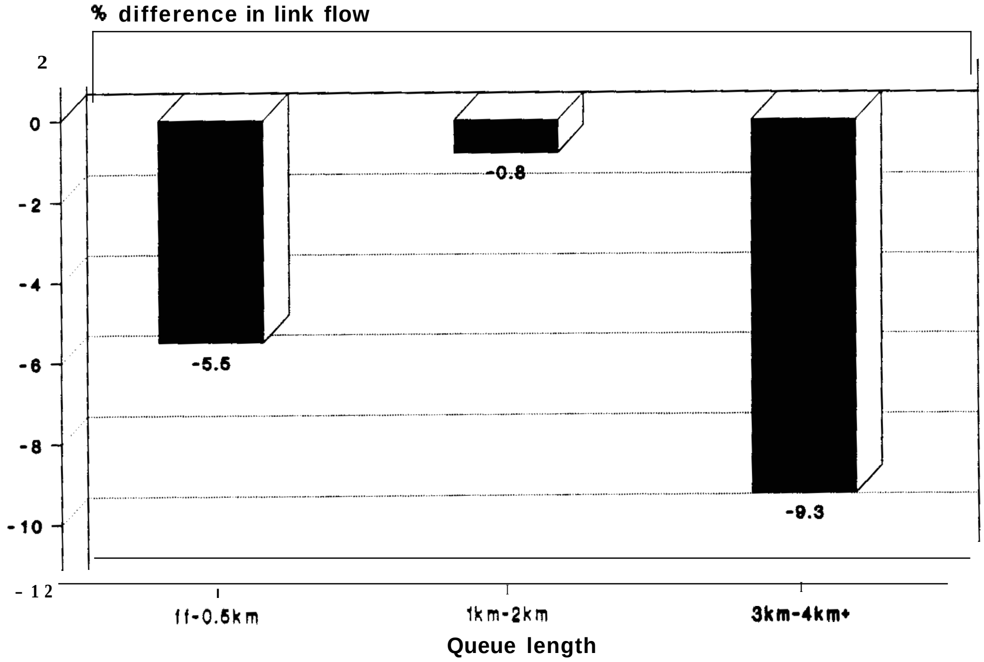
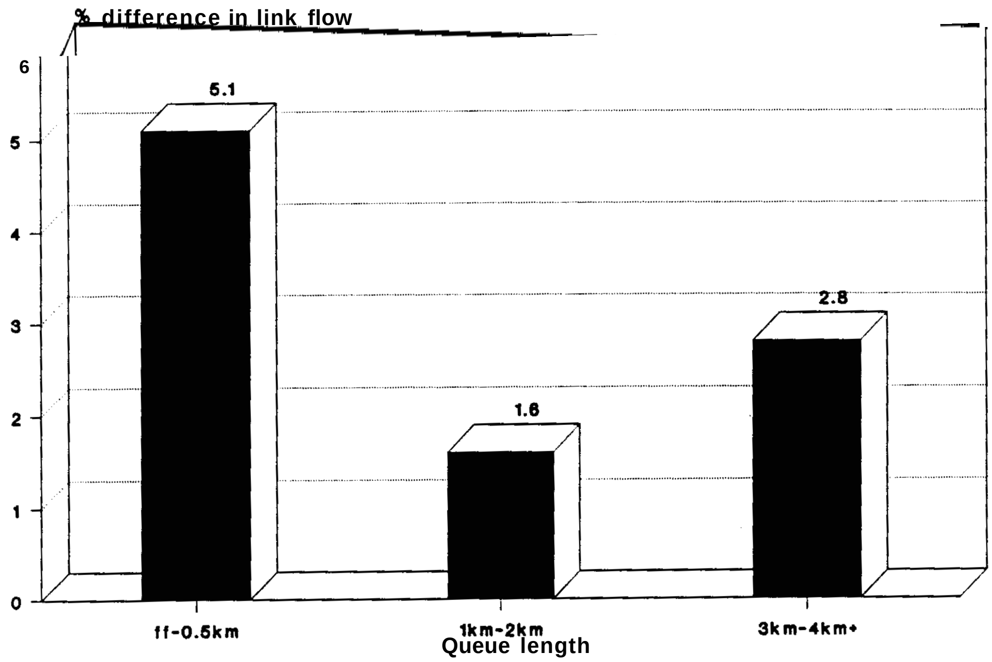


Figure 5.4. Differences in Mean Flow Rate Under Controlled Conditions when signs changed to indicate a decreased level of congestion



5.2. Cumulative Arrival Curves

To trace link flow behavior over time, cumulative arrival curves, A(t), were examined over a 20-minute period 5 minutes before and 15 minutes following a message change. Figure **5.4** shows the average cumulative number of arrivals in one minute intervals under variable conditions with different messages during morning peak hours. The curves shown in this figure are arrival curves, $\lambda(t)$, for messages indicating different levels of congestion. $\lambda(t)$ for each message type, indicated in queue length, is obtained by approximation to a smooth function of an average arrival, $\langle A^{(j)}(t)\rangle$, where j represents different days when data were taken. Assuming that the ramp can accommodate a constant average arrival rate μ when busy, equivalent to a service capacity of ***30*** vehicles per minute, $\lambda(t)$ can be evaluated with respect to μ. The data indicated that $\lambda(t) \approx \mu$ when the message indicated a queue length of 0.5 kilometers and $\lambda(t) < \mu$ when the message indicated a queue length of 1 km or greater. The traffic flow data also suggest that $\lambda(t)$ is a function of the congestion level indicated on the VMS. $\lambda(t)$ is significantly below μ when the message indicated a change to a queue length of ***3*** kilometers or greater. The results shown below are $\lambda(t)$ with different messages for **an** increased level of congestion during morning peak hours.

When the **VMS** indicated a queue length of 0.5 km, the average arrival curve $\lambda(t)_{0.5}$ is:

$$\lambda(t)_{0.5} = \begin{cases} 32 + 23.07t & -5 < t < 0 \\ 178.33 + 24.87t & t > 0 \end{cases}$$

When the **VMS** indicated a queue length of 1 km, the average arrival curve $\lambda(t)_1$ is:

$$\lambda(t)_1 = \begin{cases} 27.5 + 21t & -5 < t < 0 \\ 163.25 + 22.9t & t > 0 \end{cases}$$

When the VMS indicated a queue length of ***2*** km, the arrival curve $\lambda(t)_2$ is:

$$\lambda(t)_2 = \begin{cases} 25.25 + 22.78t & -5 < t < 0 \\ 166.88 + 19.77t & t > 0 \end{cases}$$

When the VMS indicated a queue length of 3 km, the average arrival curve $\lambda(t)_3$ is:

$$\lambda(t)_3 = \begin{cases} 31 + 20.5t & -5 < t < 0 \\ 154 + 19.7t & t > 0 \end{cases}$$

When the VMS indicated a queue length of 4 km, the average arrival curve $\lambda(t)_4$ is:

$$\lambda(t)_4 = \begin{cases} 18 + 18.6t & -5 < t < 0 \\ 141 + 12.8t & t > 0 \end{cases}$$

To detect variations in arrival rates under the same message, $\lambda(t)$ under the "controlled conditions" was also evaluated and compared with $\lambda(t)$ under the "variable conditions." The traffic flow data indicated that $\lambda(t)$ was relatively constant under the "controlled conditions."

Figure 5.5 illustrates a decrease in the arrival rate on the access ramp with respect to the increased level of congestion on A86 during evening peak hours.

Figure 5.5. AM Traffic Cumulative Arrivals
when the VMS indicated an increased level of congestion

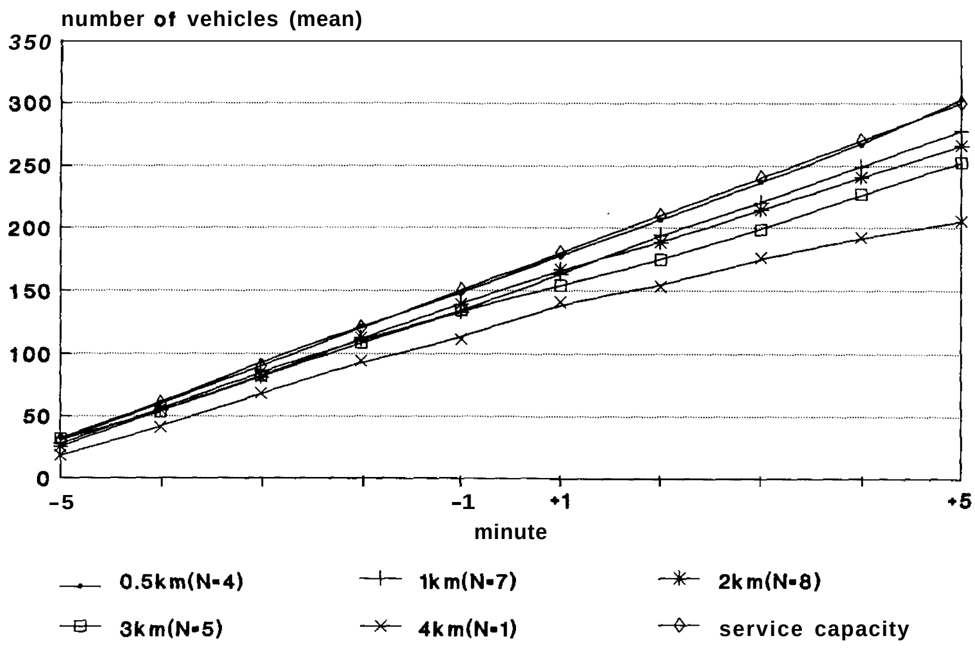
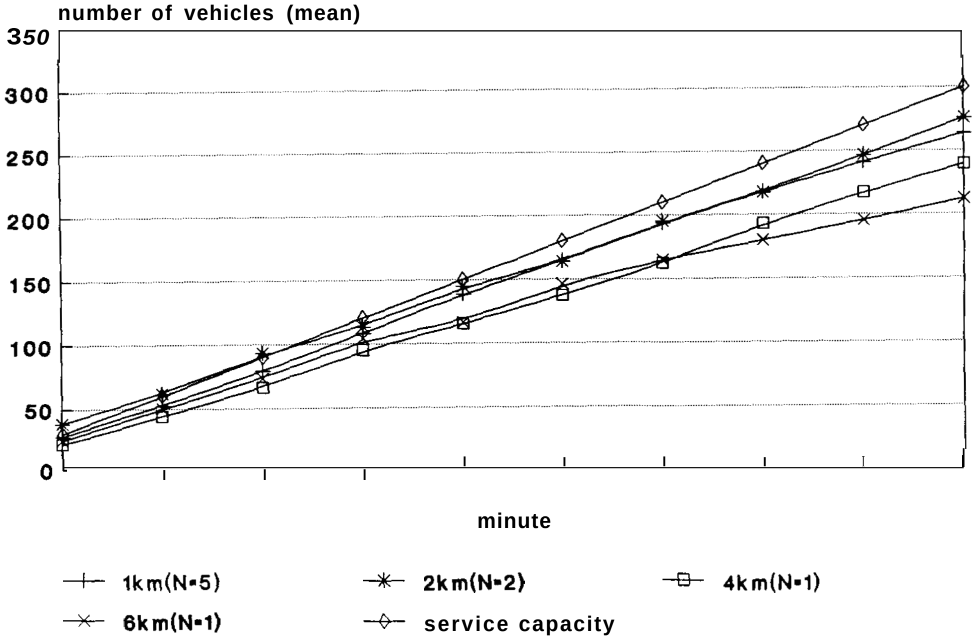


Figure 5.6. PM Traffic Cumulative Arrivals
when the VMS indicated an increased level of congestion

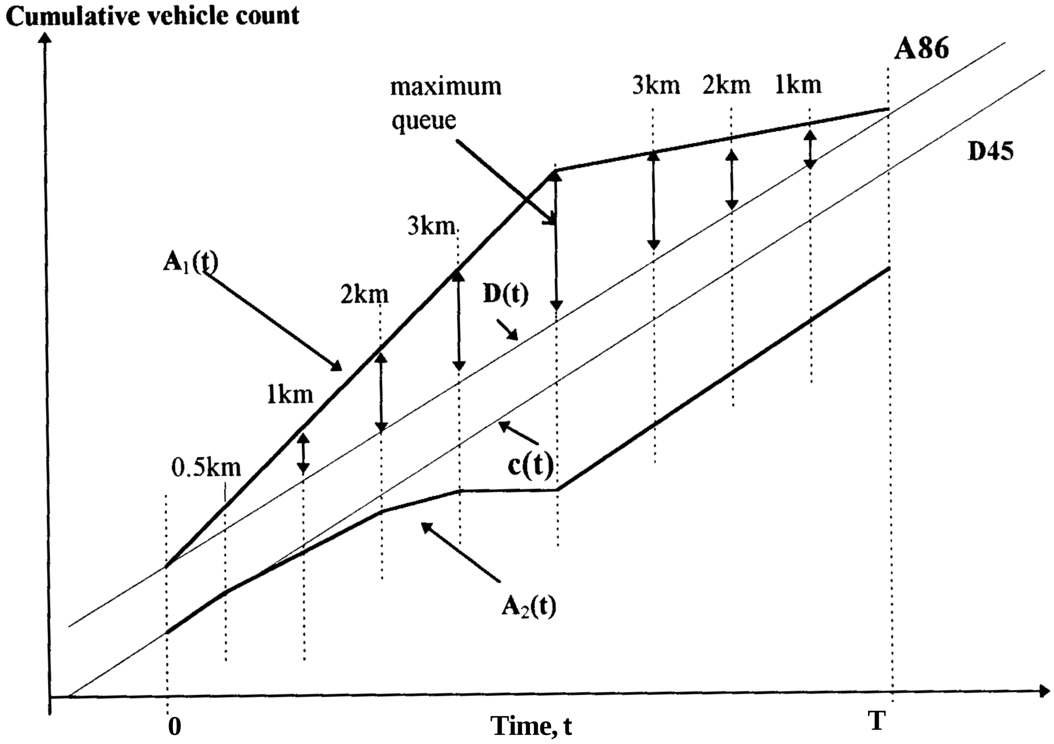


5.3 Relationship Between Queue Information and Link Flow

The above statistical and graphical analyses led to the assumption that flow rate on the access ramp to **A86** is relative to the flow rate on **A86. In** other words, if traffic on **A86** increases, it is expected that traffic on the access ramp and its parallel arterial street, D45, will also increase. VMSs, however, will alter link flow on **A86** and D45 depending on the type of message that is disseminated. The vehicle arrival rate on the access ramp will decrease as the message changes to indicate a higher freeway congestion level, i.e., from free flow conditions to a queue length of 1 kilometer **(km)**, from a 1 km to a **2** km queue, or from a **2** km to a **3** km queue, assuming that all other conditions remain constant. Conversely, the arrival rate on the access ramp will increase **as** the message changes to indicate a lower freeway congestion level. This effect, however, was not revealed in the differences in means test because the arrival rate on the access ramp was constant. The constant arrival rate in this case could mean that the increased number of vehicles wanting to take **A86** in response to the message displayed is approximately equal to the decreased number of vehicles arriving at the ramp due to reduced demand after the maximum peak time.

Based on the arrival curve analysis, the relationship of link flow between **A86** and D45 with queue information was developed and is shown in Figure 5.4. In this model, the ramp capacity is assumed to be fully utilized during peak hours and that the volume-to-capacity (v/c) ratio is 1. Figure 5.4 shows the average arrival curve with respect to queue information derived from loop detector data.

Figure 5.7. Relationship Between A86 and D45 in Vehicle Arrival Counts



$A_1(t)$ = Arrival curve on A86
$D(t)$ = Departure curve on A86
$A_2(t)$ = Arrival curve on D45
$C(t)$ = Service capacity curve on D45

With the assumption that the traffic flow on the ramp is relative to the queue length on **A86** and that all drivers were aware of the messages, the number of vehicles which responded to the messages by remaining on D45 at time t is:

$$V(t) = C(t) - A_2(t) \qquad \forall t \qquad (5.3)$$

The total traffic volume shift from **A86** to **D45** due to VMSs over the peak period between time 0 and T is the area between *c(t)* and $a_2(t)$.

$$V(t) = \int_0^T [c(t) - a_2(t)]dt \qquad (5.4)$$

With the a priori assumption that all peak hour conditions are similar and that if there is a queue on the ramp, vehicles would remain on **D45,** the probability that vehicles would not take **A86** (or remain on **D45)** given the increasing queue information is:

$$p_v(D_{45} / km) = \frac{c(t) - a_2(t)}{c(t)} \qquad (5.5)$$

The probability that drivers would take **A86** given the increasing queue information is:

$$p_v(A_{45} / km) = \frac{a_2(t)}{c(t)} \qquad (5.6)$$

Since

$$1 = \frac{c(t) - a_2(t)}{c(t)} + \frac{a_2(t)}{c(t)} \qquad (5.7)$$

The probability that drivers would not take **A86** given information regarding increases in queue length 1s:

$$p_v(D_{45} / \text{free flow - } 0.5km) = 0.01$$
$$p_v(D_{45} / \text{free flow - } 1\,km) = 0.07$$
$$p_v(D_{45} / 1km - 2\,km) = 0.11$$
$$p_v(D_{45} / 2km - 3\,km) = 0.17$$
$$p_v(D_{45} / 3km - 4\,km) = 0.31$$

In looking at the traffic behavior during morning peak hours when congestion was increasing, the information on the 0.5 km queue length had little or almost no effect on the link flow; it remained approximately at the maximum service capacity. However, when the message indicated a long queue length, the *v/c* ratio on the access ramp dropped significantly, The data fiom the French DOT experiment indicated that the *v/c* ratio on this ramp during peak hours without the use of a VMS was equal to or greater than 1.

During morning peak hours, when the VMS indicated a queue length of **3** km or greater, nearly 20% of the ramp traffic remained on D45 which otherwise might have used A86. The evening peak traffic flow showed similar trends but to a somewhat lesser degree when compared to the morning peak traffic.

The analysis of the link flow relationship suggests that VMSs most effectively influence traffic flow when congestion is increasing. When congestion is diminishing, their effect is not as significant. The preliminary analysis also indicated that the relationship between the diversion behavior and messages indicating increasing levels of congestion is approximately linear; as the queue length increases, the propensity to divert increases.

5.4. Comparison With the VMS Experiment

Between the second week of March and the last week of April 1993, a new set of data was collected using a different method; turning on the VMS for 5 minutes and then turning off the VMS for 5 minutes. The purpose of this experiment was to investigate the differences in flow rates with and without the use of a VMS. The results obtained fiom 74 observations are shown in Table 5.2.

The results of the experiment showed that flow rates were lower during the 5-minute period when the VMS indicated congestion on **A86** than during the 5-minute period when the VMS was turned off. The experiment also indicated that when the VMS indicated a queue length greater than **3** km, flow rates were lower as compared to the flow rates when the VMS indicated a lesser degree of congestion. According to the results of experiment, traffic shifts during morning peak hours were more apparent when compared with the shifts during evening peak hours.

Table 5.2. Results of the VMS Experiment under Variable Conditions

Traffic Condition on A86	Stat Term	With VMS on D45	Without VMS on D45	Total	Mean Differences	t-value
Congestion	$\bar{x}$ s N	45.9 9.3 37.0	47.0 8.6 37.0	46.4 9.0 74.0	-1.1 7.0 37.0	-0.739
Non-recurring congestion	$\bar{x}$ s N	47.4 8.6 32.0	48.7 6.9 32.0	48.0 7.8 64	-1.3 7.3 32.0	-0.925
Congestion >3 km queue length	$\bar{x}$ s N	50.0 7.0 25.0	51.6 4.1 25.0	50.8 5.8 50	**-1.6** 7.8 25.0	-1.182
Congestion during AM peak 7-9 AM	$\bar{x}$ s N	50.6 7.2 19.0	52.3 4.3 19.0	46.4 9.0 38	-1.7 8.3 19.0	-0.987
Congestion during PM peak 5-8 PM	$\bar{x}$ s N	40.8 8.7 18.0	41.3 8.5 18.0	41.1 *8.6* 36.0	-0.5 5.1 18.0	-0.130

$\bar{x}$ = mean vehicle arrival rate during the 5 minute period on the access ramp
N = number of obervations

6. Conclusions

The effects of variable message signs on link flow were investigated, using loop detector data on the access ramp to A86 from its parallel arterial road D45. Link flow data were analyzed mainly using t-test statistical techniques and arrival curve graphical methods. Despite some methodological limitations experienced in the analysis for obtaining quantitative measurements of vehicles actually diverted as a result of traffic information, the methods employed in this study were found to be useful, especially in obtaining qualitative assessments of traffic behavior for a given link. The study also found that the revealed diversion behavior was more conservative than the stated preference of those drivers who responded to the 1992 surveys in the Paris region.

The key findings of the study are that: 1) there is evidence indicating that VMSs alone can influence vehicle diversion; **2)** VMSs are most effective when the information is disseminated during periods of increasing congestion; 3) traffic response to VMSs during morning peak hours are more significant than during evening peak hours; **4)** there is a close relationship between diversion behavior and queue length information; the longer the queue length, the greater the number of vehicles which diverted; **5)** it is possible to measure the effects of VMSs on diversion behavior using traffic data fi-om a single link; and **6)** it is possible to measure the changes in link flow patterns without using data collected prior to the installation of a **VMS.** The comparative analysis between the link flow data using the continuous dissemination of traffic information and the flow data using intermittent displays of information showed little difference in link flow behavior on the access ramp to **A86.**

According to the data analysis using the continuous dissemination of queue information on A86, the flow rate was closely associated with traffic information regarding congestion level. The statistical analysis showed that a queue length of **3** km seems to be a threshold at which a significant number of drivers responded to the VMS. . The graphical analysis showed that with a message indicating a **4** km queue, the traffic flow on the access ramp reduced to 30% below capacity. With a message indicating a **3** km queue, flow was reduced to 15% below capacity. Flow was reduced to 10% below capacity with a message indicating a **2** km queue. Flow was reduced to **7%** below capacity with a message indicating a 1 km queue. VMSs had almost no effect on the flow rate when the message indicated a 0.5 km queue.

This study was the first attempt to measure the effectiveness of VMSs on traffic behavior for the **SIRIUS** program. The **SIRIUS** project consists of a three year field operational test program to evaluate the effectiveness of VMSs. On-going projects include verification of the results presented in this paper by increasing the sample size for statistical validity and the experimental study of traffic behavior with signs turned on and off intermittently to verify the results reported in this paper.

The ideal **links** in the Paris region identified for diversion behavior research include Autoroutes A6 and A3, Autoroutes A10 and N118, and Autoroutes A1 and A3. By the end of 1993, VMSs will be installed at these sites. The validity of the methods used in this paper may be determined, should **similar** studies conducted on other links in the region support the findings of this study. Once the SIRIUS system is completed at the end of 1994, the net effects of VMSs can be measured on a region-wide basis.

Appendix 1. Summary of Previous Studies

Appendix 1 reports on variable message sign (VMS) studies conducted in the U.S., Canada, and Australia. VMS research topics are listed in Table 1. The findings of these research studies are also reported in this appendix.

Table A1. VMS Research Topics

1. System Characteristics a) Sign type: Lamp matrix, disk matrix, drum, neon (Relative attention-getting and legibility characteristics **of** these are not fully known.) b) **Number of** messages: 25-100 programmed messages c) Physical characteristics **of** signs: Static **or** variable lines Size **of** signs **(1** cm letter height/6 meter distance **for** legibility) d) Interconnection to signs: Telephone Coaxial cable Cable and radio band e) Surveillance and control signs: Detectors Police patrol CCTV Operator push-button control Automatic computer control and manual override
2. Operational Characteristics a) Information type: Advisory signs Guide signs Advance signs b) Location **of** signs: Effectiveness **of** sign location c) Display **of** signs: When ***to*** display signs
3. Public Opinion in the US, Canada, and Australia **a)** Perception **of** variable message signs b) Interest in using the system
4. Travel Behavior and VMS Usage a) Use **of** variable message signs b) Response to variable message signs c) Diversion behavior

Findings of Previous Studies:

ADVISE DYNAMIC SIGNS (Melbourne, Australia, 1988)

ADVISE (Advisory Display of Variable Information for Speed and Economy) is a dynamic driver-information system using VMSs. Driver information includes optimum through speed, prepare to stop warnings, speed tolerance limits, and look-ahead distance for traffic conditions. The system was installed on Canterbury Road. One year after the ADVISE system was installed, an evaluation study was conducted to test the effectiveness of the system in terms of fuel savings and safety improvements using the survey research method.

Operational Characteristics:

The display information comes from a short-term database of traffic signal timings held in the ADVISE computer. The display information is derived from real-time data sent from the regional traffic management computer. Based on the real-time traffic data, future signal timings and queue lengths are calculated at each segment of Canterbury Road. The regional computer is part of the Roads Corporation of Victoria Signal CO-ordination of Regional Areas of Melbourne system.

To assess driver responses to VMSs, attitude surveys were conducted in 1988 among households living in the suburbs surrounding Canterbury Road in Melbourne, Australia. Two surveys were conducted; a telephone survey of 800 households and a detailed survey of 300 drivers from within these households.

Findings:

The majority of survey participants (77%) favored ADVISE. They preferred road signs (54%) as opposed to radio (35%) or in-vehicle devices (1 1%). In terms of the use of information, 77% replied that they had used the traffic intensity information and claimed that the information was of value. Regarding speed information, 73% indicated that they had changed their driving in response to the information and **42%** indicated that they drove more carefully. Demand on driver information was slightly higher in moderate traffic conditions (71%) than in heavy (50%) or light **(63%)** conditions. The VMSs helped reduce the number of stops (69%). Although the majority of drivers (61%) said they did not speed up in response to the speed reduction advice sign, 14% said they did speed up contrary to such advice; 90% responded that they valued the speed advice.

The distance information was used by the half of the respondents. Since the installation of the ADVISE system, fuel consumption has been reduced by 3 to **4%,** although driving speed has remained about the same. Stops have decreased, but travel time is unchanged. There has been an increase of road usage since the installation of the system.

Accidents are shown to be significantly fewer than before (tow truck calls have been reduced by 25% and calls in the daytime and in the evening have been reduced by almost half). Community cost savings from ADVISE, taking into account the fuel, maintenance and accident call figures, show a benefit-to-cost ratio of over **20:**1.

<u>THE ONTARIO SYSTEM - CHANGEABLE MESSAGE SIGNS</u>
(A DRIVER PREFERENCE SURVEY, 1988)

As a part of the Freeway Traffic Management System of Ontario, VMSs were implemented on Highway 401 in Toronto. To ascertain the kind of messages drivers preferred for describing traffic incidents on the highway, a motorists preference study was conducted using the survey research method. The sample size was 539 motorists.

<u>Findings</u>:

General response to VMSs is positive; 69% of the respondents said that VMS is a good idea. Only 18% of the respondents expressed concerns regarding the cost of VMS, whether or not tax payers would want them, and the reliability of the information. 11% responded negatively to VMS and suggested that the use of VMSs should be minimized.

In describing traffic conditions, the most preferred message was HEAVY CONGESTION and the second most preferred was TRAFFIC SLOWDOWN. In accident situations, the most preferred messages were MAJOR ACCIDENT AHEAD, LEFT 2 LANES LOCKED or MAJOR ACCIDENT AHEAD, 1 KM BEFORE AVENUE ROAD. Information on delay was not desired at all.

For traffic congestion information, in the case of heavy congestion, the most preferred message was HEAVY CONGESTION, NEXT 3 KM and the second most preferred was using speed descriptors, SPEED 20-40 KM/H, NEXT 3 KM. In the cases of moderate congestion and minor congestion, the most preferred messages were MODERATE CONGESTION and MINOR CONGESTION, respectively. The second most preferred was the use of speed descriptors.

In describing rush hour traffic, the most preferred messages were RUSH HOUR CONDITIONS AHEAD NEXT 5 KM or NORMAL TRAFFIC NEXT 5 KM. Blank signs (no messages) or time and weather messages were least preferred. Most respondents wanted real-time traffic information. They preferred delay warnings 2 to 3 km and 4 to 5 km in advance of the traffic problem.

In responding to diversionary and advisory messages, the greatest diversion occurred with messages indicating that either the collector or express lanes were closed. When messages HEAVY CONGESTION or MODERATE CONGESTION were displayed, drivers diverted to a similar extent as to messages indicating LANES CLOSED. Drivers also diverted in response to messages pertaining to a major accident or lanes blocked. More drivers diverted in response to messages indicating HEAVY CONGESTION AHEAD for long sections (10 km) than for short sections (3 km). Drivers did not differentiate between messages referring to moderate congestion and those referring to minor congestion. The message CONSTRUCTION AHEAD produced as much diversion as the message HEAVY CONGESTION CLEARS IN 10 KM, indicating that drivers perceive construction as being very disruptive to traffic. Although the message SPEED 20-40 KM/H suggests very slow traffic, much less diversion occurred for messages using speed indicators compared with the use of the message HEAVY CONGESTION.

When a message contained specific advice, such as REDUCE SPEED or TAKE THE COLLECTOR LANES, most drivers followed the advice. The message HEAVY CONGESTION, NEXT 3 KM was more correctly interpreted than speed indicator messages such as SPEED 30-40 KM/H.
The study also found that there was no correlation between sociological variables, i.e., sex, age, education, and preference or interpretation of signs. Suggested research questions include: can the messages be read quickly; are all abbreviations commonly understood; are all messages comprehensible to all drivers, particularly those with less than a high school education?

INFORM SYSTEM - Long Island Freewnv Corridor Study (1992)

INFORM (INformation FOR Motorists) is a corridor traffic management system located on Long Island in New York State. The corridor is approximately 56 km (35 miles) long. 2400 vehicle detectors provide data by which traffic flow characteristics are measured and calculated.

Operational Characteristics:

An operations facility for data processing and communications houses all of the data gathering, processing, and control equipment. **A** 24-hour staff is provided for 365 days each year. **64** ramp meter sites in initial operations have demonstrated a 13% reduction in travel time for metered motorists and a 20% reduction in travel time for non-metered motorists. For radio communications monitoring, INFORM operators monitor citizen band and police radio communications for incident verification and traffic management. INFORM controls 110 intersections in the corridor, intersections on Long Island expressway service arterial routes.

Variable Message Sign Operation:

The operational procedures for signing are based on human factors; a standing "Variable Message Sign" committee was formed by the New York State Department of Transportation. The type of information displayed on the signs **is** limited to what is approved in advance by the committee. The committee decided to withhold information pertaining to the nature of delays because of the possibility that motorists might elect to observe the incident rather than to divert. The experience showed that displaying NORMAL TRAFFIC CONDITION AHEAD was ineffective. They decided not to display this message because drivers were not clear as to the meaning of this message. However, a slight speed increase was observed immediately downstream of the sign. Furthermore, if signs are posted at all times, motorists may not react to important messages. In New York State, the message DELAY was used rather than CONGESTION because Long Island motorists were more familiar with the word DELAY. Therefore, signs had to be changed to DELAYS, **EXITS** 50-54 fi-om CONGESTION, **NEXT** 3 MILES.

Findings and Conclusions:

The use of VMSs can be an effective strategy to help alleviate traffic congestion. In the case of the Long Island corridor, a fi-eeway management system including VMSs can achieve the popularity needed to obtain government and public support necessary for installation and the continued operation and maintenance of the system.

The Long Island experience suggests that an integrated system can be used to automatically generate and display problem and location information to define delays. The use of automatic sign message generation is an aid to the system operator, but is limited in its application and must be operator supervised. Sign messages should be composed with words that are used in everyday conversation by the motoring public. Formation of a committee to formulate and periodically review sign usage policies is an effective way to provide consistent and well understood messages.

It is difficult to predict how many drivers will divert in a given environment on a given day since many factors influence diversion choices. However, if we examine this phenomenon fiom an operational point of view, even with the low diversion percentages, it is possible to increase throughput of urban corridors. Approximately 50% of Long Island motorists surveyed have reported that they use VMS information to avoid delays. Voluntary diversions are obtainable, have been measured, and can consistently be initiated with VMSs. For the Long Island VMS system, it is estimated that the benefit-to-cost ratio is about **3:**1.

Features of Freeway Traffic Advisorv and Incident Management Systems (1979)

VMS systems for traffic advisory and incident management are used by many agencies including California DOT, City of Cincinnati, Colorado Division of Highways, Minnesota DOT, New Jersey Turnpike Authority, Pennsylvania DOT, and New York DOT. There are wide variations in the size of systems, sign type and physical characteristics, interconnect, surveillance, and control systems.

Sign Types Currently Being Used in the **U.S.**:

The sign types currently used for traffic advisory and incident management systems include lamp matrix, disk matrix, rotating drum, and neon. The choice of sign was generally dictated by cost, requirements for flexibility, and the state of technology at the time the systems were designed.

Two important **VMS** characteristics are conspicuousness (target value) and legibility. The relative attention-getting and legibility characteristics of the various types of VMSs are not filly known, particularly when the signs are side-mounted. Lamp matrix sign messages can be flashed or sequenced to attract driver attention. Research is needed to filly assess these characteristics.

Legibility distance refers to the distance at which drivers can begin to read VMS messages. Legibility distances of the majority of VMSs are not fully known at this time. The relative conspicuousness of the scroll, neon, fiber optics, flap matrix, and vane matrix are not known. However, the rule-of-thumb is that 1 cm letter height is good for ***6*** meter (50 feet) distance legibility.

VMS Locations:

The current practices in locating VMS signs are to install small systems to address specific problem areas and a global system for long stretches of highway. Regardless of the approach, general location guidelines used in the U.S. are such that VMSs are placed upstream of bottlenecks and upstream fiom major decision points (e.g., ramps and interchanges that will allow drivers to divert). The California experience has shown that the most critical locations are in advance of interchanges or roads where drivers can take some action either voluntarily or in response to specific instructions displayed on

VMSs. When VMSs are located beyond decision points, the only thing that can be accomplished is to alert drivers of slow traffic. All other traffic-related information displayed in terms of accidents, congestion, and delay will not assist in improving drivers' trips. VMSs must be integrated with existing static directional signs in terms of location and messages.

Number and Sign Messages:

Variations of messages need to be available for quick access. The choice of messages will be dictated largely by the objectives of the system (e.g., traffic and incident information, environmental hazards, diversion, instructions). In the United States, the number of highway-related messages stored for quick access varies between 25 and 100.

The methods commonly available in changing VMS messages are: (1) automatic computer control with manual override; **(2)** manual keyboard or teletypewriter control; and **(3)** manual push-button control with optional keyboard or teletype control. The experience of most agencies is that the push button control system is more efficient than the other systems (Pennsylvania, Caltrans).

In general, the **U.S.** agency experience indicates that the use of VMSs for traffic advisory and incident management is effective. The degree of effectiveness, however, is dictated by individual agencies' ability to consistently display timely, accurate, and reliable information upstream from traffic problem areas and upstream from major decision points (e.g., ramps and interchanges where drivers have the opportunity to divert).

Although objective field evaluation studies and documentation are somewhat lacking, the effectiveness of VMSs has been subjectively assessed by the agencies through field observations, viewing CCTV, reviewing traffic data from a computer printer or displayed on a CRT, or reports from local police stations. The Caltrans study regarding the use of VMSs on the Santa Monica Freeway indicated that there was a 17% reduction in the fatal plus injury accident rate. The VMS messages increased diversion to off-ramps that were more than 0.8 km (1/2 mile) upstream from congestion-producing incidents. The VMS messages increased diversion even though specific diversion messages were not displayed. Some motorists with a high potential to divert, diverted sooner to off-ramps upstream from their normal ramp. Other motorists with a lower diversion potential were induced to divert when they realized the cause and extent of the congestion. Lane blockage messages induced changing into open lanes. Speeds reduced approximately **5** km/h **(3** mph) and declarations were less severe when incident messages (e.g., SLOWING AHEAD) were displayed. The majority of the Santa Monica Freeway users thought that the VMSs were useful.

A review of the current application of VMSs for traffic advisory and incident management revealed wide variations in the size of systems, sign type and characteristics, interconnect, surveillance, and control systems. Nonetheless, each agency surveyed indicated satisfaction with the choice of VMSs. Lamp matrix signs have higher power consumption costs, but it has not been established whether other sign types provide equal or better target value, legibility or flashing and sequencing capabilities.

Information on the comparative legibility distances of the various types of VMSs is not available. Limited studies however indicated that 85th percentile legibility distance of a 450 mm (18 inch) lamp matrix sign is about 200 m *(650* ft). VMS letter heights vary among installations, although the trend is toward the 450 mm (18 in) letter for lamp and disk matrix signs. Smaller letter heights are currently used on rotating drum and neon signs. Several operating agencies reported that 2 line, 16 character (including word spacing) per line, signs having sequencing capabilities are adequate to display traffic-related information on lamp matrix signs. An upper limit would be 20 characters per line. Agencies using three line disk matrix signs also indicated that possibly 16 characters would be adequate for traffic-related messages. The character arrays on lamp matrix signs can either be modular or continuous. Disk matrix signs are currently modular. Most operating agencies are now recommending the continuous array.

Adverse Road or Weather Conditions:

The Wyoming and Colorado experiments reported that they had good results with the application of VMSs for managing traffic for adverse road and weather conditions. Both agencies also found that it was necessary to activate flashing beacons whenever important messages were displayed on the VMSs.

Speed Signs:

There is no supportive data that clearly establish the effectiveness of regulatory changeable message speed signs in reducing operating speed. The New Jersey Turnpike Authority reported that the accident and fatality rates declined since the VMS system was installed. The speed signs, however, were used in conjunction with other advisory signs, and it was difficult to isolate the relative contributions of each sign type.

Findings:

In all cases on the expressways and with low volumes on the freeways, posted speeds affected a reduction in both mean and 85th percentile speeds, generally 8 to 16 km/h (5 to 10 mph). Drivers were not willing to reduce their speeds according to the posted speed unless there was an apparent reason to do so. Posted speeds less than 56 to 64 km/h (35 to 40 mph) had little effect on reducing speeds. Based on a limited test, very little difference was found in the effectiveness of regulatory and advisory speed limit signs.

The U.S. experience suggests that as with any type of VMS, driver credibility must be maintained. If the signs are not changed to reflect current conditions, credibility can be lost. The spacing of changeable speed signs, both advisory and regulatory, is also critical. If the speed infomation is displayed too far in advance of the problem area, drivers may become uncertain after reducing their speed and elect to increase their speeds again prior to the congested location. Experience with changeable speed signs indicates that drivers do not reduce their speeds to coincide with the posted speed. The effectiveness of the signs in alerting drivers to problems ahead is inconclusive.

MANUAL ON REAL-TIME MOTORIST INFORMATION DISPLAYS
(U.S. Federal Highway Administration; Dudek, 1986)

In 1986, the U.S. Federal Highway Administration developed guidelines for designing VMSs based on human factors. The important aspects of the guidelines are described as follows:

Real-time information displays are basically intended for incident responsive traffic management; that is, responsive to abnormal conditions such as freeway incidents or accidents. For displaying messages, two schools of thought on this issue were considered: one is to always display a message whether or not there is an incident on the fi-eeway and the other is to display a message only when unusual conditions exist. The **U.S.** DOT recommends not to display messages unless there is a reason to convey messages. The reason for this recommendation is that trivial information would discourage drivers to pay attention to important messages. Therefore, for a more effective system, messages should be displayed only when some type of driver response is required, i.e., change of speed, path or route.

The primary function of a VMS system is to manage traffic by rerouting vehicles to alternate facilities. Success of the diversion strategy will be dependent upon convincing drivers that they will be better off by taking the recommended alternate route. When VMSs were used for special-event traffic in Dallas, on average between 71% and 85% of the fieeway traffic enroute to the special event used the recommended route. Some drivers elected not to change routes, primarily because of uncertainty and lack of credibility associated with the information. Possible reasons for drivers not diverting were: (1) the alternate route was anticipated to have traffic problems; **(2)** they did not understand the message; **(3)** the alternate route was unfamiliar to them; and **(4)** they did not have confidence in the information. The study showed that some drivers, albeit a small percentage, would not divert even in response to an effectively designed sign due to skepticism based upon previous driving experiences.

Information Type:

Real-time signing systems consist of three types of information: advisory signs, guide signs, and advance signs. Advisory signs consist of message contents directed to: (1) a problem statement (accident, maintenance, construction, etc.); **(2)** an effect statement (delay, heavy congestion, etc.); **(3)** an attention statement (addressed to a specific audience); and **(4)** an action statement (what to do). The purpose of advisory messages signs is to provide drivers with enough information to make informed decisions. Guide signs provide the mechanism for drivers to follow a route other than the intended primary route to their destination, or to follow a diversion route to bypass an incident and associated congestion. The message contents are destination affirmation and route affirmation and direction. Advance signs are used in conjunction with an advisory visual display and the message contents are information alert, nature of information (best route, traffic conditions, etc.), destination for which information applies, and location of the information ***(AHEAD*** or specific distance). In the **U.S.,** the most commonly used information types are advisory signs.

Appendix 2. VMS Experiment

If traffic data are to be used for diversion studies, it will be desirable to gather data from three point locations, one upstream of the variable message sign (VMS) and one on each link downstream of the VMS after the road splits. Using these data will give a result with greater accuracy in the estimation of the number of vehicles actually diverted. However, even with such data, it is difficult to estimate what percent of the diverted vehicles consists of those who were influenced by traffic information unless the data are supplemented by motorist surveys. Further research is needed in the methodological areas of traffic data analysis so that the effectiveness of the advanced traveler information system can be accurately measured.

The experimental site chosen for this study **is** not the most ideal configuration for the diversion behavior research because **A86** does not directly serve the city center of Paris and the frontage road D45 runs along **A86** for about 20 kilometers. However, this site was chosen primarily because of the availability of data. **As** data on other sites become available, the French National DOT will continue the evaluation of the **SIRIUS** system. All sites with VMSs will eventually be set up with an automated system capable of collecting data every 20 seconds.

When the infrastructure of the SIRIUS system is completed at the end of 1994, it will be possible to assess the net effects of the VMSs on the entire network. Meanwhile, the realistic approach would be to study the effects of VMSs on individual links. Since the second week of March 1993, a new set of data has been collected using a different method, the alternate turning on and off of VMSs in 5-minute intervals.

As stated earlier, the research questions included to what extent VMSs affect motorists route choices and whether motorists respond to differently to different types of messages. Traffic volume data alone cannot be used to accurately determine the percentage of traffic diverted in response to messages. However, the first step of the data analysis is to determine the normative pattern of traffic flow on D45 and **A86,** then to estimate the number of vehicles diverted from D45 to **A86** according to abnormal behavior of traffic patterns. Even with data collected at three points, the challenge is how to estimate the number of vehicles which diverted as a result of VMSs. The experimental study by the French DOT of the alternate turning on and off of VMSs in 5-minute intervals was designed to investigate the differences in arrival rates with and without VMSs. The French DOT experiment showed the decreased traffic flow on the access ramp to **A86** when the VMSs indicated an increased level of congestion on **A86.**

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