AN EVALUATION OF THE DETROIT FREEWAY OPERATIONS (SCANDI) PROJECT

By

Lidia P. Kostyniuk, Ph.D., P.E.

Thomas L. Maleck, Ph.D., P.E.

William C. Taylor, Ph.D., P.E.

Abdul-Rahman I. Hamad, Ph.d.

Sponsored by

The Michigan Department of Transportation

and

The United States Department of Transportation
Federal Highway Administration

June 1988

COLLEGE OF ENGINEERING
MICHIGAN STATE UNIVERSITY
EAST LANSING, MICHIGAN 48824

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FHWA-MI-RD-88-02	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle
An Evaluation of the Detroit Freeway Operations (SCANDI) Project.

5. Report Date
June, 1988

6. Performing Organization Code

7. Author(s) Linda P. Kostyniuk, Thomas L. Maleck, William C. Taylor, Abdul-Rahman I. Hamad

8. Performing Organization Report No.

9. Performing Organization Name and Address
Department of Civil & Environmental Engineering
Michigan State University
East Lansing, MI 48824

10. Work Unit No.

11. Contract or Grant No.
H.P.R.0010(11)

12. Sponsoring Agency Name and Address
Michigan Department of Transportation
Federal Highway Administration

13. Type of Report and Period Covered
Final Report

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The Michigan Department of Transportation (MDOT) presently manages a project for providing operational control and service for a portion of the freeway system within the city of Detroit. This Detroit freeway operations group is well known as the Surveillance Control and Driver Information (or SCANDI) System. A contract was executed with the Department of Civil and Environmental Engineering at Michigan State University (MSU) to evaluate the effectiveness of the project, test alternative strategies, and make recommendations. The project consists of four subsystems; Motorist-Aid Telephones, Changeable Message Signs, Television Surveillance, and Ramp Metering.

The benefits from ramp metering are more than anticipated and could be even greater with revisions to the metering plan. The television surveillance operation is performing adequately in detecting freeway incidents along critical sections of the Ford Freeway. The motorist aid telephones are used fairly extensively despite their poor condition and limited reliability. The changeable message signs cannot be properly evaluated because of their very poor visibility, but we believe they should play a role of informing the motorist as part of an incident management plan.

It is evident that the continuing need for maintenance is a major burden to the cost effective operation of this project. If the continued operation of this project is to be successful, MDOT should explore the use of current state-of-the-art technology in minimizing maintenance and operational costs.

17. Key Words
Ramp-Metering
Motorist-Aid
TV-Surveillance
Simulation

18. Distribution Statement

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price

Form DOT F 1700.7 (8-69)

ACKNOWLEDGMENTS

This project was completed under a contract with the Traffic and Safety Division, Michigan Department of Transportation. A traffic simulation model, INTRAS, was furnished by The Federal Highway Administration. The model was invaluable in evaluating the ramp metering operation. A special thanks to all of the students for their efforts in the successful completion of this project.

The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the Michigan Department of Transportation nor the Federal Highway Administration.

TABLE OF CONTENTS

List of Figures

List of Tables

1. INTRODUCTION

The Michigan Department of Transportation (MDOT) presently manages a project for providing operational control and service for a portion of the freeway system within the city of Detroit. This Detroit freeway operations group is well known as the Surveillance Control And Driver Information (or SCANDI) system. The design, implementation and start-up of the SCANDI system had to overcome several difficulties and was accomplished over a period of several years. Upon the successful implementation of the system, MDOT expressed a desire to conduct a comprehensive evaluation of positive and negative impacts of the SCANDI project. A contract was executed with the Department of Civil and Environmental Engineering at Michigan State University (MSU) to evaluate the effectiveness of the project, test alternative strategies, and make recommendations. A steering committee consisting of membership from the Federal Highway Administration, MDOT (from the Bureau of Planning, metro District Office, and the Traffic and Safety Division), and the principal investigators at MSU oversaw the research effort.

2. SCANDI DESCRIPTION

The SCANDI project currently covers both directions of parts of four freeways:

a. all of the Ford (I-94) Freeway within the City of Detroit (14.2 miles);

b. all of the Lodge (M-10) Freeway within the City of Detroit (12.2 miles);

c. part of the Fisher (I-75) Freeway east of the Jeffries;

d. 3.4 miles of the Chrysler (I-375) Freeway south of the Ford Freeway.

The SCANDI system consists of four somewhat separate subsystems: changeable message signs, motorist aid telephones, television surveillance, and ramp metering. Each of the subsystems are discussed separately.

2.1. Communications

Two central processors are part of the system, with one serving as the host and the other as a backup. The detector communications consists of one central communication unit and 104 remote communication units (located throughout the field). The remote units are polled every 1/100 of a second via a set of 8 coaxial cables.

2.2. Loop Detectors

Inductive loop vehicle detectors have been installed at approximately every 1/3 of a mile on all lanes of the freeway. Each exit and entrance ramp is also equipped with a set of detectors. Data taken from these detectors (1352 loops) are used to determine traffic volumes, average occupancy, and average speeds.

2.3 CHANGEABLE MESSAGE SIGNS (CMS)

There are nine changeable message signs mounted on bridges and overpasses. Seven of the signs are located on inbound routes and two are on outbound routes. Each sign is a tri-color, rotating-element matrix. A microprocessor-driven base station is located in the control center. Communication with the central processing unit (CPU) is via SCANDI communication lines for six signs and via Bell Telephone lines for the remaining three signs.

2.4 MOTORIST AID TELEPHONES (MAT)

The Motorist Aid Telephone System consists of 69 telephone call boxes located along 13.5 miles of Ford Freeway (I-94) within the city limits of Detroit. The call boxes are about 1/3 mile apart on both the eastbound and westbound directions. The call boxes are located just off the right shoulder of the freeway. Most are located behind bridge abutments to protect the call box, stopped vehicle, and the person making the call from oncoming traffic. Some call boxes are located near ramps. At both types of locations there is adequate room for a vehicle to pull off the road and have reasonable protection from oncoming traffic.

2.5 CLOSED CIRCUIT TELEVISION SURVEILLANCE (CCTV)

The visual surveillance system of SCANDI consists of 10 television cameras. SCANDI's closed circuit television system began operation on 12/17/1980 with 4 cameras. Six more cameras were added on 12/17/1982. The cameras are located at particularly troublesome locations with high accident occurrence, frequent congestion, and/or downstream of a changeable message sign. Observers at the SCANDI control center monitor the pictures from the cameras from 6 a.m. to 7 p.m. Monday through Friday and on special weekends.

Each camera has a pan/tilt mechanism, zoom lens, focus, and automatic light level adjustment which are remotely controlled from the SCANDI control center. The cameras are enclosed in environmental housings to protect them from the weather. The CCTV system is linked by a coaxial cable which has the capability of accommodating over 180 TV channels.

3. MOTORIST AID TELEPHONES

The Motorist Aid System of SCANDI was built by Phillips Corporation and installed by Sperry Rand Corporation. It went into operation in December, 1980. The system consists of 69 telephone call boxes located along 13.5 miles of Ford Freeway (I-94) within the city limits of Detroit. Table 3.1 contains the location of the call boxes with respect to the surface streets.

The call boxes are located just off the right shoulder of the freeway. Most are located behind bridge abutments to protect the call box, stopped vehicle, and the person making the call from oncoming traffic. This is shown in Figure 3.1. Call boxes are also located near ramps. Figure 3.2 and 3.3 show this configuration. At both types of locations there is adequate room for a vehicle to pull off the road with reasonable protection from oncoming traffic.

Figure 3.4 shows the inside of a call box. A motorist makes a call to the Michigan State Police (MSP) by simply lifting the telephone. The telephones are connected with the SCANDI office and the State Police Detroit Office by the SCANDI system coaxial cable. Volunteers from the Michigan Emergency Patrol (MEP) and/or the State Police monitor the calls. The MEP volunteers are on duty during the morning and afternoon peak periods and during special events which bring large volumes of traffic into downtown Detroit. The State Police monitor the calls at all other times. SCANDI personnel do not listen to the calls, but check periodically to assess the quality of the transmission. The location of the box from which the call is made is identified automatically by the system. Similarly, if the phone is out-of-order, an audible signal and a flashing light go on at the State Police monitoring station identifying the malfunctioning call box. An automatic record is made of the incidence of a call, a hold, and termination

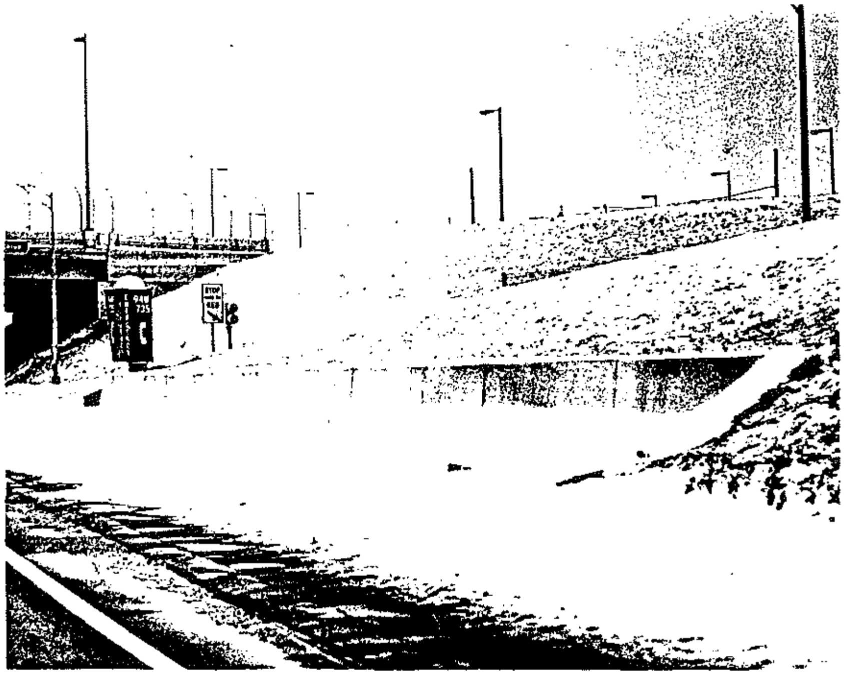
Table 3.1

LOCATION OF CALL BOXES

EASTBOUND			**WESTBOUND CALL BOXES**		
BOX	LOCATION	UPSTREAM RAMP	BOX	LOCATION	UPSTREAM RAMP
700	East of Wyoming	Michigan Ave	701	West of Wyoming	Livernois
702	West of Trenton	Weir	703	West of Addison	Livernois
704	At Lumley	Lonyo	705	At Lumley	Livernois
706	At Tarnow	Lonyo	707	At Tarnow	Livernois
708	East of Martin	Cecil Ave.	709	At Martin	Livernois
710	East of Livernois	Cecil Ave.	711	West of Wesson	30th
712	At Junction	Livernois	713	West of Junction	30th
714	East of 30th	Livernois	715	West of 30th	Grand River
716	E of W. Grand Blvd.	30th	717	At W. Grand Blvd	Grand River
718	East of 24th	W Grand Blvd	719	East of 24th	Grand River
720	East of Jeffries	W Grand Blvd	721	East of Jeffries	Trumbull
722	At 14th	Linwood	723	East of 14th	Trumbull
724	East of Trumbull	14th	725	West of Trumbull	Woodward
726	West of Third	14th	727	At Third	Woodward
728	East of John R	14th	729	West of John R	Dubois
730	W. of Russel St. Exit	Beaubien	731	West of Chrysler	Dubois
732	East of Dubois	Beaubien	733	West of Dubois	Mt. Elliot
734	W. of E. Grand Blvd	Chene	735	East of E. Grand Blvd	Mt. Elliot
736	East of Mt. Elliot	Chene	737	West of Mt. Elliot	Van Dyke
738	West of Helen	Mt. Elliot	739	West Helen	Van Dyke
740	East of Van Dyke	Mt. Elliot	741	West of Van Dyke	Gratiot
742	West of Rhons	Van Dyke	743	West of Rhons	Gratiot
744	West of Cadillac	Gratiot	745	East of Cadillac	French
746	East of French	Gratiot	747	West of French	Conner
748	E. of N.Bd Conner	French	749	West of N.Bd Conner	Chalmers
750	West of Barrett	NB Conner	751	East of Barrett	Chalmers
752	W. of Chandler Park	NB Conner	753	E. of Chandler Park	Chalmers
754	At Coplin	NB Conner	755	East of Coplin	Chalmers
756	East of Chalmers	NB Conner	757	At Chalmers	Whittier
758	E. of Lakepoint	Outer Dr	759	West of Lakepoint	Whittier
760	E. of Chatsworth	Outer Dr	761	West of Chatsworth	Whittier
762	W. of Courville	Outer Dr	763	East of Courville	Cadieux
764	E. of Kensington	Outer Dr	765	East of Kensington	Cadieux
766	West of Morang	Cadieux	767	East of Morang	Moross
768	West of Moross	Casieux	769	East of Moross	Vernier

Figure 3.1. Location of Call Box Behind Bridge Column

Figure 3.2. Location of Call Box Near Ramp



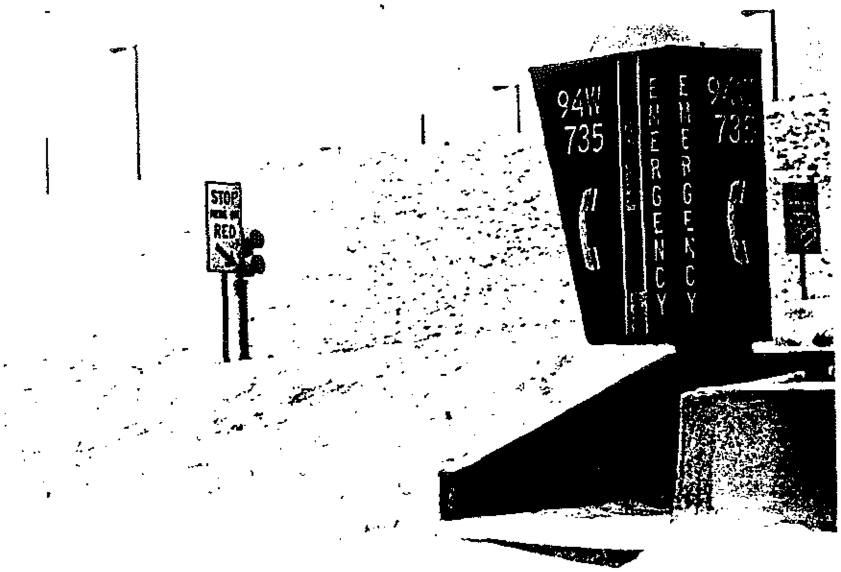


Figure 3.3. Call Box Near Ramp

Figure 3.4. Inside of Call Box

of a call. The record is a hardcopy printout, which identifies the phone unit and records the types and time of phone activities.

When a call comes in, the monitor talks to the caller and takes appropriate action. This may include sending an emergency vehicle such as an ambulance, fire truck, or patrol car to the site. If a tow truck is required, the closest towing service from a list approved by the City of Detroit is called. Sometimes the caller just asks for information or needs to send an emergency message. There are also "crank calls." While no records of response times are kept, the State Police report that the response time when an emergency vehicle or patrol car is required is under 20 minutes.

The calls which require action are recorded into a daily log at the State Police station. This log is turned over to the SCANDI office at the end of each month.

3.1. Use Of The SCANDI Motorist AID Telephone System

The calls which require aid of some sort are logged onto the daily log at the MSP post and categorized into the following categories:

Abandoned vehicle
Car assist
Accident
Fire
Medical emergency
Traffic hazard
Traffic violation
Other

Most of the categories are self-explanatory. The car assist category includes aid requiring changing of tires, getting fuel, calling a tow truck or other service vehicle, making a phone call, or giving of information. The no service calls are those where no-vehicle is by the phone when help arrives. These include cases where the vehicle left without assistance as well as false calls which were not recognized as such by the monitor. Calls that are obviously prank calls are not recorded into the log.

The log has been kept since the beginning of the operation of the motorist aid telephone system. These records were obtained, coded onto a computer file, and summarized. The records were also explored by type of day, i.e. weekday or weekend.

Table 3.2 shows the quarterly distributions of the calls logged by the State Police for each year from the second quarter of 1981 through 1985. Also shown on the figure are the distributions of the car assist calls, accident calls, and the no service calls. The car assist calls constitute the largest portion of calls over the analysis period. This portion appears to be consistent and relatively constant. The second largest portion of calls is in the no service category, those where no vehicle was present when help arrived.

Table 3.3 gives the number of calls, the average number of calls per day, and the percentages of calls categorized as car assist and no-service calls for each year of operation and for the total time period from 1981 through 1985. The overall average number of calls per day was 11.7. The number of calls/mile/day is .87 which is somewhat lower than other voice

Table 3.2

Quarterly Distribution of Calls

Quarter Ending	Car Assists	Accident	No Service's	TOTAL
June 81	808	105	275	1381
Sept 81	1136	126	414	1877
Dec 81	894	90	353	1434
Mar 82	881	120	241	1329
June 82	981	81	352	1618
Sept 82	736	52	247	1191
Dec 82	354	32	64	505
Mar 83	583	60	223	941
June 83	774	75	286	1195
Sept 83	792	56	185	1176
Dec 83	658	79	226	1046
Mar 84	637	103	161	986
June 84	588	86	209	1010
Sept 84	538	65	220	938
Dec 84	444	48	103	707
Mar 85	412	62	109	684
June 85	486	73	147	845
Sept 85	468	58	100	738
Dec 85	504	62	74	719

call box systems. There are 383.6 million vehicle-miles of travel annually along the motorist aid route. Therefore, there is one call for every 136,700 vehicle-miles of travel.

There was a clear decrease in the number of calls over the years of operation. Neither the state police, SCANDI staff, nor the available records could offer any explanation for this decline. The percentage of calls classified as car assist calls was a constant 60% over the period of operation. the percentage of calls to report accidents is also relatively constant at 7%. The no-service calls made up approximately 20% of all calls over the time of operation.

Table 3.4 gives the average number of calls by weekday and weekend. With the exception of 1981 the average daily number of calls on weekdays is greater than on weekends. In 1981 there is no significant difference between the weekday and weekend average. The average number of calls on a weekday is 12.6 and on a weekend it is 9.4.

Table 3.3

AVERAGE NUMBER OF MOTORIST AID CALLS/DAY BY TYPE OF CALL AND YEAR

	1981*	1982	1983	1984	1984	1981-1985
No. of Calls	4692	4643	4358	3641	2986	20320
Average Calls/Day	17.06	12.72	11.94	9.95	8.18	11.71
% Car Assist Calls	60.5	63.6	64.4	60.6	62.6	60.0
% No-Service Calls	22.2	19.5	21.1	19.0	14.4	19.6
% Accident	6.8	6.1	6.2	8.3	8.5	7.0

* Data available from April 1, 1981.

Table 3.4

AVERAGE NUMBER OF MOTORIST-AID CALLS/DAY
BY TYPE OF DAY AND YEAR

	1981*	1982	1983	1984	1985	1981-1985
Weekday	16.98	13.54	12.40	11.75	9.63	12.65
Weekend	17.27	10.66	10.80	5.48	4.54	9.35

* Data available from April 1, 1981.

Table 3.5 shows that the portion of calls for car assists does not vary by weekday or weekend. A similar analysis found that the portion of no service calls did not vary by weekday or weekend, either.

The seasonal variations in the number of motorist-aid calls per day are presented in Table 3.6 and Figure 3.5. The highest average number of calls are received in spring (April, May, June). This was true from 1982 through 1985. In 1981 the highest daily average was recorded in summer (July, August, September), and the spring and fall (October, November, December) averages were essentially the same. There is no log for the first quarter of that year. For the years of 1982 through 1985 the second highest average was recorded in summer, followed by winter, and finally fall. The table also shows the consistent decrease in the number of calls over the time of the operation of the system. The low average value of 0.88 calls per day for weekends in the fall of 1982 could not be explained by examination of the logs. The state police could not offer an explanation either.

Table 3.5

CAR ASSISTS AS % OF TOTAL CALLS

BY YEAR AND TYPE OF DAY

	1981*	1982	1983	1984	1985	1981-198
Weekday	61.43%	63.90%	64.40%	60.60%	61.80%	62.51
Weekend	58.12%	62.50%	64.40%	60.30%	67.20%	61.91

Table 3.6

AVERAGE NUMBER OF CALLS/DAY

		Winter	Spring	Summer	Fall
1981*	Weekday		15.05	20.09	15.77
	Weekend		15.50	21.19	15.12
1982	Weekday	15.23	18.43	13.32	7.30
	Weekend	13.62	16.15	12.00	.88
1983	Weekday	11.17	13.09	13.85	11.45
	Weekend	0.69	13.23	10.08	11.19
1984	Weekday	11.98	13.17	12.26	9.61
	Weekend	7.96	5.92	5.22	2.81
1985	Weekday	9.45	11.08	9.21	8.80
	Weekend	3.04	4.81	5.00	5.31
1981-1985	Weekday	12.00	14.16	13.83	10.58
	Weekend	8.33	11.05	10.66	7.09

* Data available from April 1, 1981.

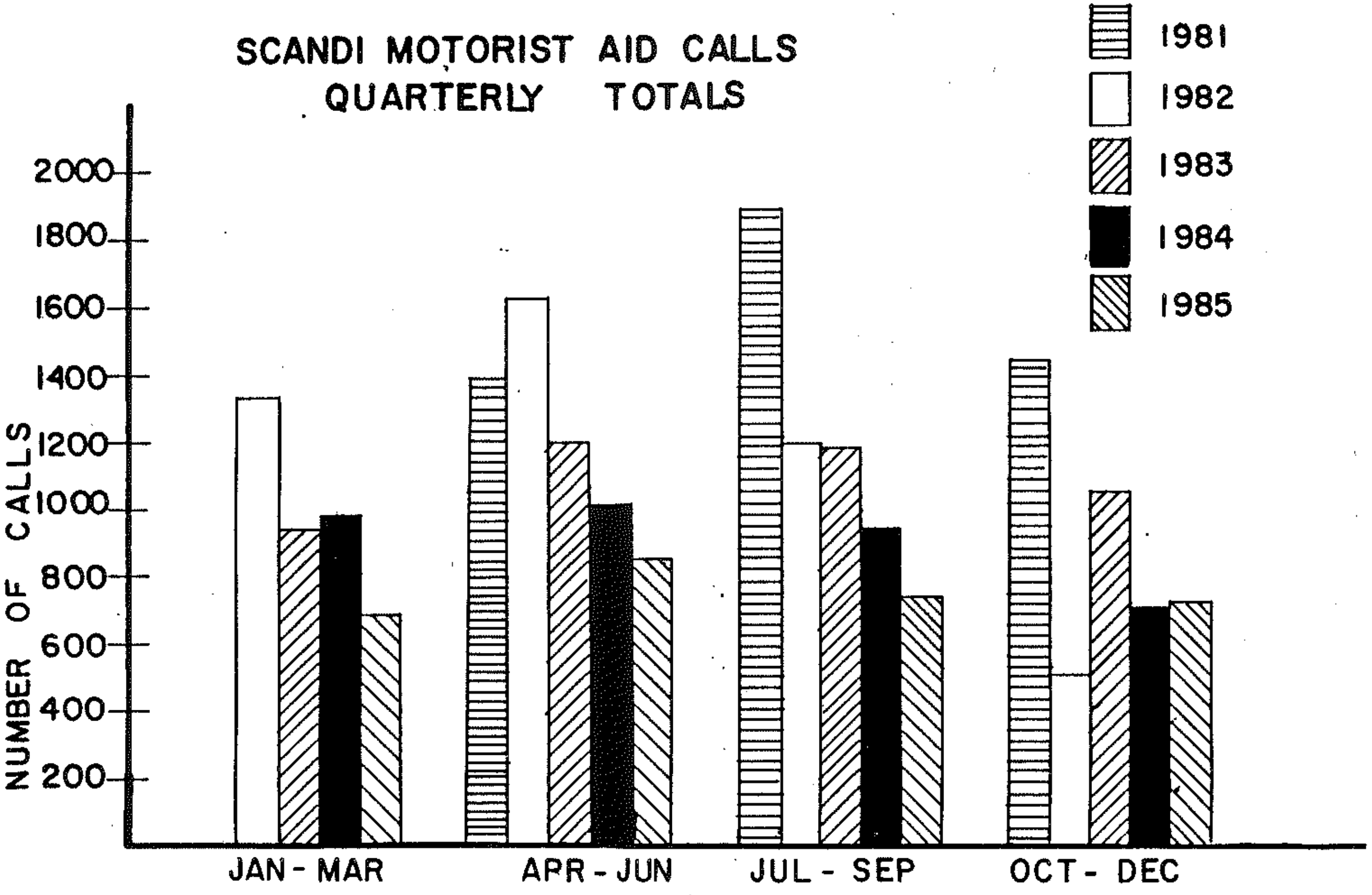


Figure 3.5 Motorist-Aid Calls - Quarterly Totals: 1981-1985

It was desired to obtain a spatial and temporal distribution of the calls. The State Police reported that they have not observed any particular pattern of calls. The only source of this information was the record of all phone activity that is automatically made every time a call is made. This record, which is on a paper tape printout, also contains the time of each such activity and the number of the phone unit involved. Records of spurious signals, false calls, phone checks, and all prank and nuisance calls are also included. With care, however, it is possible to obtain a reasonable picture of the distribution of the calls. Records from several days of 6 months were selected from the SCANDI files and tabulated by time-of-day and location. The time of a call was classified into one of the following categories:

Weekday	Peak Period	- 6:30 am to 9:00 am and 3:30 pm to 6:00 pm
	Day	- 9:00 am to 3:30 pm and 6:00 pm to 10:00 pm
Weekend	Day	- 6:30 am to 10:00 pm
	Night	- 10:00 pm to 6:30 am

The location of calls was examined by noting the spatial patterns of high phone activity.

Table 3.7 summarizes the time-of-day classifications of the sample records. Examination of the table shows that the average number of calls/day in this record exceeds the average obtained from the Motorist Aid Telephone System log. The discrepancy between these averages can be explained. While care was taken to exclude records from spurious signals or automatic circuit tests we could not filter out all of these false calls.

The "crank" calls which were identified as such by the monitor and not recorded in the log could not be filtered out either.

If we assume that the "extra" calls are distributed uniformly over the day, we can estimate the time-of-day distribution of the calls. On the average about 24% of the weekday calls are made during the peak periods, 54% are made during the off-peak day period, and 22% are made during the night. On weekends 72% of the calls are made during the day and 28% during the night.

Table 3.7
Time-of-Day Distribution of Calls

Month, Year Number of Days	Nov '83 30	May '84 10	Jan '85 8	Feb '85 12	Mar '85 12	Apr '85 8
Weekday						
Peak	58	38	30	30	47	19
Day	164	104	64	59	77	41
Night	43	35	24	47	24	20
Weekend						
Day	67	41	15	12	69	18
Night	29	32	8	7	15	10
Calls/day*	12.0	25.00	17.6	12.9	19.3	13.5
Calls/day in log (for month)**	7.0	10.77	6.9	8.2	7.8	8.5

* Includes false calls and "crank" calls.
** Includes only calls recorded in State Police log.

The examination of the records of the location of the phone calls shows that the phones between Jefferies (I-96) and Chrysler (I-75) Expressways are used somewhat more frequently than those in other locations. This section of freeway is the most congested in the State of Michigan.

3.1.1 Summary of System Use

The motorist aid telephone system is used on the average of 11.7 times a day. On weekdays this average is slightly higher at 12.6 calls per day and on weekends it is 9.4 calls per day. The rate of use is one call per 136,700 vehicle-miles of travel which falls into the range of rates reported by other motorist aid systems (13). Approximately 60% of the calls are for car assistance, (i.e car problems or information). This corresponds to similar percentages in Illinois (13) where 63% of the calls are reported to be for vehicle disability and in Texas (10), where the percentage of calls for service is reported to be 58.5%. Seven percent of all the calls on the SCANDI system are calls reporting accidents. This is somewhat higher than other reports (for example, Illinois reports 4% of its calls are concerned with accidents). Most of the calls are made during the day, with 54% of the weekday calls occurring in the off-peak daytime and 24% during the peak periods. The remaining 22% are made during the night. On weekends 72% of the calls are made during the day and 28% of the calls are made during the night.

On an average weekday there are

3.2 calls during the peak periods
6.8 calls during the rest of the day
2.6 calls during the night.

Of these calls

0.9 are about accidents
7.6 are for car assists
2.5 are no service calls
1.6 are for other reasons.

On an average weekend day

6.8 calls are during the day, and

2.6 calls are during the night.

Of these calls

0.7 are about accidents

5.6 are for car assists

1.9 are no service, and

1.2 are for other reasons.

3.1.2 **Comparison to Other Systems**

Table 3.8 shows the usage of the SCANDI motorist aid system and other operating systems. The use of the SCANDI system in terms of the calls/mile/day is in the range of the other systems. It is not quite as high as other voice-phone systems, but is considerably higher than the push-button systems.

Table. 3.8. Comparison of SCANDI and Other Motorist Aid Systems

Agency	Type of System	Monitored by	Location	Length (mi)	No. of units	Calls/ day	Calls/ mi/day	Comments
Baltimore Transport & Traffic	Radio-Phone	Baltimore Transport & Traffic	I-8 I-10	5	40	8	1.60	Vandalism is a problem. Considering cellular phone system.
Florida DOT	Radio-push button	State Police	I-75 I-85	--	960	140		Went from voice phones to push button radio.
Illinois	Radio-push button	IDOT	I-55 I-70 I-270 I-255	60	267	23	0.38	
Los Angeles County	Phone-voice	California Highway Patrol	All County Highways	500	3051	1000	2.00	Reduces patrol activity = 6300 hours. Cost per call = $1.60 (excluding construction)
Massachusetts DOT	Radio-push button	State Police	I-91 1-93 I-95	220	840	40	0.18	
New Jersey Expressway	Radio-push button	State Police	N.J. Expressway	44	88	7	0.16	Considering voice communications
Connecticut DOT	Radio-voice	State Police	I-91 I-94 Rt. 9	225	750	--	--	
Louisiana DOT	Radio-push	State Police	I-10	17	68	--	--	On bridge-Lake Pontchetrain
SCANDI	Phone-voice	State Police	I-94	13.5	69	11.7	0.87	

3.2. System Reliability and Maintenance

An important issue in determining the effectiveness of the motorist Aid System is the reliability of the system. A phone can be rendered inoperable by a failure of the cable or a wire pair inside the cable or by a failure of the telephone unit itself. When a telephone unit is not functioning, a signal (audible at first then followed by a blinking light) goes on at the State Police Office. This signal also identifies the location of the malfunctioning unit. The State Police relay this information to SCANDI, which is responsible for repairing the unit.

The State Police report that the phones are frequently out-of-order. They estimate about 5 or 6 failures per week. Of these, about 25% involve more than one telephone unit failure. Such multiple-unit failures are usually a result of bad weather such as storms or floods or of cable problems typically caused by construction or maintenance operations. SCANDI personnel noted that since several phone units are 'on circuit, a circuit failure will affect all phones on that circuit.

Vandalism is reported by the State Police and by SCANDI personnel as another major cause of failure. The cord is cut or the telephone instrument is damaged. The State Police reported that even in their protected locations, a call box is struck by a vehicle about once a year. SCANDI personnel report that weather contributes to the deterioration of the call box operation which results in failures.

The maintenance of the call boxes consists of responding to the State Police reports of malfunctioning call boxes and a yearly cleaning by special summer co-op workers.

When a unit is reported to be out of order, SCANDI technicians are dispatched to the site. If the unit cannot be readily repaired in the field, it is replaced with a spare unit, and taken to the SCANDI shop for repair. SCANDI personnel estimate that about 20 units per year are taken into the shop for repair.

The State Police report that typically a failed telephone is back in operation on the same day the failure was reported. However, they state that sometimes it is 2 or 3 days before the unit is functioning again.

A check of the completed SCANDI work orders from 1985 showed that work on the Motorist Aid Telephone System accounted for 10% of the 1985 work orders. About one third of this work was in response to vandalism. The lights, dome, and receiver were the parts most often vandalized.

All available field check records of the Motorist Aid System were requested and a field check of a sample of the call boxes was conducted as part of this effort. Records from only 2 field checks were made available to us. One was from June 1985 and the second was from August 1985. These show that 14 and 10 of the 69 telephones, respectively, were not operating at the time of the checks.

An independent field check of the Motorist Aid System was carried out on July 14, 1986. We randomly sampled 33% of the call boxes (11 on west-bound Ford Freeway (I-94) and 13 on the east-bound route). Of the 24 call boxes tested, 3 were found to be missing parts of the handset and were inoperative and 5 were physically intact but were not working. Twelve of the units provided adequate communication with varying amounts of noise on the line. Communication was possible but difficult on another 4 of the units. The monitor at the State Police base could generally hear the caller, but the caller could barely hear the monitor on several of the units. The best transmission was in the centrally located telephones and the quality of transmission deteriorated noticeably at the east end of the system.

The physical damage to the telephones and the shelters varied from simple graffiti to almost complete destruction of two of the shelters. Parts missing from the telephones themselves included the complete handset from 2 units and the ear piece from one unit. Most of the vandalism to the phones was at the west end of the system where the phones are easily accessible from the surface streets. The phones in the central area, particularly in the area of the major interchange of Chrysler Freeway (I-75) and Lodge Freeway (US-10), are somewhat inaccessible to vandals. Table 3.9 presents a summary of our field study.

The system reliability as determined by the field checks of all units in June 1985 and August 1985 was 85% and 77% respectively. The reliability as determined by the field check of a random sample of the units in July 1986 was between 49% and 81% with a confidence level of 95%. The field check of July, 1986 found the quality of transmission was very poor in 1/4 of the units that were functioning.

4. CLOSED CIRCUIT TELEVISION SURVEILLANCE (C.C.T.V.)

The present visual surveillance system of SCANDI consists of 10 cameras. There are also 2 spare cameras. The camera locations are described in Table 4.1. When an accident is observed the State Police are notified by telephone and a T.V. picture is transmitted to their headquarters. The State Police then decide whether to send a patrol car, an ambulance, fire truck or other emergency vehicle. SCANDI personnel determine if the incident warrants a message to be displayed on the changeable message signs. All observed incidents are recorded in a log.

Table 3.9

FIELD CHECK OF MOTORIST AID SYSTEM 7/14/86

Unit	Physical Condition	Operating Condition
704*	Phone gone	None
705**	Shelter broken, lamp gone, panels missing	Dead
706	Glass broken	Loud, clear
707	Shelter stripped, lamp gone	Dead
708	OK	Loud, noisy
715	OK	Dead
716	Enclosure OK	No phone
718	OK	Loud, clear
721	Ear piece missing	None
722	Handset rattles	Loud, noisy
725	OK	Loud, clear
730	Glass broken	Loud, noisy
735	OK	Loud, buzz
738	OK	Loud, clear
742	OK	Loud, clear
744	OK	Dead
745	OK	Loud, static
749	OK	Dead
750	Glass broken	Loud, noisy
751	OK	Hard to hear, buzz
756	OK	Loud, clear
759	OK	Hard to hear, buzz
764	OK	Buzzing, static
767	Glass broken	Hard to hear, buzz

* - Units with even numbers are located on east bound Ford Freeway

** - Units with odd numbers are located on west bound Ford Freeway

Table 4.1

Location of CCTV Cameras

Camera	Location	Mounted On	Near Changeable Message Sign
3	I-94 at Trumbell St.	25 ft. pole	--
4	I-94 at Woodward Ave.	Wayne State University parking structure roof	--
5	I-94 at Brush St.	25 ft. pole	--
6	I-94 at Russell St.	on sign truss	--
7	Lodge Freeway at West Grand Blvd.	25 ft. pole	#6
8	Lodge Freeway at M.L. King Blvd.	25 ft. pole	#1 and #9
9	Lodge Freeway at Howard St.	Michigan Plaza Building roof (22-floor bldg)	#8
10	Fisher Freeway at Cochrane Rd.	25 ft. pole	#3
11	Fisher Freeway at Cass Ave.	25 ft. pole	#4
12	Chrysler Freeway at Mack Ave.	25 ft. pole	#7

Figure 4.1 shows the location and field of coverage of the TV cameras.

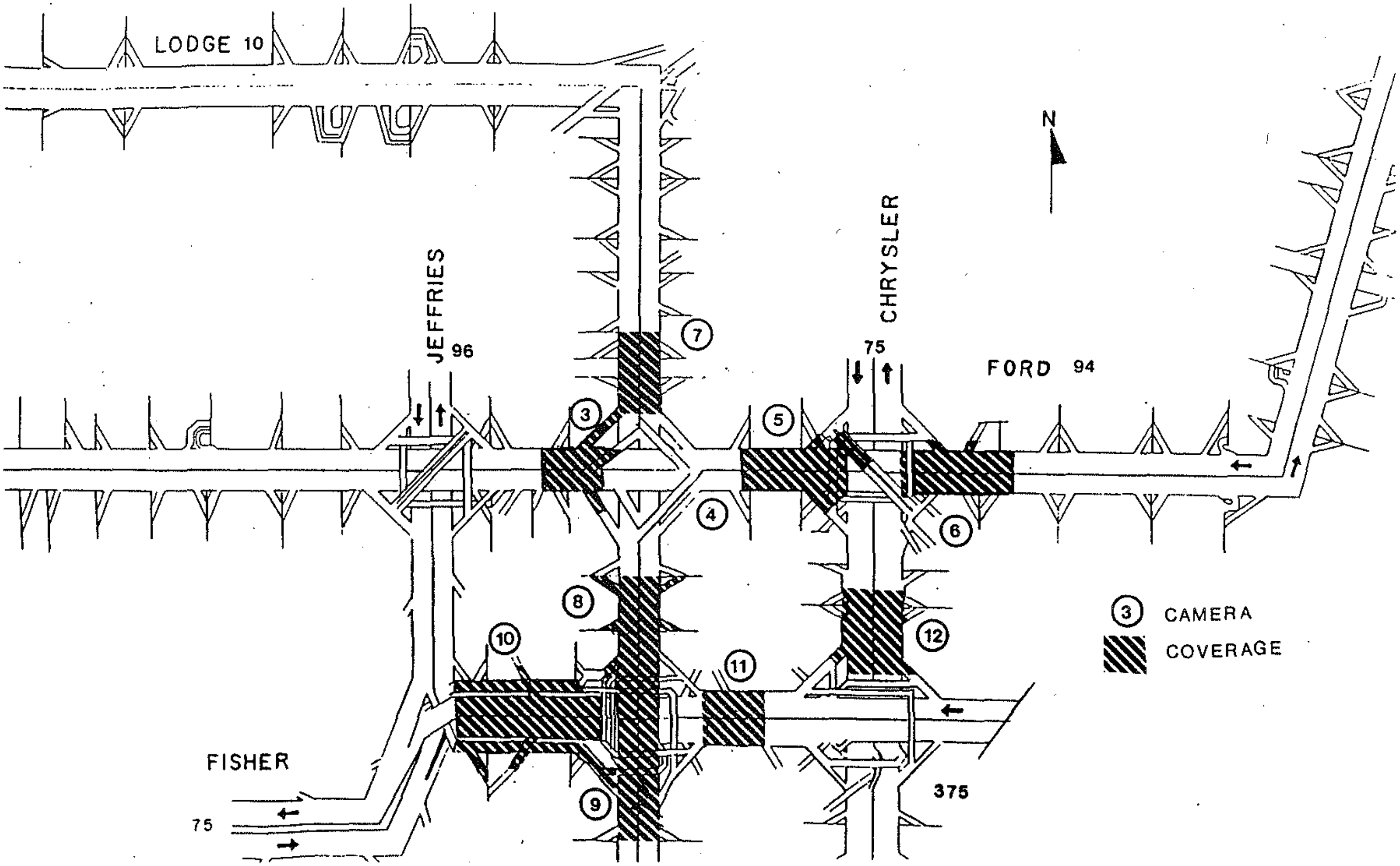


Figure 4.1. Location and Coverage of CCTV Cameras

Approximately 6.6. miles or 30% of the 22 miles of Detroit's central freeway network are covered by the CCTV system.

4.1. Comparison of Camera Coverage and Accident Locations

Are the worst problem areas covered by the surveillance system? To answer this question it is necessary to identify the locations where frequent incidents occur. Since incidents are not recorded, it was decided to use the reported traffic accidents as a surrogate measure for incidents.

Accident records from the Michigan Department of Transportation MIDAS files were obtained for the central 22 miles of the freeway network (including ramps) for the period 1982 through 1984. The accident locations were plotted on a map and compared to the locations covered by the CCTV cameras. It should be noted that all accidents regardless of day of week or time of day were counted in this analysis since the objective of the analysis was to see if particularly troublesome spots were within camera range.

The results indicate that 28% of all accidents and 29% of all injury accidents in the study area are in locations covered by the cameras. The present CCTV system covers 30% of the mileage of the freeways used in this analysis, which is approximately the same as the percentage of accidents occurring in the analysis area.

The SCANDI staff stated that it would be desirable to monitor the entire SCANDI freeway system. This could be done with 64 cameras (one camera for every 1/2 mile) and would be well within the system capabilities. If that was not feasible then the staff suggested several locations where cameras would be very useful. These locations were:

A. I-94 West of Jeffries (I-96)

B. I-94 East of Jeffries (I-96)

C. I-94 between Chene and Mt. Elliot

D. I-94 between Conner and French

The additional coverage of these 4 cameras would be approximated as shown on Figure 4.2. The actual coverage would depend on the placement of the cameras. This new coverage would bring the total coverage to 41% of the total SCANDI mileage.

The existing and proposed camera range covers the locations of 42% of all accidents and 43% of the injury accidents. Table 4.2 gives the segment lengths and accident frequencies used in this analysis.

Other additional camera locations were tried. In all cases the percentage of accidents and miles covered were approximately the same. This indicates that the accident distribution along the central freeway network is relatively uniform and that placement of additional cameras should be governed by factors other than just accidents.

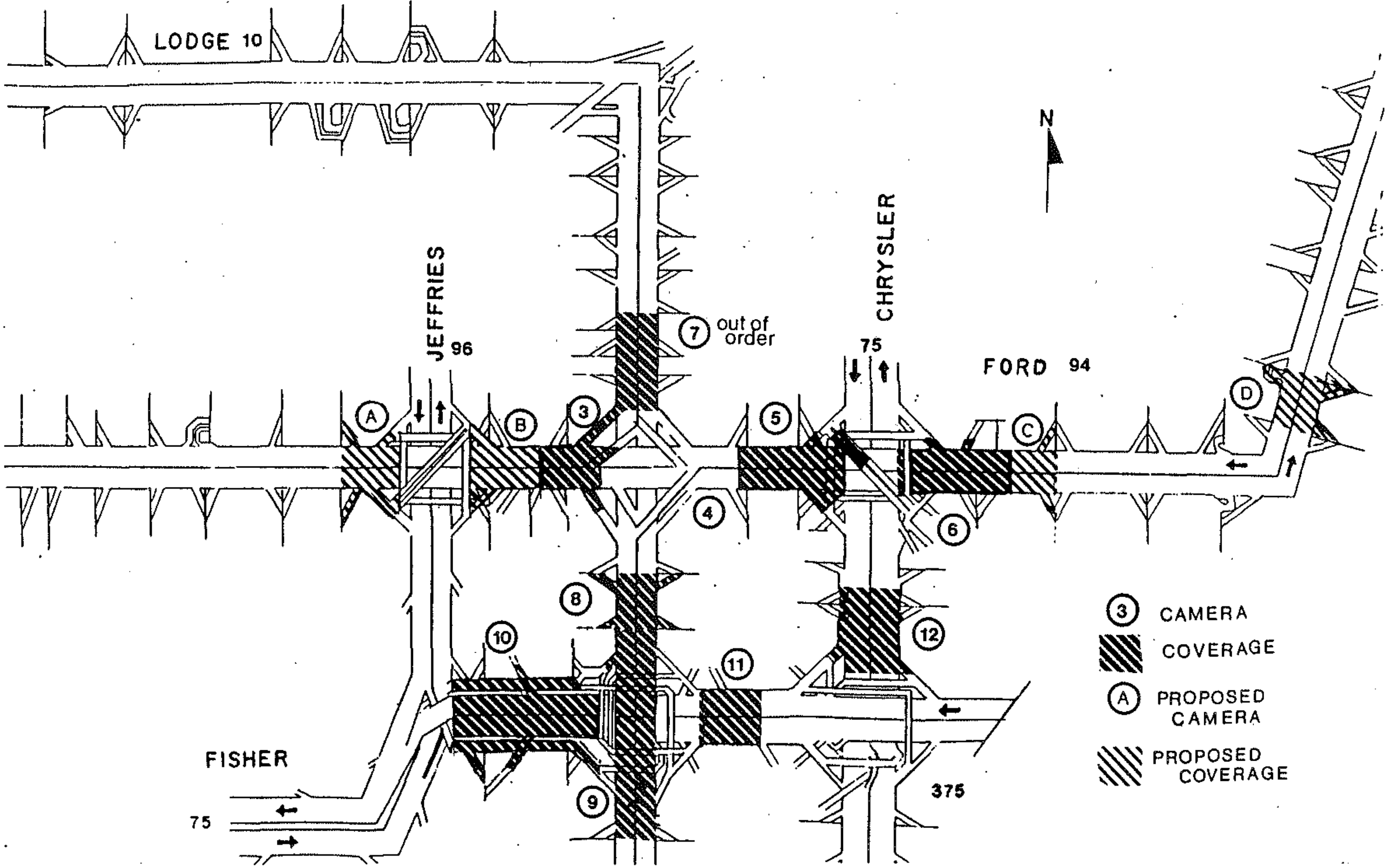


Figure 4.2 Additional Camera Coverage

Table 4.2

Comparison of Accident Location and Camera Coverage

Camera	All Accidents 1982 - 1984	Injury Accidents 1982 - 1984	Miles Covered
3	362	155	0.33
4 & 5	669	315	0.63
6	774	368	1.00
7	225	115	.56
8 & 9	603	331	1.91
10	237	108	0.68
11	211	84	0.58
12	238	107	0.97
TOTAL	3,349	1,583	6.66
PROPOSED CAMERAS			
A	424	221	0.58
B	677	326	0.78
C	248	118	0.47
D	269	144	0.62
TOTAL WITH PROPOSED CAMERAS	4,967	2,392	9.11
TOTAL IN ANALYSIS AREA	11,859	5,536	22.2

4.2 Analysis of CCTV Log

The observers at SCANDI headquarters watch the freeway on the TV monitors and contact the state police if an incident occurs for which help may be required. They also enter information about the incident into the CCTV log. The information entered about each incident consists of:

1. Who reported the incident (SCANDI or State Police)
2. Date
3. Time of start of incident
4. Time of end of incident
5. Cause
6. Camera and direction
7. Lane of incident
8. Lanes affected
9. Assistance - agency summarized
10. Time of notification
11. Time of arrival
12. Action taken
13. Pavement surface
14. Weather
15. Comments.

The cause of incidents are classified into the following categories:

Accident

Vehicle breakdown

Traffic congestion

Debris on road

Stalled vehicle

Traffic violation

Inclement weather

Shoulder incident

Other.

The categories are self-explanatory. However, upon questioning SCANDI staff, it was learned that the categories "vehicle breakdown" and "stalled vehicle" are used interchangeably by the observers. it was, therefore, decided to group these two together. The combined category is referred to as "disabled vehicle" in this report. Logs covering the entire life (1981-1985) of the CCTV system were obtained, coded, and analyzed.

The "accidents" and "disabled vehicle" categories account for approximately 93% of the incidents observed each year. The category of "debris on road" has the highest percentage of the remaining categories, with a few incidents recorded each year. Each of the remaining categories of incidents has only a few entries over the life of the CCTV system.

It was clear from the log entries that not all incidents require assistance. The records indicate that about half of the drivers solved their problems and drove away. In many of the incidents of disabled vehicles, no assistance was recorded. Moreover, no assistance was recorded for about half of the accidents. Further investigation revealed that these were minor accidents where the vehicles were not blocking traffic and no help was needed.

In subsequent calculations as to the reduction of incident duration attributable to the CCTV system, it was necessary to filter out those incidents which were observed, but for which no assistance was recorded.

Table 4.3 gives the distribution of the recorded incidents from 1981 through 1985. It can be seen that "disabled vehicles" form the largest category (range of 53% to 71%) of the incidents observed via CCTV cameras. The next largest category is "accidents" with a range of 21% to 38% of the observed incidents.

Table 4.4 gives the frequencies and classification of the incidents for which assistance is recorded.

Table 4.5 shows the distribution of the average duration of all incidents, and also the average duration of just accidents and disabled-vehicle incidents that did not exceed two hours. Table 4.6 gives the assistance response times for the same incidents. Incidents that exceeded two hours were treated separately.

The average duration of incidents lasting less than two hours was 20.7 minutes. The average accident incident duration was 25.8 minutes, and the average disabled vehicle incident lasted 18.3 minutes. The average response time for all incidents was 12 minutes. It was 9.3 minutes for accidents and 14 minutes for incidents involving disabled vehicles.

The number of incidents and the number of accidents observed through each of the cameras were tabulated and are shown in Table 4.7 and Table 4.8, respectively.

It can be seen that cameras 3 through 6, which are located on the Ford Freeway (I-94), were used to witness far more incidents than the other cameras. It should be reemphasized that these particular four cameras were located over known trouble spots, whereas cameras 7 through 12 were located near changeable message signs.

Table 4.9 gives the distribution of the observed number of incidents and accidents by season.

TABLE 4.3
Frequency of Incidents Recorded by Scandi CCTV Observers

YEAR

INCIDENT	1981	1982	1983	1984	1985	Total
Accident	18 (24.0)*	51 (21.5)	61 (32.2)	75 (35.4)	80 (38.6)	285 (31.0)
Disabled Vehicle	53 (71.7)	170 (71.7)	120 (63.5)	121 (57.0)	110 (53.1)	574 (62.4)
Debris	3 (4.0)	3 (1.3)	2 (1.1)	7 (3.3)	6 (2.9)	21 (2.3)
Congestion	0 (0.0)	0 (0.0)	2 (1.1)	1 (0.5)	6 (2.9)	9 (1.0)
Violation	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Inclement Weather	1 (1.3)	2 (0.8)	1 (0.5)	1 (0.5)	2 (1.0)	7 (0.8)
Shoulder	0 (0.0)	1 (0.4)	0 (0.0)	1 (0.5)	0 (0.0)	2 (0.2)
Other	0 (0.0)	10 (4.2)	3 (1.6)	6 (2.8)	3 (1.5)	22 (2.3)
TOTAL	75 (100)	237 (100)	189 (100)	212 (100)	207 (100)	920 (100)

* column percentage

TABLE 4.4
Frequency of Incidents for which Assistance is Recorded

	YEAR					
INCIDENT	1981	1982	1983	1984	1985	Total
Accident	18	27	21	32	43	141
Disabled Vehicle	19	73	52	43	68	255
Debris	13	0	0	3	6	12
Congestion	0	0	0	0	1	1
Traffic Violation	0	0	0	0	0	0
Inclement Weather	0	1	1	0	0	2
Shoulder Incident	0	3	0	2	2	7
Other	0	0	0	0	0	0
TOTAL	40	104	74	80	120	418

TABLE 4.5
Incident Duration by Year

	Duration (minutes)				
	1981	1982	1983	1984	1985
All Incidents	20.43* (13.8)**	21.7 (20.3)	19.6 (19.1)	20.8 (17.2)	20.8 (17.5)
Accidents	26.4 (14.4)	23.7 (17.2)	26.1 (23.0)	25.2 (18.8)	24.0 (18.3)
Disabled Vehicle	18.1 (12.4)	21.0 (21.1)	16.2 (14.9)	17.2 (14.2)	17.8 (16.4)

* average
** standard deviation

TABLE 4.6
Response Time by Year

	Response Time (minutes)				
	1981	1982	1983	1984	1985
All Incidents	11.3* (6.8)**	16.0 (19.2)	9.3 (7.8)	11.3 (9.8)	12.2 (13.0)
Accidents	10.7 (5.6)	10.3 (7.2)	7.9 (7.4)	8.1 (5.8)	9.8 (10.3)
Disabled Vehicles	12.5 (7.9)	19.4 (22.8)	10.2 (8.1)	14.1 (11.6)	13.7 (15.1)

* average
** standard deviation

TABLE 4.7
NUMBER OF INCIDENTS BY CAMERA AND YEAR

	Year					
Camera	1980	1981	1982	1983	1984	1985
3	2	15	33	31	29	42
4	3	27	107	58	51	26
5	0	21	56	32	31	36
6	1	20	94	45	42	39
7	-	--	3	14	24	23
8	-	--	--	44	13	15
9	-	--	--	9	17	13
10	-	--	--	3	8	10
11	-	--	--	8	12	10
12	-	--	--	10	16	14

TABLE 4.8
NUMBER OF ACCIDENTS BY CAMERA AND YEAR

	Year					
Camera	1980	1981	1982	1983	1984	1985
3	0	6	10	13	9	16
4	1	9	28	21	18	12
5	0	6	7	8	12	15
6	0	2	11	7	14	7
7	--	--	0	7	7	13
8	--	--	--	2	7	3
9	--	--	--	3	9	5
10	--	--	--	1	5	5
11	--	--	--	2	4	6
12	--	--	--	3	8	9

Table 4.9

Incidents, Accidents, and Disabled Vehicles by Season

Season	Event	1981	1982	1983	1984	1985
Winter Jan.-March	All incidents	*	60	50	87	68
	Accidents		14	19	33	26
	Disabled vehicles		40	29	49	38
Spring	All incidents	26	96	38	98	53
	Accidents	6	7	10	39	26
	Disabled vehicles	18	81	27	42	25
Summer July-Sept.	All incidents	25	62	31	20	46
	Accidents	8	14	4	4	15
	Disabled vehicles	17	48	26	16	25
Fall Oct.-Dec.	All incidents	22	73	93	44	53
	Accidents	5	21	34	17	24
	Disabled vehicles	16	48	52	24	25
Average	All incidents	24.3	72.7	53.0	62.2	54.0
	Accidents	6.3	14.0	16.7	23.3	22.7
	Disabled vehicles	17.0	54.2	33.5	32.7	28.2

---

* System went into operation at end of 1980. Log startup problems were obvious, Data not included here.

4.3. Maintenance and Reliability

The cameras have to be adjusted in the field about once every two months. SCANDI staff report that Camera 6, located on a sign truss over I-94 at Russell Street, needs the most maintenance because of vibrations. There have been no major problems with the cameras otherwise. Examination of the work orders from 1985 show that about 25% of the work recorded for the CCTV system was related to unclear or "washed out" pictures.

So far there has been no vandalism on the cameras. This may be because they are not obtrusive, are mounted in high locations and the public is not generally aware of their existence. The records from the SCANDI daily failure log were obtained and summarized for 1985 and the first six months of 1986. Table 4.10 gives the number of camera-days that cameras were not operating for each month of this period. The most frequent reason for cameras not operating has been problems with the cable.

Table 4.10

Camera-Days

Out-of-Order

Month	1985	1986
January	25	63
February	76	35
March	45	30
April	47	89
May	58	70
June	32	--
July	13	--
August	45	--
Septebmer	67	--
October	31	--
November	23	--
December	18	--
Average no. of out-of-order cameras/day	2	2.8
Maximum possible out-of-order cameras/day	8	10
Average daily out-of-order rate (%)	25%	28%

5. CHANGEABLE MESSAGE SIGNS (CMS)

There are nine changeable message signs on the SCANDI system. Operation of the signs began on 12/12/80. Seven of the signs are located on inbound routes and two are on outbound routes. they are mounted on bridges and overpasses. The Changeable Message Signs (CMS) consist of nine rotating-element, tricolor, continuous matrix signs placed at various locations in the system, and a micro processor-driven base station located in the control center. Communication between the central processing unit (CPU) and the signs is via SCANDI communication lines for six signs and via Bell telephone lines for the remaining three. The signs are not internally illuminated, but are lighted by a set of external lights. These consist of four 500-watt quartz lights per sign. The message for the sign is selected by the operators of the system. When a particular message is desired, the signal is transmitted to the sign and the elements rotate to the appropriate positions to form the message. When no traffic-related message is desired, the signs are left blank.

Each sign consists of 2430 three-sided elements. Each element face is 2.5 inches square. The elements are placed in 90 columns, which are 27 elements high. The elements and electronics are housed in a walk-in cabinet which is 8 feet high by 20 feet wide by 4 to 5 feet deep (the sign face is angled, therefore the cabinet is 4 feet deep at the bottom and 5 feet at the top). Each sign has three major components: the controller, the driver rack, and the power supply.

The sign controller consists of a micro processor, a synchronous interface, and a tricolor interface. The micro processor contains eight kilobyte (KB) of system memory (EPROM) and two KB of Random Access Memory (RAM).

Rotation of the elements on the sign is controlled by a series of eighteen tricolor driver cards which comprise the driver rack. Each tricolor driver card controls an area of the sign 16 columns wide by 9 rows high.

Each sign contains a series of rechargeable batteries which will furnish the power necessary to drive the signs in case of power failure. In the absence of power, the system is set to blank and the sign remains in that state until power is restored. Thus, the danger of being unable to blank the sign due to power failure is minimized.

The main CPU consists of a micro processor containing 22 KB of EPROM, 2 KB RAM, and 3 KB of core memory. The core memory is used to store the message library. In addition to message storage, the CPU sends all commands to each sign, polls each sign in order to determine communication status, and maintains a system clock. The CPU also has asynchronous interfaces between the micro processor and the cathode ray tube monitor (CRT) and between the processor and printer. The CPU polls each sign every nine seconds in order to determine the status of communication. If communication is not established on the first polling, no action is taken. However, if after three pollings no communication is established, the failure will be noted on the system status display. In addition, if a sign fails to receive communication for a period of 3.5 minutes, it will automatically turn blank.

The CMS is operated from a keyboard/color (CRT) console. The CRT displays the system status at all times. System status includes the sign number and location, the status of communication, and the number of any message currently being displayed. The CRT can also mimic messages as they will appear on the sign, as well as cataloging the text of messages in memory. The processor is also connected to a printer which prints out all changes in the status of the system and indicates the time of the change. The system contains a one-quarter-inch magnetic tape unit which is used to back up the message library.

The system has two levels of operation, "operator" level and "super" level. Operation at the operator level allows the user to select messages from the library and place them on any sign in the system. The library can store over 300 messages. Access to the operator level is via a password. The name of the current user is printed out by the printer. In addition to the "operation" level, the "super" operator can create messages, assign passwords, perform backup functions, and operate the system clock. Access to the "super" level is via a special password.

The tricolor element can display black, yellow, or white either as a letter color or a background color. For example, messages can be displayed as black on yellow or yellow on black. However, yellow letters cannot be used with a white background and vice-versa. In addition to static displays, using one letter color and one background color, the message can be flashed. That is, the foreground and background colors can be interchanged. The entire sign face or a portion thereof can be flashed. Thus, black and yellow warning signs and black and white regulatory signs can be displayed (on the same face if desired) and the message can be displayed in a dynamic mode to attract greater attention. Both the color combinations and the mode (static or dynamic) are determined by the "super" operator.

Letters can be displayed in a variety of heights and widths. The standard letter size is 5 elements wide by 7 elements high. This standard size can be made taller, shorter, or narrower. Letters can be displayed as upper or lower case. Giant letters are available which cover two or three lines on the sign. In addition to letters and numbers, arrows can be displayed, along with an assortment of punctuation characters. Letter size is determined by the "super" operator.

5.1. Sign Usage

The following table (Table 5.1) is a summary for the years 1984 and 1985 of the numbers of occurrences and length of time that the signs were in use.

Table 5.1

CMS use in 1984 and 1985

Location 1

	1984			1985	
Month	Occurrences	Total Time On (min)	Month	Occurrences	Total Time On (min)
Jan	5	559	Jan	3	193
Feb	2	74	Feb	3	198
Mar	0	0	Mar	8	389
Apr	5	28890	Apr	15	13426
May	15	9878	May	19	42023
Jun	13	9356	Jun	9	29750
Jul	24	40106	Jul	24	35700
Aug	17	33886	Aug	5	9427
Sep	15	56804	Sep	12	19055
Oct	8	5063	Oct	12	5500
Nov	7	4675	Nov	16	5192
Dec	8	3686	Dec	6	10021
Total	119	192977 min	Total	132	170874 min
Ave. time on		27 hours/mo	Ave. time on		21.6 hours/mo

Location 2

1984 Month	Occurrences	Total Time On (min)	1985 Month	Occurrences	Total Time On (min)
Jan	1	404	Jan	1	136
Feb	0	0	Feb	0	0
Mar	0	0	Mar	0	0
Apr	4	28864	Apr	1	5921
May	12	8034	May	0	0
Jun	8	8894	Jun	2	1114
Jul	21	44228	Jul	1	219
Aug	16	33098	Aug	1	477
Sep	14	32538	Sep	0	0
Oct	3	300	Oct	2	4876
Nov	2	1063	Nov	9	1972
Dec	0	0	Dec	0	0
Total	81	157423 min	Total	17	14715 min
Ave. time on		32.4 hours/mo	Ave. time on		14.4 hours/mo

Location 3

1984 Month	Occurrences	Total Time On (min)	1985 Month	Occurrences	Total Time On (min)
Jan	9	1044	Jan	12	987
Feb	12	766	Feb	6	253
Mar	6	578	Mar	5	394
Apr	15	29894	Apr	9	13347
May	12	7852	May	18	42129
Jun	7	8796	Jun	6	20923
Jul	18	27221	Jul	20	18627
Aug	11	19598	Aug	14	7855
Sep	16	26730	Sep	23	20789
Oct	11	8606	Oct	11	4934
Nov	11	5094	Nov	10	2762
Dec	5	721	Dec	13	10770
Total	133	1369900 min	Total	147	143770 min
Ave. time on		17.2 hours/mo	Ave. time on		16.3 hours/mo

Location 4

Month	1984 Occurrences	Total Time On (min)	Month	1985 Occurrences	Total Time On (min)
Jan	4	434	Jan	5	201
Feb	1	89	Feb	1	110
Mar	0	0	Mar	0	0
Apr	3	28823	Apr	7	13480
May	6	7291	May	7	18233
Jun	9	8128	Jun	0	0
Jul	21	32406	Jul	4	4188
Aug	14	23462	Aug	1	477
Sep	15	32557	Sep	0	0
Oct	4	312	Oct	6	1631
Nov	3	4008	Nov	1	895
Dec	5	8865	Dec	10	10394
Total	85	146375 min	Total	42	49609 min
Ave. time on		28.7 hours/mo	Ave. time on		19.7 hours/mo

Location 5

Month	1984 Occurrences	Total Time On (min)	Month	1985 Occurrences	Total Time On (min)
Jan	10	1056	Jan	7	354
Feb	16	1041	Feb	0	0
Mar	6	519	Mar	3	212
Apr	13	29719	Apr	9	13364
May	19	8621	May	18	42137
Jun	9	9569	Jun	9	21655
Jul	25	71941	Jul	30	35918
Aug	21	108585	Aug	13	7775
Sep	18	33012	Sep	21	19776
Oct	14	47523	Oct	10	4690
Nov	13	5320	Nov	22	5590
Dec	6	729	Dec	14	10748
Total	170	317635 min	Total	156	162219 min
Ave. time on		31.1 hours/mo	Ave. time on		17.3 hours/mo

Location 6

Month	1984 Occurrences	Total Time On (min)	Month	1985 Occurrences	Total Time On (min)
Jan	2	421	Jan	1	136
Feb	0	0	Feb	2	219
Mar	0	0	Mar	8	511
Apr	4	28878	Apr	9	13198
May	4	7273	May	25	38748
Jun	10	8263	Jun	11	27075
Jul	17	33740	Jul	23	35486
Aug	16	28215	Aug	10	7514
Sep	14	32538	Sep	18	19280
Oct	3	365	Oct	16	2140
Nov	3	1986	Nov	19	5355
Dec	1	93	Dec	16	10966
Total	74	141772 min	Total	158	160628 min
Ave. time on		31.9 hours/mo	Ave. time on		16.9 hours/mo

Location 8

Month	1984 Occurrences	Total Time On (min)	Month	1985 Occurrences	Total Time On (min)
Jan	28	1673	Jan	13	1065
Feb	22	1378	Feb	14	913
Mar	14	1018	Mar	18	1334
Apr	21	30303	Apr	9	6401
May	25	10541	May	12	29659
Jun	22	18084	Jun	8	20760
Jul	21	32812	Jul	19	34947
Aug	22	28012	Aug	22	12229
Sep	26	34148	Sep	22	19702
Oct	22	2828	Oct	18	9731
Nov	16	6597	Nov	24	5659
Dec	6	893	Dec	13	10818
Total	245	168287 min	Total	192	153218 min
Ave. time on		11.4 hours/mo	Ave. time on		13.3 hours/mo

Location 9

	1984			1985	
Month	Occurrences	Total Time On (min)	Month	Occurrences	Total Time On (min)
Jan	17	1349	Jan	16	1232
Feb	11	725	Feb	8	628
Mar	10	789	Mar	13	1101
Apr	17	29981	Apr	12	13591
May	22	8999	May	16	42048
Jun	21	17928	Jun	6	20614
Jul	18	26895	Jul	22	36754
Aug	25	36009	Aug	19	11885
Sep	26	34203	Sep	20	19643
Nov	16	5061	Nov	22	4008
Dec	10	9611	Dec	13	10778
Total	210	180343 min	Total	183	171834 min
Ave. time on		14.3 hours/mo	Ave. time on		15.6 hours/mo

All Locations

	1984			1985	
Month	Occurrences	Total Time On (min)	Month	Occurrences	Total Time On (min)
Jan	96	8237	Jan	77	5749
Feb	79	5010	Feb	44	3138
Mar	46	3688	Mar	69	5017
Apr	96	265184	Apr	85	106441
May	150	81608	May	133	294771
Jun	125	122784	Jun	58	162993
Jul	188	348331	Jul	169	237333
Aug	169	347543	Aug	107	68141
Sep	169	316703	Sep	141	138341
Oct	99	75323	Oct	106	48484
Nov	85	40276	Nov	149	37248
Dec	51	34314	Dec	99	85334
Total	1353	1649091 min	Total	1237	1192990 min
Ave time on		20.3 hours/mo	Ave. time on		16.1 hours/mo

5.2 CMS Impacts

Because of the present poor readability of the signs, it was not possible to conduct a reliable evaluation of their impact upon redirecting traffic. However, a preliminary study was done by the SCANDI staff when the signs were in much better condition.

The incident studied occurred on the north bound Chrysler Freeway (I-75) at Ford Freeway (I-94), as shown in Figure 5.1, at 15:15 on Monday, November 26, 1984. This accident blocked all lanes of north bound I-75, warranting alternate route messages. The incident lasted for 45 minutes. Table 5.2 is a comparison of the traffic volumes at two key stations.

It appears that the alternate route attracted approximately 17% and 35% more vehicles over average for that time period at the two key detector stations. However, we cannot discount radio traffic reports as having an impact on drivers taking alternate routes.

Table 5.2

Traffic Volume Comparison

Zone 136 Data: NB US-10 Ramp to EB I-94:

TIME	AVG. VOL.	11-26-84	%	
15:15	195	196	0	
15:30	193	219	+13	
15:45	142	183	+29	Overall
16:00	134	189	+41	17%
16:15	143	172	+20	Increase
16:30	167	196	+17	
16:45	144	154	+ 7	

Zone 14 Data: EB I-94 Ramp to NB I-75:

TIME	AVG. VOL.	11-26-84	%	
15:15	269	294	+ 9	
15:30	257	342	+33	
15:45	200	315	+58	Overall
16:00	175	357	+104	35%
16:15	187	296	+58	Increase
16:30	278	293	5	

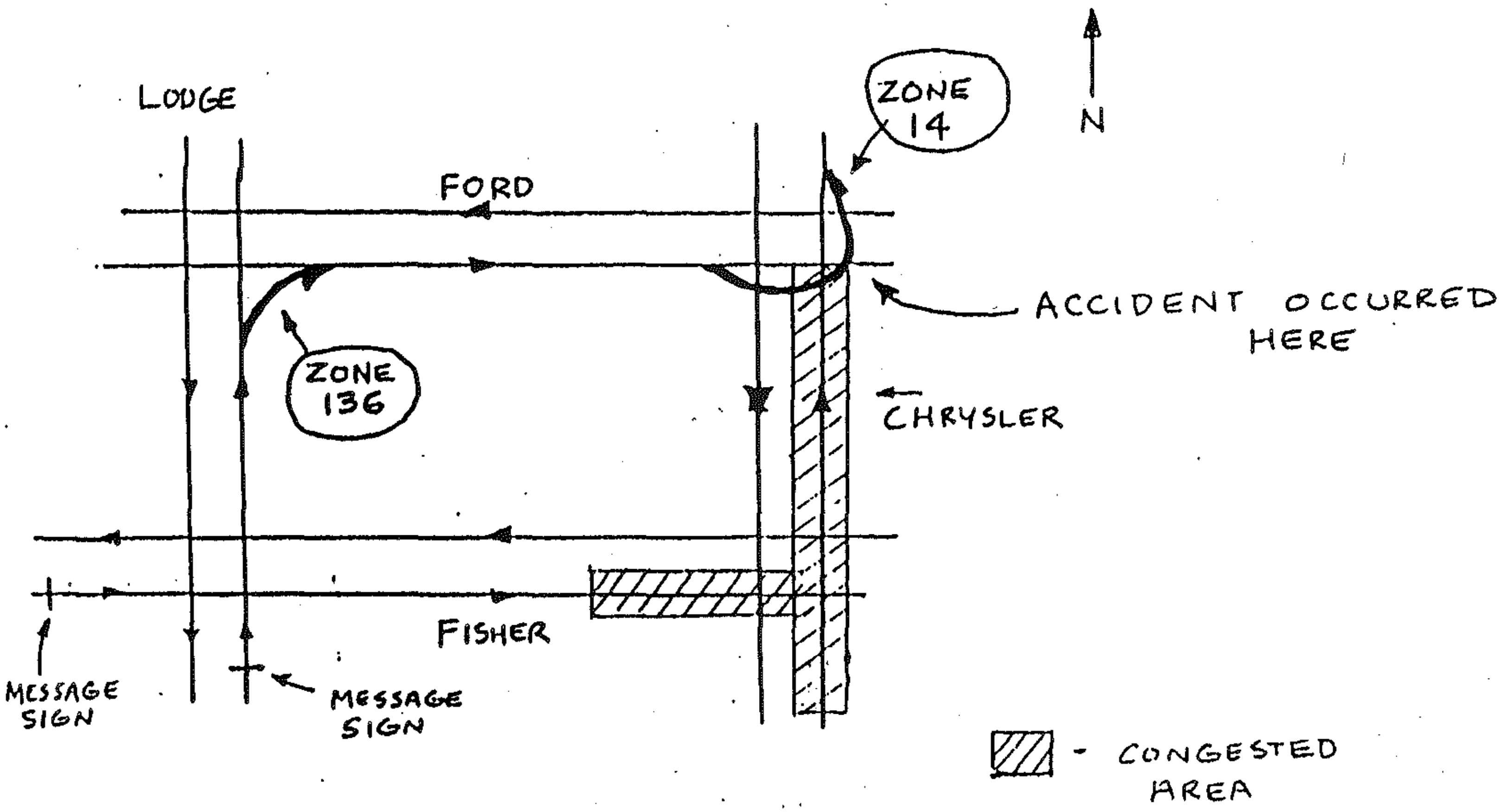


Figure 5.1 CMS Impact Study Area

6. RAMP METERING

Ramp metering is a strategy of freeway operations designed to improve the flow of freeway traffic by controlling the rate at which additional vehicles are allowed into the traffic stream. The primary goal of ramp metering is the efficient use of the highway system.

The freeway on-ramp is the interconnecting roadway between the freeway and the adjoining highway or street that provides vehicle access to the freeway. Freeway ramp control systems are used to control the flow of vehicles onto the freeway and thereby maintain freeway operations at an acceptable service level.

Ramp control systems can be implemented on individual on-ramps or on a sequence of on-ramps. Different types of systems have been used since the early 1960's, including:

1. Ramp closure;
2. Pre-timed or fixed-time control;
3. Gap-acceptance control;
4. Traffic responsive or real-time control.

The most rudimentary ramp control system is a ramp closure. For this type of control, vehicle access to the freeway for a given on-ramp is prohibited during the peak periods. This type of control is used where a downstream one-way constriction, called a bottleneck, adversely restricts the free movement and flow of traffic because the traffic demand exceeds the available freeway capacity. By eliminating the additional on-ramp flow via a ramp closure, the traffic obstruction at the bottleneck is prevented. Ramp closure is considered by many traffic engineers to be the least desirable type of control.

Pre-timed ramp control systems utilize one or two traffic signals located on the ramp upstream of the beginning of the acceleration lane. For many applications the traffic signal rests in red until a ramp vehicle arrives at the traffic signal, at which time it is turned green to allow vehicle passage. The traffic signal remains green until the vehicle is detected by an inductive loop, called a check-out sensor, which is located just downstream of the traffic signal. When the check-out sensor detects a vehicle the traffic signal is turned yellow for a short period of time until it again displays red. If a subsequent vehicle is waiting at the traffic signal, it is detained there to allow for a pre-time interval or separation between ramp vehicle releases. In this way pre-timed ramp control limits or meters vehicle access to the freeway. At some locations, instead of single vehicle metering, two or more vehicles are permitted access to the freeway when the vehicle signal is turned green.

In gap-acceptance ramp control, the release of ramp vehicles from the ramp-side traffic signal is coordinated so that both the freeway acceptable gaps and ramp vehicles arrive at the merge area at the same time. An acceptable freeway gap is an opening in the right lane freeway traffic that exceeds a predefined time separation below which ramp drivers are not able or willing to make a merge. Drew, R. (1967) defines an acceptable gap as "one equal to or larger than the critical gap," where the critical gap is "that gap for which an equal percentage of ramp traffic will accept a smaller gap as will reject a larger one."

The gap-acceptance type of ramp control differs from the pre-timed control in that with pre-timed control the release of ramp vehicle is not coordinated in any way with the acceptable freeway gaps. For gap-acceptance control two freeway inductive sensors are used by a mini-computer to determine the size of the freeway gap, and the speed at which the gap is traveling towards the merge area. The actual release time of the ramp vehicles is computed so that both the acceptable gap and the ramp vehicle arrive at the merge area simultaneously. Gap-acceptance control systems also employ a maximum waiting time from the moment a ramp vehicle activates the check-in sensor. If the computer does not find an acceptable gap within that time period the vehicles is released from the traffic signal in the same way as in pre-timed ramp control.

In real-time ramp control systems, traffic is monitored along a section of the freeway for the purpose of adapting the ramp metering rate or flow in accordance with the existing freeway traffic conditions. With a traffic responsive system, when the freeway flow is approaching downstream capacity, the flow from the ramp is reduced to prevent a breakdown in the freeway flow. A traffic responsive system also permits an increase in the ramp flow whenever the freeway flow decreases. Typically, the monitoring of freeway traffic conditions is a function of either a volume or an occupancy measure. For either measure, the ramp traffic flow is based upon maintaining the total demand to a value to or less than the downstream capacity in order to maintain a given service level.

6.1 SCANDI Ramp Metering System Description

The ramp metering operation of SCANDI started on November 17, 1982 with 6 ramps on the Ford Freeway (I-94). Nineteen more ramps on I-94 were added on January 27, 1984. Three additional ramps were added on November 18, 1985.

Currently, fifteen consecutive ramps on the Ford Freeway in each direction have ramp controllers and the necessary detector complement. Growth capability of up to 250 metered ramps has been provided for the system.

The ramp control communications system consists of one Central Control Unit (CCU) located in the central computer room and 28 Remote Control Units (RCU) located on I-94, one per ramp controller. Once each 1/4 second the CCU poles each ramp controller RCU. All ramp controller RCUs have different addresses and are serviced by a single channel, one RCU per millisecond.

The computer commands the state of the red and green signal as well as the power on/off through the CCU to the RCU to the ramp controller. The computer monitors the state of each of these plus the operability of the communications. At the quarter second point, the computer sends the complete block of commands for the next 1/4 second to the CCU. It then receives from the CCU a complete block of responses accumulated over the last quarter second. Failure evaluation are made on this response data.

The computer monitors the freeway lane occupancy. The "turn on" threshold occupancy for all the ramps is in the range of 10 -13% occupancy. This is the value of occupancy for freeway speeds of 35 to 45 mph and is an indicator of congestion. Ramp metering is intended to maintain the level of service on the freeway at levels of service C or D. The metering on a ramp will stop if the occupancy decreases to the "turn off" threshold value. These values are in range of 6 - 9% occupancy and are associated with speeds of 50 to 55 mph.

The ramp meters can also be turned on in response to incidents that have been reported or detected by the T.V. cameras or by the computer.

The rate at which vehicles are allowed to enter the freeway from the metered ramps is 15 vehicles/minute. This is 4 seconds per vehicle. The ramp signal is set for 2.5 seconds of red and 1.5 seconds of green. The system has the capability of operating at slower or higher rates. However, the present operation uses only the specified rate.

The ramp metering typically goes into operation during the morning peak period (7-9 a.m.) and during the evening peak period (3-6 p.m.). About once per month there is a situation during the off-peak period (such as an accident or spilled load) that results in a condition which warrants ramp metering.

As part of this system, detectors are found immediately upstream of each entrance ramp. Total volume, average occupancy and average speed on the freeways are computed by the data from these detectors.

All entrance ramps have been equipped with a passage detector in each lane. The passage detectors are used by the ramp meters to tell when a vehicle has cleared the meter. These detectors are also used to measure the volume onto the freeway and are located immediately downstream of the ramp meter stop line. The demand detectors are located immediately upstream of the ramp meter stop line and inform the ramp meter when a vehicle is ready to enter the freeway. The queue detectors are located at the upstream end of the metered entrance ramps and from these data the existence of an excessively large queue can be detected.

The ramp meter traffic signals are located at the downstream end of entrance ramps on the Ford Freeway and can display either a red or a green signal. These signals can either be steady green, cycled between red and green or turned off. The all green mode is displayed for 30 seconds prior to and after the metering period. Each ramp is equiped with the following fixed signing:

1. Two "STOP HERE ON RED" signs located at the painted stop bar.
2. Two "ONE CAR PER GREEN" signs located 50 feet upstream of the stop bar.
3. One "PREPARE TO STOP WHEN FLASHING" sign located at the top of the ramp.

Metering traffic onto the freeway by alternating between red and green is the normal mode of operation.

A study was performed to determine the "on-time" of the ramp metering system. The system logs were reviewed for the first nine days of May, 1986 to determine metering times for several ramps. The metering is set to automatic mode at times varying over a period of approximately one-half hour each day, at approximately 7:00 a.m., and 2:30 p.m. Almost invariably, the automatic vehicle counters switched on the metering within three to five minutes after the operator set the system to automatic mode. The shutoff times varied, and some of the meters cycled on and off several times during the time they were set; however, most remained on continuously. The greatest variation was seen when the system was left in automatic mode over the weekend, and the metering did not come on until 8:00 Monday morning. The automatic system shut off the metering Friday evening approximately two hours later than the operators shut it off the following Friday evening. No cycling of the metering appeared to occur during the weekend when it was left in automatic mode.

The time at which an operator changes the ramp control from manual to automatic is recorded in a log. There is also a record whenever a ramp meter turns on automatically. At any time that the SCANDI system is operating, one can get a minute by minute status of all the ramps.

6.2 Summary of Literature Review

The literature review reveals that the use of ramp metering as a control strategy for urban freeways is widely used. Different ramp metering strategies are used, but the fixed-time metering strategy is considered most reliable and simplest to implement.

The strategy of metering a freeway-to-freeway interchange ramp is also discussed in the literature review, the technique has been used successfully in San Diego.

Nothing was found that addressed simulation of freeway-to-freeway control strategies in conjunction with the usual control strategies at local on-ramps by means of computer models. Gordon (1972) developed some ideas, but they were theoretical and based upon developing mathematical equations to calculate the delay and queue at the on-ramp of the interchange.

Table 6.1 summarizes the features and results of the ramp control systems included in the literature review.

The use of traffic simulation models as a reliable approach to evaluate the effectiveness of ramp metering operations is also documented in the literature. There are many traffic simulation models available, and Table 6.2 summarizes the features of those models which simulate freeway traffic.

Table 6.1

Summary of Ramp Control Cases

				RESULTS		
		SECTION LENGTH	No. OF RAMPS	V	Veh. Hours	
FREEWAY	CITY	mi		mph	Freeway	Local
Harbor	Los Angeles	5	6	+20	-1000	+130
Hollywood	L.A.	-	2	-	- 500	+ 50
San Diego	Chula Vista	3.2	4	+16	-	-
Gulf	Houston	6	9	+16	- 360	+ 23
Lodge	Detroit	3.2	8	+15	- 200	-
Dan Ryan	Chicago	3.6	4	-	- 627	-

Table 6.2

Summary of Freeway Simulation Models

MODEL	MODEL TYPE	MODEL PURPOSE	TRAFFIC FLOWS
INTRAS	stochastic microscopic	incident detection and evaluation of control strategies	vehicle-specific time-stepping simulation.
FREFLO	deterministic macroscopic	simulate freeway 1-direction	conservation equation dynamic speed density
FRECON	macroscopic	simulate freeway 1-direction	modified from FREFLO
FREQ	macroscopic	simulate freeway and evaluate priority lanes.	H.C.M. (speed-volume curve)
CORQ	macroscopic	queueing in freeway corridor.	step-function travel time.
CORCON	macroscopic	queueing in freeway corridor.	step-function travel time.
TRAF	macroscopic	all networks	FREFLO
TRAFLO-M	macroscopic	all networks	DYNEV

parts of this table taken from Aerde et al., 1987.

6.3 Implementation of INTRAS

Since the INTRAS model has not been released for public use yet, a copy of it was acquired directly from FHWA for the study.

The FHWA program of the model was written for the IBM mainframe, and the first step in the implementation was to adopt the program and the model so that it could be run on the MDOT Burroughs computer. The conversion process was a lengthy one, since the Burroughs has an old FORTRAN compiler and its random access memory (RAM) is too small to handle all the subroutines and large arrays of the model.

These limitations of the Burroughs mainframe computer led to many changes in the source code of the model. The major changes were the elimination of the fuel consumption and the plotting subroutines from the program and the reduction of many storage arrays.

Since the INTRAS simulation model requires much input data with many variables involved, the second step in the implementation process was to divide those variables into two categories: control variables and fixed parameters. These are defined below:

Control variable: The primary goal of this study was to evaluate the present operation of SCANDI and determine possible ways to improve the freeway traffic operation by optimizing the metering rate on the on-ramps. This specific goal led to the choice of only one control variable; the timing of the signals which control the metering rate of the ramps.

INTRAS has the ability to model this metering rate in four different ways because it has four types of ramp metering control methods: clock time metering, speed control metering, demand/capacity metering, and gap acceptance merge control.

In this study, clock time metering was the control method used to model the control variable. This decision was based on the conclusion, from the literature review, that it is the simplest method to implement and the most reliable of the four methods. Furthermore, the literature review (Munjal, 1973, and Buhr, et al., 1969) revealed that the other three control methods have high failure rates and are not stable because their implementation depends totally on accurate and continuous operation, which is usually hard to achieve.

Fixed parameters: The rest of the potential variables, both network variables and model parameters, were kept fixed during the study.

6.4. Study Area

The evaluation was conducted on the portion of the Ford Freeway (I-94) within the Detroit city limits, that is, where the ramp meters are installed on that freeway.

The Ford Freeway (I-94) runs about 15 miles inside the city of Detroit, where it has three major freeway-to-freeway interchanges. All of the nonfreeway entrance ramps have ramp metering signals to control vehicle entry to the freeway at a rate of one car per green interval.

Because of the size of the network it was not feasible to collect data at each location of interest along the freeway. Instead, a set of locations was chosen that will cover all different operational situations (i.e., the merging areas after local entrances in different locations along the freeway).

Figure 6.1 shows the selected locations. Each location will be referred to by the immediately preceeding ramp. The choice of the locations is planned in a way that: (1) both directions of the freeway would be covered; (2) ramps in between freeway-to-freeway interchanges would be sampled; and (3) ramps at the outskirts of the freeway would be sampled. Another consideration in the sampling was to cover, in most locations, both the morning and the evening peak hours.

The following table, Table 6.3, shows the selected locations, date, time, and duration of data collection.

Table 6.3

Selected Locations: Date, Time, and Duration of Data Collection

LOCATION	DIR.	DATE	TIME	DURATION	METER
Linwood	East	09/03/86	8:00-5:30	10 min/hr	on
Linwood	East	09/10/86	8:00-5:30	10 min/hr	off
Mt. Elliot	West	09/17/86	9:00-5:30	10 min/hr	on
Mt. Elliot	West	09/18/86	9:00-4:30	10 min/hr	off
Van Dyke	West	09/17/86	8:30-noon	10 min/hr	on
Van Dyke	West	09/18/86	8:30-noon	10 min/hr	off
John R.	West	10/15/86	3:30-5:00	15 min/30 min	on
John R.	West	10/16/86	3:30-5:00	15 min/30 min	off
Trumbull	West	10/28/86	3:30-5:30	15 min/30 min	on
Trumbull	West	10/29/86	3:30-5:30	15 min/30 min	off
Gratiot	East	11/18/86	3:30-5:00	15 min/30 min	on
Gratiot	East	11/19/86	3:30-5:00	15 min/30 min	off
Mt. Elliot	West	04/16/87	7:30-3:00	5 min/30 min	off

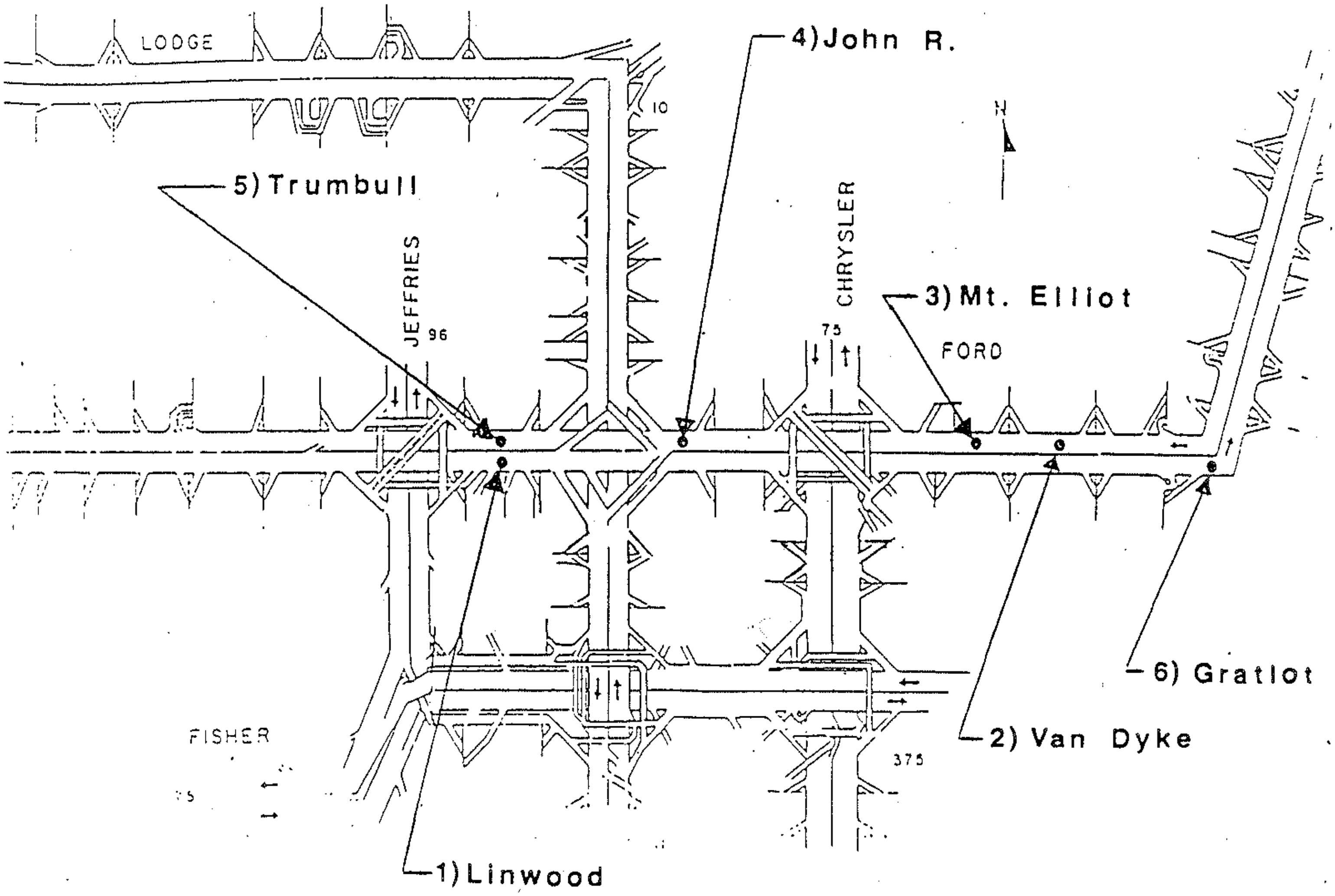


FIGURE 6.1

SELECTED LOCATIONS FOR SAMPLING

6.5. Data Collection

6.5.1. Data Elements

There are two sets of data collected for this study: (1) data for building the network, and (2) data needed for calibrating and validating the model.

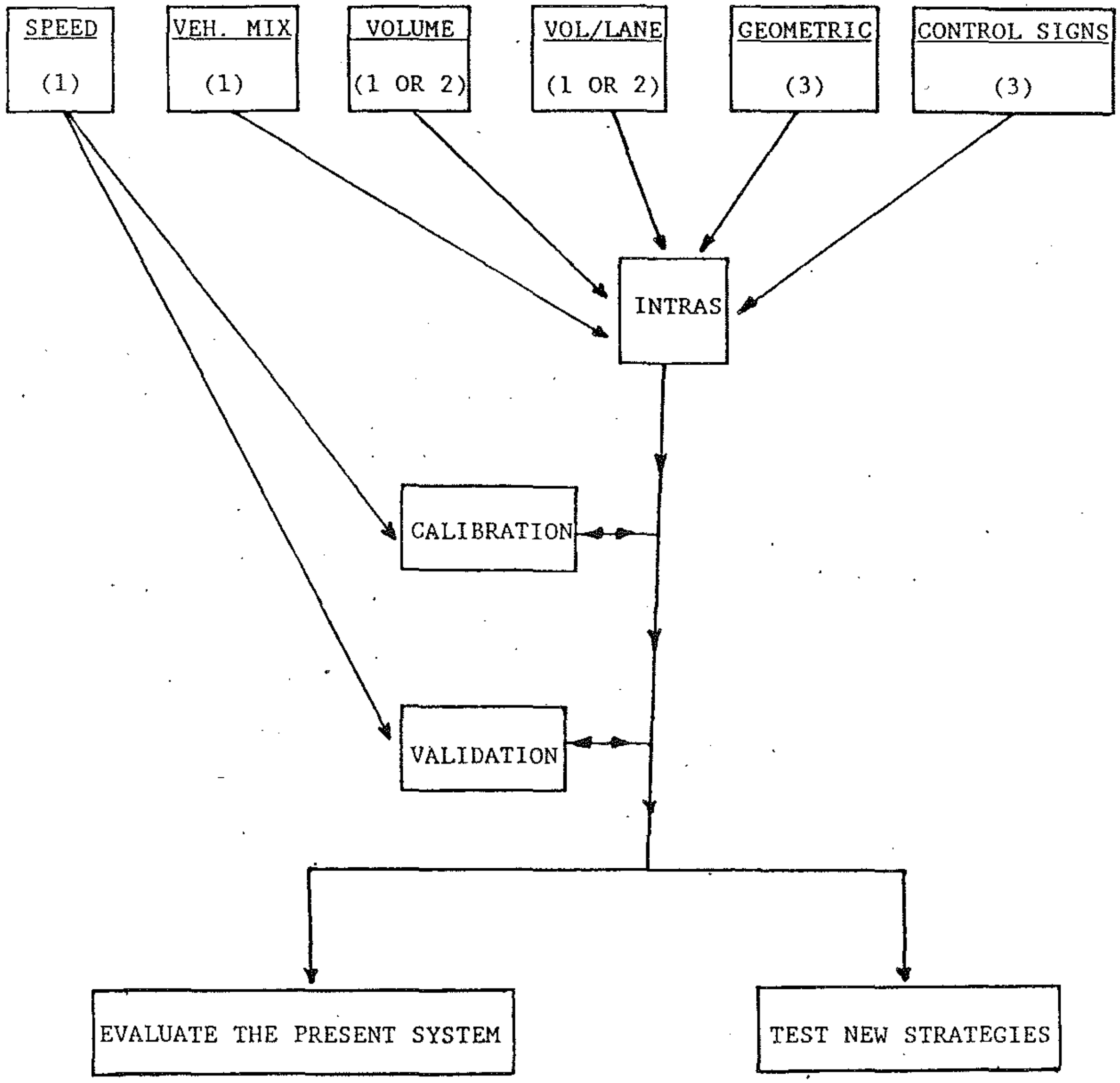
1. Model building data: Table 6.4 summarizes the geometric and operational data elements needed for running the INTRAS model. The geometric data were taken from the Ford Freeway design plans, and the operational data were collected from the computer outputs of the main frame computer that controls the SCANDI system. This data includes volumes on each lane on the freeway, volumes on entrance and exit ramps, and occupancy level.

2. Field data: This data includes vehicle speeds, vehicle mix, and volumes on the main freeway, and vehicle mix and volumes on the on-ramp at each sample location.

Figure 6.2 summarizes the data elements needed for this study and their sources.

Figure 6.2

DATA ELEMENTS, SOURCES AND FLOW THRU THE STUDY



---

(1) Field data (2) SCANDI computer data (3) Design plans

Table 6.4

Input Data Required for INTRAS

GEOMETRIC

Links defined by upstream, downstream node numbers.

Link lengths.

Number of lanes.

Turn pockets.

Grade.

TRAFFIC VOLUMES

On all entry links nodes stratified by vehicle type (up to 5 types)

Link-specific turn movements.

TRAFFIC CONTROL SPECIFICATIONS

Stop and yield signs.

Turn restrictions.

Traffic signals.

Traffic control may be fixed-time or traffic-actuated.

Route diversion specifications.

DRIVER'S AND OPERATIONS CHARACTERISTICS

Driver's response mechanisms: free-flow speed, sensitivity, discharge headway.

Link-specific mean speed for free-flowing traffic.

Vehicle-type operational characteristics: acceleration, deceleration.

6.5.2. Field Date Collection Procedures

The collection of data was done in two steps. First, pilot data was collected during the period between April and July 1986. These data were used to check both the ability of the model to operate correctly and the ability of the students involved in the data collection phase to operate with consistency and accuracy. Second, the final data was collected at the selected sampling location between August 1986 and April 1987.

The dates for collecting the final data were chosen to represent normal traffic operations and volumes for the city of Detroit (i.e., when schools are open). Furthermore, the data were collected only during normal weekdays (i.e., Tuesday, Wednesday, and Thursday). The reason for this is to avoid any abnormal traffic situations due to the start of the week (i.e., Monday) or due to the weekend traffic fluctuation during Friday afternoon hours. Efforts were made to collect the data during dry weather days so that the weather condition effect on driver behavior would not affect the evaluation process.

A video camera with a built-in timing clock was used to collect the data. This was done by placing the camera on the bridge that crosses over the freeway following the intended sampling location.

Pavement taping marks were placed at 50-foot intervals on the shoulders of each selected location prior to filming, to be used when performing data reduction.

6.6. Data Reduction

The Mt. Elliot entrance ramp onto the westbound Ford Freeway will be used as an example to illustrate the data reduction procedure used. The data used for this example was collected on September 18, 1986, between 10:00 a.m.

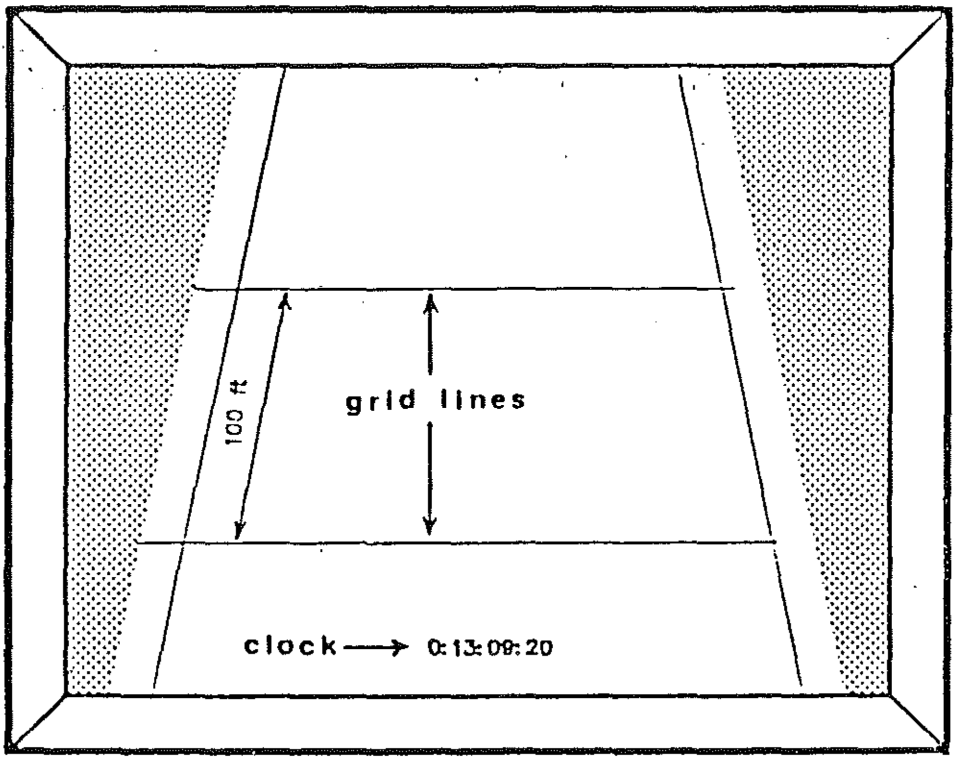
and 10:10 a.m. and is considered to be a representative sample for the one-hour period between 10:00 a.m. and 11:00 a.m. The steps described below summarize the reduction procedure.

6.6.1. Building the Grid

Using the pavement marks that were placed on the shoulder, a grid consisting of two lines that are 100 feet apart was drawn on the monitor screen showing the filmed data, as in Figure 6.3 below.

Figure 6.3

Placement of Grid on the Screen



6.6.2. Sample Size

Two procedures were used to reach a decision on the sample size required for the study.

1. Statistical approach: The following equation was used to determine the sample size.

$$n = \left[(Z_{\alpha/2})^2 * (S)^2\right] / d^2$$

which gave: $n = 43$ vehicles

where: n = the sample size;

d = tolerable margin of error of mean value;

S = standard deviation of sample distribution;

Z = standard normal statistic (table value);

α = level of significance.

A study was conducted to calculate the values needed for the equation, and the results were found as follows:

d = ± 2.0 mph was found to be a reasonable assumption. This was decided by comparing the estimation of the different persons collecting the data with the speeds of pilot vehicles with the known speed appearing on the screen along with the regular traffic.

S = 6.67; this was the average value of the values of standard deviation from different data sets. These values are shown in Table 6.5.

Z = 1.96, assuming 95% confidence level.

2. Empirical approach:

   a. A sample of volume (i.e., 15 vehicles) was chosen from the collected field data, and the average observed speed was plotted as indicated by point 1 in Figure 6.4.

   b. A second sample of the same size was selected, and the average speed of those two samples was plotted as point 2.

   c. This procedure was continued until a stable average speed (S1 = 58.90) was reached at point 4.

   d. The volume associated with that value (i.e., 60 vehicles) was considered the sample size that will assure stable measures by students estimating the speeds.

As a result of the two approaches, the sample size n for this study was taken as n = 60 vehicles per data set.

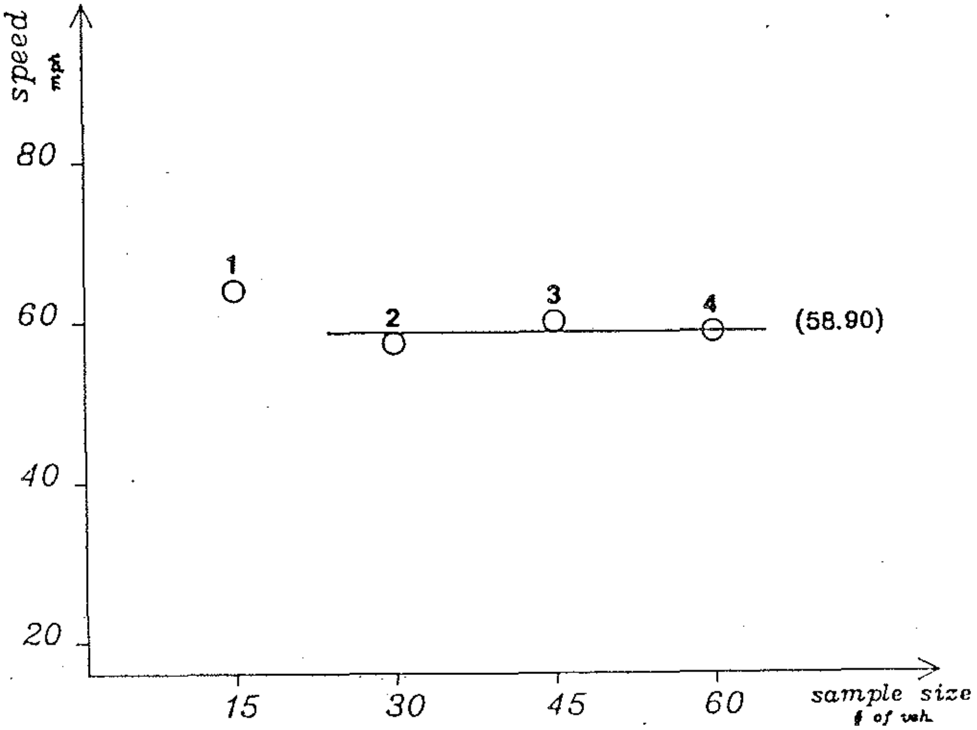


Figure 6.4 Choosing The Sample Size

6.7. Calibration of INTRAS

Calibrating any model requires the analyst to make several runs for one set of data (i.e., one time sample at one location), and for each single run a chosen parameter(s) will be given a new value(s) until the difference between the MOE from the model and the observed MOE from the field data becomes statistically insignificant. The MOE that was compared in this study was the average speed.

6.7.1. Car Following Model

The main formula in the INTRAS model that was focused on during the calibration is the "car following model." This model calculates and defines the acceleration of the following car depending on the relative locations and speeds of the two cars (i.e., the leading car and the following car) and the type of driver of each car (INTRAS defines ten types of drivers on the road ranging from very aggressive to timid).

Table 6.5

Calculation of Standard Deviation (S.D.)

LOCATION	DATE	TIME	AVE. SPEED	S.D.
Linwood	9/3/86	13:00	9.25	7.23
		14:00	58.24	7.34
		16:30	61.33	5.78
		8:00	38.63	9.98
		9:00	49.22	7.40
		10:00	54.85	5.56
		11:00	57.57	7.84
		12:00	54.94	5.45
Mt. Elliot	9/17/86	8:00	57.80	7.26
		9:00	60.03	6.70
		10:00	63.41	6.03
		11:00	58.78	5.26
		12:00	61.09	9.22
Mt. Elliot	9/18/86	9:00	35.21	5.50
		10:00	58.91	7.54
		11:00	60.72	6.32
		12:00	58.83	6.09
Van Dyke	9/17/86	8:30	59.05	7.24
		9:30	60.54	7.94
		10:30	55.06	5.03
		11:30	53.74	6.10
Van Dyke	9/18/86	8:30	27.58	5.51
		9:30	53.15	6.11
		10:30	61.24	6.76
		11:30	58.17	5.57

ave. SD = 6.67

This formula also contains an array of car-following parameters that relates to the "driver's sensitivity." The input values for this array can be changed externally by changing the values assigned to the type of driver using a special input card.

This card is one of the special input cards entitled "Embedded Data Change Cards" in INTRAS (Wicks and Andrews, 1980). Its purpose is to change the values of the driver's sensitivity already embedded in the model. the values that can be assigned to the parameters through this card range from 0 to 99. The smaller that the values of the parameters get, the more aggressive the drivers are assumed to be.

The default values of the parameters on card 43 are as the following:

I	1	2	3	4	5	6	7	8	9	10
Sensitivity Factor	15	14	13	12	11	10	9	8	7	6

where; I is the driver type.

The values that were found to best calibrate the INTRAS model for Detroit data look like the following:

I	1	2	3	4	5	6	7	8	9	10
Sensitivity Factor	11	10	9	8	7	6	5	4	3	2

The driver type and the sensitivity factor associated with it are randomly assigned to the vehicles entering the freeway when those vehicles are generated at the entry links.

6.7.2. Calibration Procedure

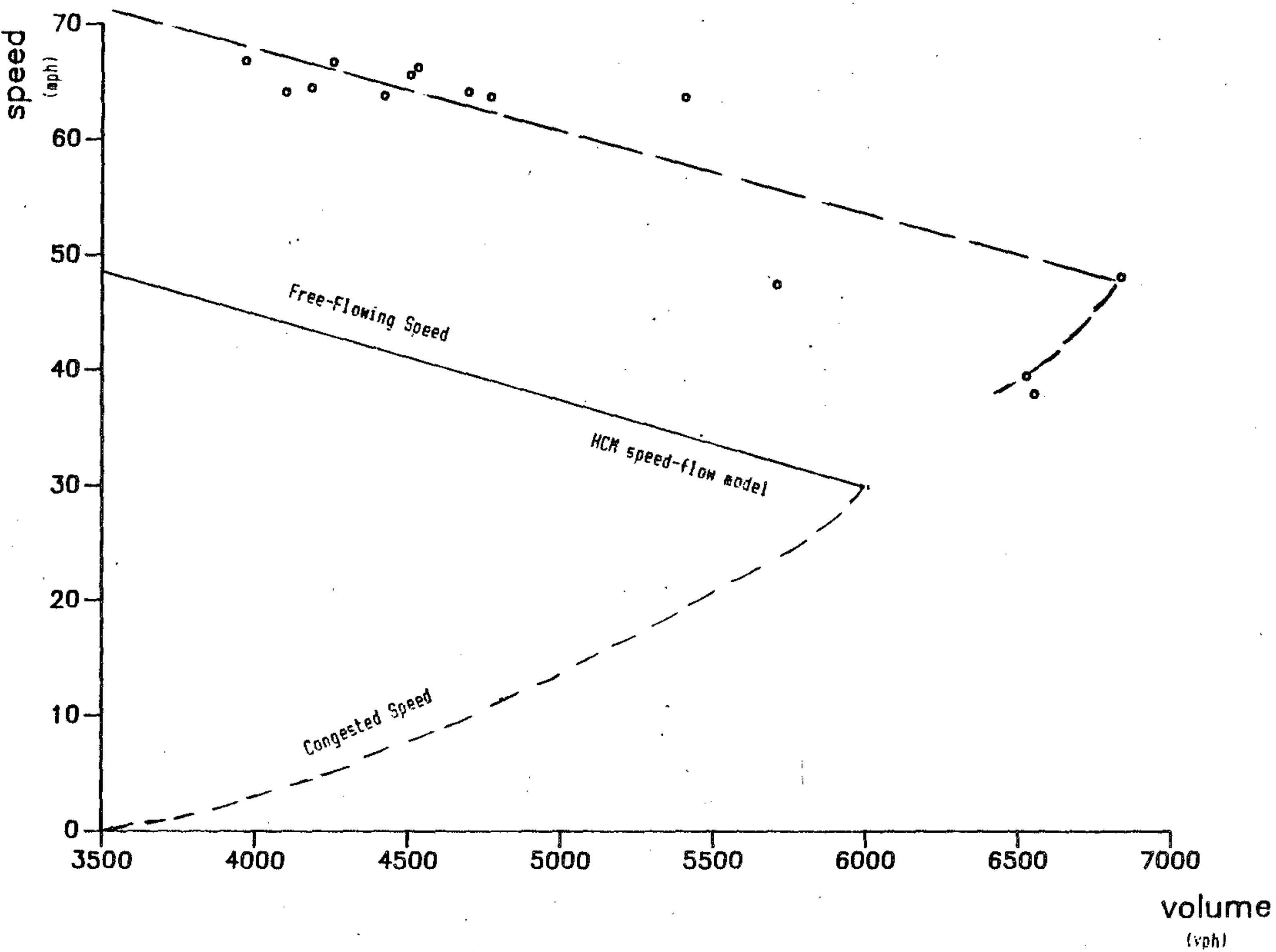
In this study, the model was calibrated using the volume, vehicle mix, and speed data collected at the Mt. Elliott location on the westbound Ford Freeway on 04/16/87/.

Figure 6.5 shows the volume-speed curve for this data. This curve is very similar in shape to the classic volume-speed curve in the highway Capacity Manual, 1985, which was superimposed over the same figure. The main differences between the two curves are the longer peak value of the Detroit data (which means higher volume) and the higher speeds in the Detroit data. This indicated that the data is similar to the general nationwide traffic behavior, but it has some special characteristics, this means that some of the default parameter values for INTRAS (which was calibrated to fit the general traffic behavior) needed to be changed so that the model can could replicate the Detroit data.

A sub-network was used to calibrate the model. The sub-network, Figure 6.6, contains the stretch of westbound Ford Freeway that starts just upstream of the Mt. Elliot entrance ramp and ends after the merging area that follows the ramp. The merging area is the area of interest in this study, and it is the area where the field data was collected.

The model was run, after coding the sub-network and loading it into the model, using the observed volume and vehicle mix data. Starting with the volume observed at 7:30 a.m., the model was run and the values on the embedded data change card were changed for each run until the output speed (C1) got close to the observed speed (S1) from the field at 7:30 a.m.

The last step was repeated for all the fourteen data points collected on that date. This was done by using the same sub-network for Mt. Elliot, but the hourly volume and the vehicle mix were adjusted for each data point.



Speed-Volume Curve for Mt. Elliot - 4/16/1987

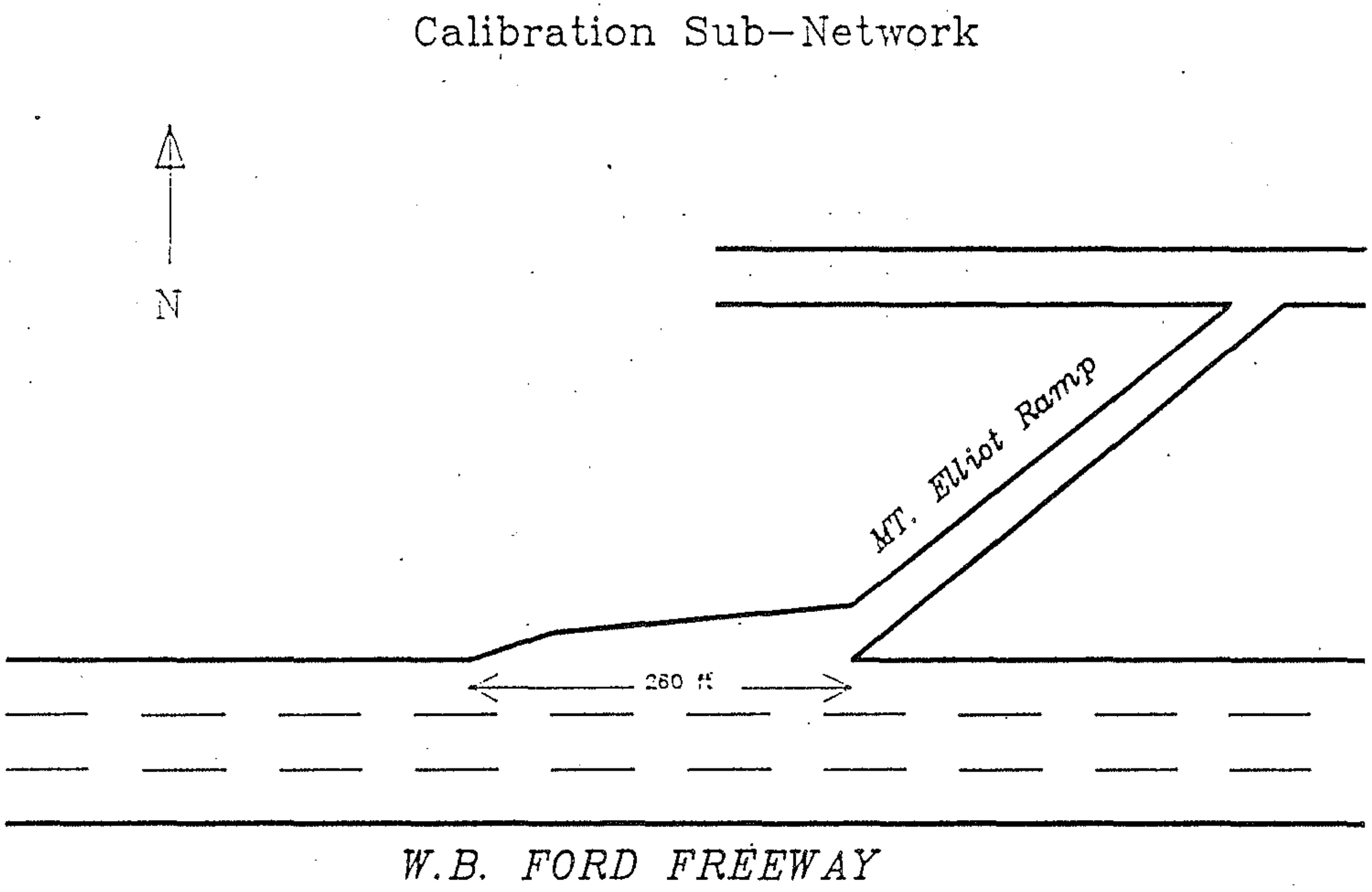


FIGURE 6.6

MT. ELLIOT SUB-NETWORK

The model output speeds and the observed speeds are shown in Table 6.6 and are plotted on Figure 6.7.

Figure 6.5

Table 6.6

Observed and Model Speeds for Mt. Elliot - 4/16/1987

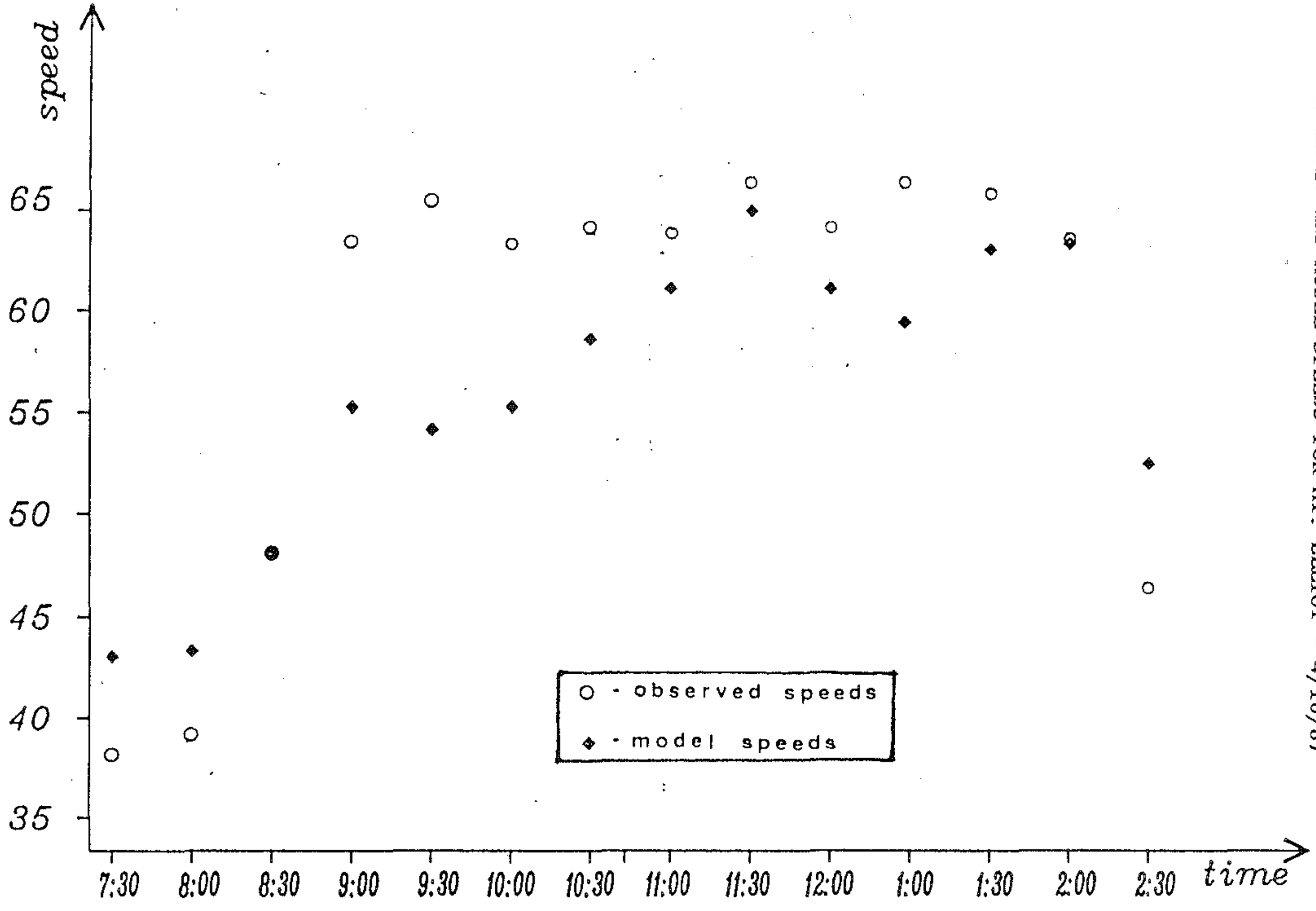
TIME	**OBSERVED SPEED** Si - mph	MODEL SPEED Ci - mph	DIFFERENCE Di = Si = Ci
7:30	37.84	43.3	-5.46
8:00	29.39	43.5	-4.11
8:30	48.01	48.0	0.01
9:00	63.57	55.6	7.97
9:30	65.54	54.2	11.34
10:00	63.75	55.7	8.05
10:30	64.06	58.4	5.66
11:00	64.05	60.9	3.15
11:30	66.79	65.0	1.79
12:00	64.38	61.0	3.38
1:00	66.70	59.3	7.40
1:30	66.20	62.8	3.40
2:00	63.65	63.4	0.25
2:30	47.36	51.3	-3.94

D = 2.782

Sd = 5.072

FIGURE 6.7

OBSERVED AND MODEL SPEEDS FOR MT. ELLIOT - 4/16/87



6.7.3. The Significance Level Test

Since the sample size is small, the model output speeds were tested against the observed speeds using a paired comparison and a t-test. The pairs were in the form $Di = Si - Ci$, and the null hypotheses was:

$$Ho : \delta = 0$$

$$\text{and, } H1 : \delta \# 0$$

$$\text{where: } \delta = E(Di) = E(Si-Ci).$$

The main assumption involved is that the paired differences Di's constitute a random sample from a normal population $N(\delta,\sigma)$.

$$D = \Sigma\, Di/n \quad \text{and } Sd = [\Sigma(Di-D)]/(n-1)$$

which gave the following results for this sub-network:

$$D = \pm\ 2.782 \text{ mph and } Sd = 5.072$$

Then a 95% confidence interval (α = 5%) (CI) for δ is given by the equation:

$$D \pm (t_{\alpha/2} * Sd)/\sqrt{n}$$

which gives: $CI = (-0.13 \cdot + 5.69)$

where: $t_{\alpha/2}$ is based on d.f. = 13. The t table gives $t_{\alpha/2}$ = 2.145. A test of $Ho : \delta = 0$ is based on the statistic test:

$$t = \bar{D} / [Sd/\sqrt{n}] \ , \ d.f. = n-1$$

that gave: $t = 2.052$ which is smaller than $t_{\alpha/2} = 2.145$.

The calibration was considered successful when the null hypotheses passed the t-test; this was when the calculated value of t became smaller than the tabulated t value, and at least half of the individual points passed the CI test, as shown in Figure 6.8. This means that the model, with the new parameter values, is ready to be used to replicate the traffic behavior in Detroit with an acceptable margin of error.

6.8. Validation

The intent of validation is to run the model (in this case INTRAS) with different data than the data used for calibration, but without changing the values of the calibrated parameters. This different data can be at the same location (i.e., Mt. Elliot) or at other locations on the Ford Freeway (I-94).

The validation of the model consists of five parts, as follows:

1. the same location (i.e., Mt. Elliot), but with different data from a different date (i.e., 09/18/86) with the ramp metering off;

2. the same location with different data from a different date (i.e., 09/17/86) with the ramp metering on;

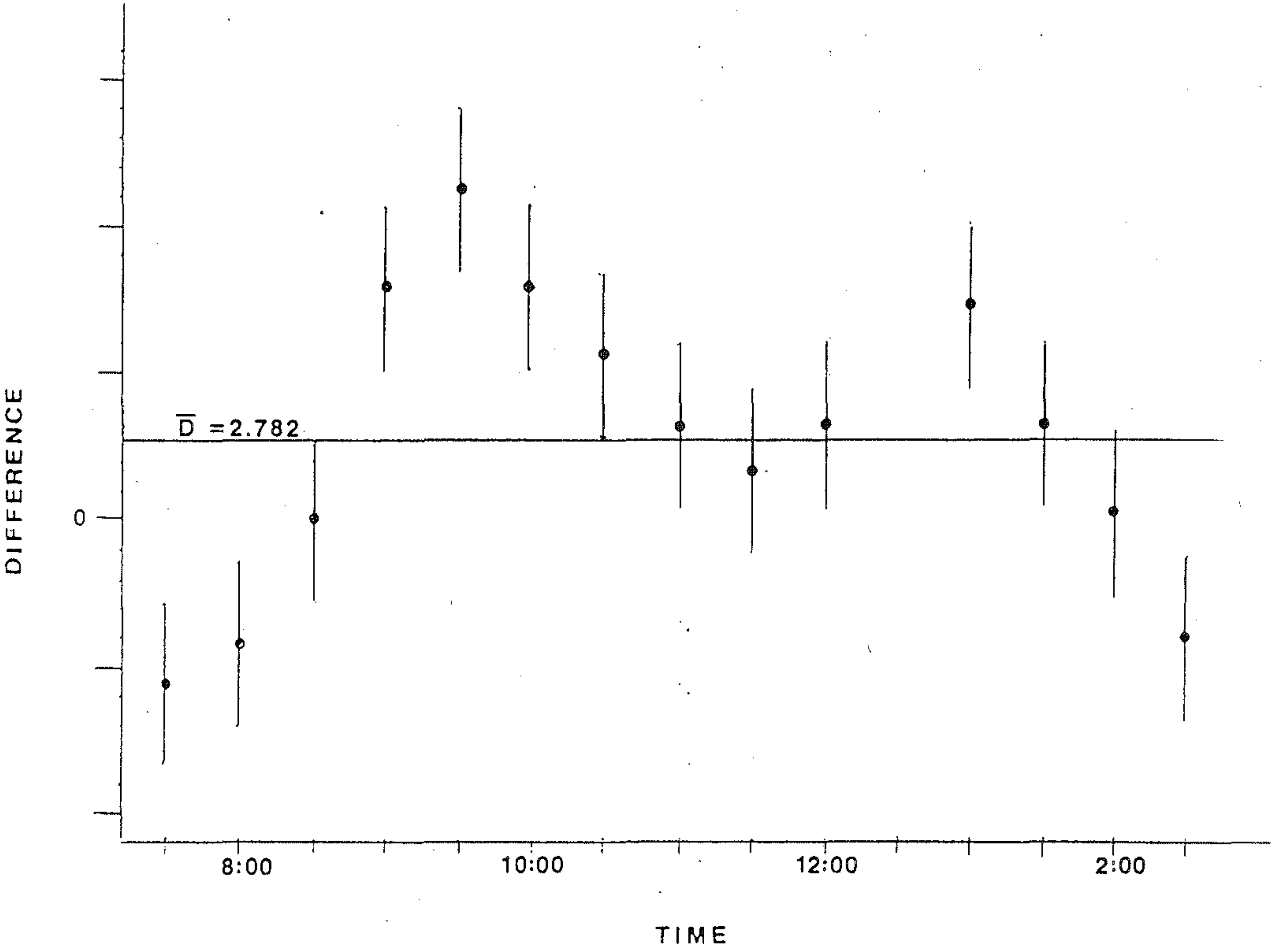


Figure 6.8 The Confidence Interval Test

3. a new location (i.e., Gratiot) on the east direction of the Ford Freeway with ramp metering off;

4. a new location (i.e., Trumbull) on the west direction of the Ford Freeway with ramp metering off; and

5. a new location (i.e., Van Dyke) on the west direction of the Ford Freeway with ramp metering on.

Several data points for each of the five parts above were loaded into the model each as a sub-network. The model was run for each sub-network and the results of those runs are shown in Table 6.7.

The model output speeds in each of the five parts compared very well to those in the field. In almost all cases, the difference between the observed speeds and the model speeds passed the CI test. The validation process was considered successful, and the model at this point is considered able of simulating the Detroit freeway system with acceptable accuracy.

6.9 Evaluating the Present Control Strategy

The control method used to run INTRAS is called "clock time metering." To simulate clock-time control of on-ramps, one fixed metering rate (vehicles per minute) is specified at each node. A countdown clock is assigned to each associated on-ramp and the signal is set to "green" until a vehicle is discharged, when the clock is set to "red" (Wicks and Andrews, 1980).

The evaluation procedure was conducted on the eastbound Ford Freeway for one afternoon peak hour, as discussed in the following sections.

Table 6.7

The Validation Results

LOCATION	DATE	TIME	OBSERVED SPEEDS	MODEL SPEEDS	METERS
MT. ELLIOT	9/18/86	9:00	35.21	40.00	OFF
		10:00	58.91	61.90	OFF
		3:00	53.02	53.70	OFF
MT. ELLIOT	9/17/86	9:00	60.03	52.20	ON
		10:00	63.41	63.20	ON
		3:00	56.12	58.60	ON
GRATIOT	11/19/86	3:30	63.19	61.10	OFF
		4:00	62.77	60.20	OFF
		4:30	58.64	57.70	OFF
TRUMBULL	10/29/86	3:30	38.10	39.30	OFF
		4:30	38.38	39.70	OFF
VAN DYKE	9/17/86	8:30	59.05	63.2	ON
		9:30	60.54	64.3	ON

6.9.1. The Basic Run (No-Metering)

The first run of the network was done with the ramp metering off. It was considered the basis of comparing the do-nothing strategy (ST#1) with the present control strategy and the suggested control strategies. This was done to define the benefits of ramp metering in terms of the MOE's of concern (i.e., average speed on the freeway; average speed of the whole system, including ramps and surface links we refer to the portions of on-ramps before the ramp signal as surface links); total delay; total vehicle-time; total vehicle-miles; and moving/total time).

6.9.2. Applying the Present Control Strategy

The second run was designed to test the operating plan currently used in this corridor (ST#2). The present metering rate is 15 vehicles per minute (i.e., 1 vehicle/4 seconds). This rate was simulated on each ramp on the east direction of the freeway and the model was run for that direction.

6.9.3. Discussion of Results

The results for the peak hour for both runs are presented in Table 6.8, where the significant benefits of the control strategy ST#2 can be clearly noticed. The increase of the average speed of the corridor is 8%, the reduction in total delay is over 17%, and about 7,900 vehicle-minutes were saved in one hour. This clearly demonstrates the effect of ramp metering in increasing the efficiency of flow on the freeway.

Table 6.8
Comparing Measures of Effectiveness for one peak hour
(No-Metering Vs. Present Strategy)

M.O.E.	NO-METERING	PRESENT METERING STRATEGY (4 sec.)	DIFFERENCE	%
Vehicle-miles	73938.41	73852.29	- 86.12	-0.1
Vehicle-minutes	105051.02	97168.53	-7882.49	-7.5
Moving/Total trip time	0.577	0.622	+0.045	+7.8
Speed mph	42.23	45.60	+3.37	+8.0
Total Delay (Veh-min)	44399.56	36717.66	-7681.90	-17.3
Delay Time(min)/ veh-mile	0.60	0.50	- 0.10	-16.7

6.10 Testing New Strategies

After determining the benefits of the present strategy, other metering strategies were tested to determine the metering rate that will maximize the benefits (i.e., increase the speeds and reduce delays).

6.10.1. Local On-Ramp Only

The first step was to apply uniform metering rates to all the local on-ramps. The rates that were tested were: 5,6,7, and 8 second headways on all ramps. The results are shown in Tables 6.9, 6.10, and 6.11.

The first new strategy ST#3 (with 5 second headway) showed a minimal change in results from the present strategy on the freeway (i.e., ST#2) and the freeway corridor overall, but the average speed on the ramps and surface links dropped. The second new strategy ST#4 (with 6 second headway) showed better results on both the freeway and the freeway corridor. The third new strategy ST#5 (with 7 second headway) showed further improvement of speeds on the freeway, but the average speed on the freeway corridor was reduced as a result of the long queues on some of the heavy volume ramps. The fourth new strategy ST#6 (with 8 second headway) crashed in the computer because the length of some of the ramp queues exceeded the length of those ramps and the simulation was aborted.

To fine tune the model results, modifications were made to the best defined strategy (i.e., ST#4). By observing the speed on each link separately and the change of speed between successive links, in the next run (ST#7) the ramps that have less than 400 hourly volume (i.e., six on-ramps on the west direction) were not metered. the model was run and the metering rate for the nine metered ramps was set to 6 seconds. The results of ST#7 showed further improvement on both the freeway and the freeway corridor, as also shown in Table 6.9.

Figure 6.9 shows curves of change in average speed among the different strategies on three levels: the freeway corridor, the freeway only, and the ramp and surface links only.

Table 6.9

Comparing MOEs of Different Metering Strategies at Local On-Ramps Only (<u>All Network</u>)

Strategy #	Veh-Minute min	Total Delay min	Change in Delay	Speed mph	Change in Speed
ST#1 No-Metering	105051	44399	0.0%	42.23	0.0%
ST#2 4 sec. headway	97168	36717	-17.3%	45.60	8.0%
ST#3 5 sec. headway	97206	37303	-16.0%	45.19	7.0%
ST#4 6 sec. headway	953524	32921	-25.9%	47.62	12.8%
ST#5 7 sec. headway	99795	39447	-11.2%	44.99	6.5%
ST#6 8 sec. headway		crashed			
ST#7 6 sec. on ramps w/volume > 400 vph	91958	31782	-28.4%	47.98	13.6%

Table 6.10

Comparing MOEs of Different Metering Strategies at

Local On-Ramps Only (Freeway Only)

Strategy #	Veh-Minute min	Volume veh/ln/hr	Density veh/ln-mile	Speed mph	Change in speed
ST#1 No-Metering	101410.86	1571	37.2	42.20	0.0%
ST#2 4 sec. headway	93466.49	1569	34.3	45.70	8.3%
ST#3 5 sec. headway	92750.24	1555	34.0	45.70	8.3%
ST#4 6 sec. headway	88798.58	1578	32.6	48.40	14.7%
ST#5 7 sec. headway	85702.91	1579	31.5	50.20	18.9%
ST#6 8 sec. headway		crashed			
ST#7 6 sec. on ramps w/volume > 400 vph	87214.52	1562	32.0	48.80	15.6%

Table 6.11

Comparing MOEs of Different Metering Strategies at

Local On-Ramps Only (Ramps and Surface Links)

Strategy #	Veh-Minute min	Moving/Total Time	Speed mph	Change in Speed
ST#1 No-Metering	3648.05	0.82	43.00	0.0%
ST#2 4 sec. headway	3702.04	0.80	42.10	-2.0%
ST#3 5 sec. headway	4455.93	0.66	34.90	-18.8%
ST#4 6 sec. headway	4726.18	0.62	32.90	-23.5%
ST#5 7 sec. headway	14086.00	0.25	13.30	-69.0%
ST#7 6 sec. on ramps w/volume > 400 vph	4743.78	0.62	32.80	-23.7%

Both Table 6.9 and Figure 6.9 show the last strategy ST#7 as the best strategy to be used in the case of the Ford Freeway in Detroit. The results indicate that this strategy will maximize the benefits of the system.

For example, the increase of the average speed over ST#1 is about 14%, the reduction in total delay is over 28%, and the anticipated saving in time is about 13,000 vehicle-minutes per peak hour. Also shown in Figure 6.9 is the change in speed for both the freeway alone and the ramp-surface nodes alone.

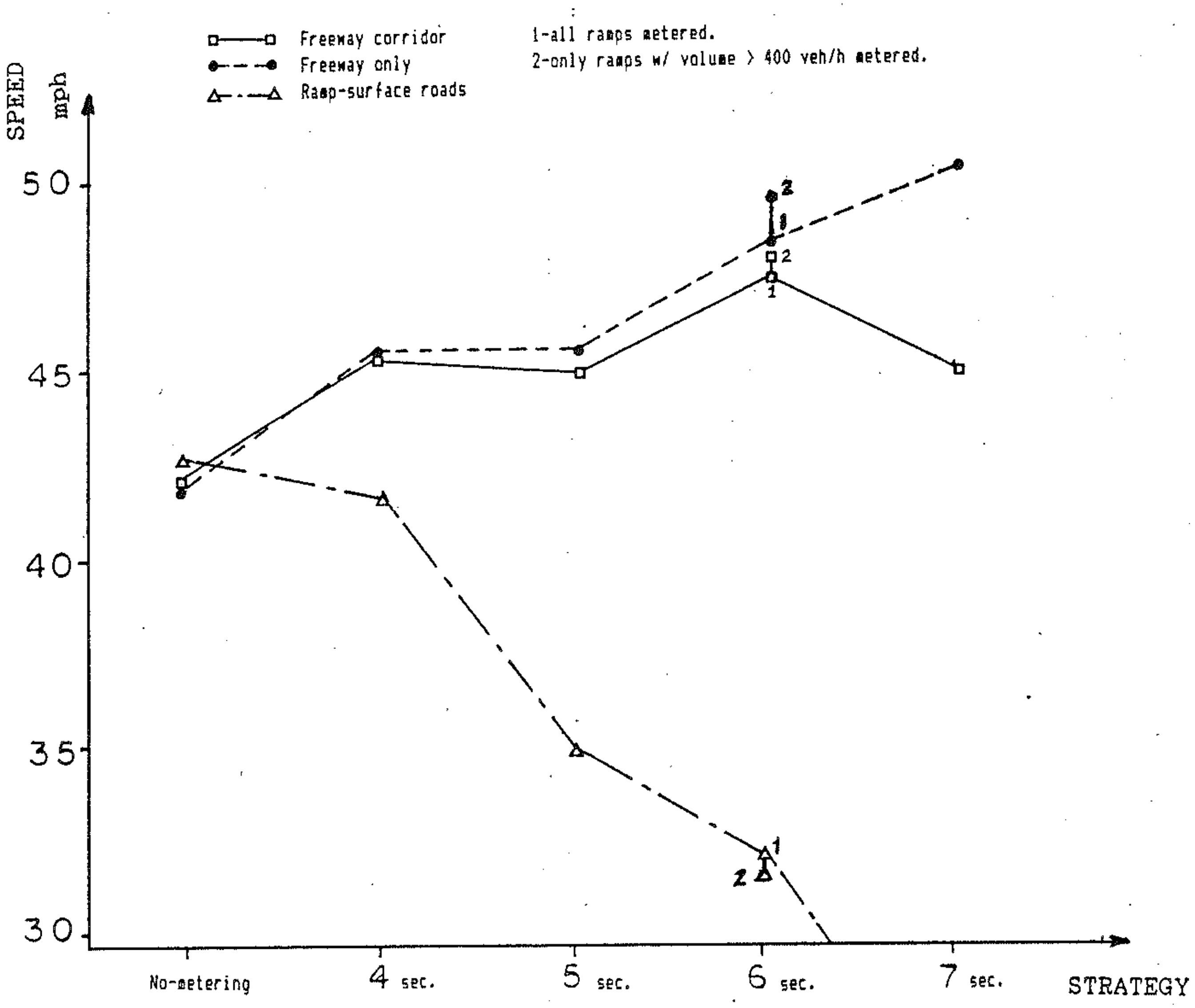


FIGURE 6.9

COMPARING AVERAGE SPEEDS OF DIFFERENT STRATEGIES AT LOCAL ON-RAMPS ONLY

6.10.2. Testing New Strategies at Both Local and Freeway On-Ramps

The next step after defining the best metering strategy to be applied at the local (nonfreeway) on-ramps was to define the benefits of metering the on-ramp part of the freeway-to-freeway interchanges that connect the Ford Freeway with three freeways [i.e., the Jeffries (I-96), the Lodge (US-10), and the Chrysler (I-75)] in the city of Detroit.

While testing the control strategies at freeway on-ramps, the metering rates of local on-ramps were kept the same as the rates that gave the best benefits in case of metering local on-ramps (i.e., in ST#7).

6.10.2.1. Existing geometry

Three new runs were made with three different metering rates applied to the freeway on-ramps. The rates were 6 second headway (ST#8), 5 second headway (ST#9), and 4 second headway (ST#10), respectively. The first two runs ST#8 and ST#9 crashed in the computer because the lengths of the queues on some of the freeway on-ramps was longer than the link length and the simulation was aborted.

The critical ramp that caused the first two runs to crash is the on-ramp from the northbound Lodge Freeway, because of both the high traffic volume and the short storage space. To solve this problem without changing the existing geometry, the model was run with all the controlled on-ramps with 6 second headway except the northbound Lodge on-ramp which was modelled with a 4 second headway (ST#11).

This was to allow more vehicles to enter the freeway and reduce the storage space needed on the northbound Lodge on-ramp. the results are presented on Tables 6.12, 6.13, and 6.14.

Table 6.12
Comparing MOEs of Freeway-to-Freeway Control Strategies
(All Network)

Strategy #	Veh-Minute	Total Delay Min	Change in Delay	Speed mph	Change in Speed
ST#1 No-Metering	105051	44399	0.0%	42.23	0.0%
ST#7 6 sec. on ramps w/volume > 400 vph	91958	31782	-28.4%	47.98	13.6%
ST#8, and **ST#9**		crashed			
ST#10 ST#7+4 sec. on all freeway ramps	94130	33301	-25.0%	47.40	12.2%
ST#11 ST#7+6 sec. on all freeway ramps except N.B. Lodge w/4 sec.	98641	38902	-12.4%	44.48	5.3%
ST#12 ST#10+Extra storage on N.B. Lodge.	90163	29426	-33.7%	49.37	16.9%

Table 6.13

Comparing MOEs of Freeway-to Freeway Control Strategies
(Freeway Only)

Strategy #	Veh-Minute	Volume veh/ln/hr	Density veh/ln-mile	Speed mph	Change in Speed
ST#1 No-Metering	101410	1571	37.2	42.20	0.0%
ST#7 6 sec. on ramps w/volume > 400 vph	87214	1562	32.0	48.80	15.6%
ST#8, and **ST#9**		crashed			
ST#10 ST#7+4 sec. on all freeway ramps	87653	1581	32.2	49.10	16.3%
ST#11 ST#7+6 sec. on all freeway ramps except N.B. Lodge w/4 sec.	89976	1554	33.0	47.10	11.6%
ST#12 ST# 10+Extra storage on N.B. Lodge.	83525	1575	30.7	51.40	21.8%

Table 6.14

Comparing MOEs of Freeway-to-Freeway Control Strategies
(Ramp and Surface links Only)

Strategy	Veh-Minute min	Moving/Total Time	Speed mph	Changes in Speed
ST#1 No-Metering	3648.05	0.82	43.00	0.0%
ST#7 6 sec. on ramps w/volume > 400 vph	4743.78	0.62	32.80	-23.7%
ST#8, and **ST#9**				
ST#10 ST#7+4 sec. on all freeway ramps.	6476.82	0.46	23.90	-44.4%
ST#11 ST#7+6 sec. on all freeway ramps except N.B. Lodge w/ 4 sec.	8665.41	0.34	17.60	-59.1%
ST#12 ST#10+Extra Storage on N.B. Lodge	6638.37	0.46	24.10	-43.9%

6.10.2.2 Modified geometry

The results of ST#11 did not reflect any improvement over the results of ST#10, so the next step was to keep the same rates as in ST#10 and modify the geometry of the northbound Lodge on-ramp. This was done by increasing the length of the surface link before the metering signal on that ramp to accommodate more vehicles. This modification represents in the real world either increasing the length of that interchange leg or adding a second lane to the interchange leg.

Figure 6.10 shows curves of change in average speed among the different metering strategies on three levels: the freeway cooridor (all network), the freeway only, and the ramp and surface links only. The best strategy was ST#12. This is because the simulated MOE's for this strategy indicate that it will give the best results on the freeway and on the freeway corridor as one network in terms of increasing the average speed and reducing the vehicle-minutes spent in the system. The negative points about this strategy are the longer waiting time on the surface streets and the need to modify the laneage on the northbound Lodge Freeway on-ramp that enter the eastbound Ford Freeway.

The longer waiting time is anticipated because of the high volumes traveling between the freeways, which will affect this factor, but the overall benefits of ST#12 more than compensate. There is also the possibility that a lot of traffic will change routes to avoid the long queues, which will reduce considerably the waiting time at the ramps. This last possibility cannot be tested with the model because it is unpredictable, but can be observed in the field. For example, recently when the northbound Lodge Freeway in Detroit was closed for repaving, the expectations were that there would be a huge increase in delay on all the alternate routes. But the observed case was much different than that, and no noticeable increases in delay were reported.

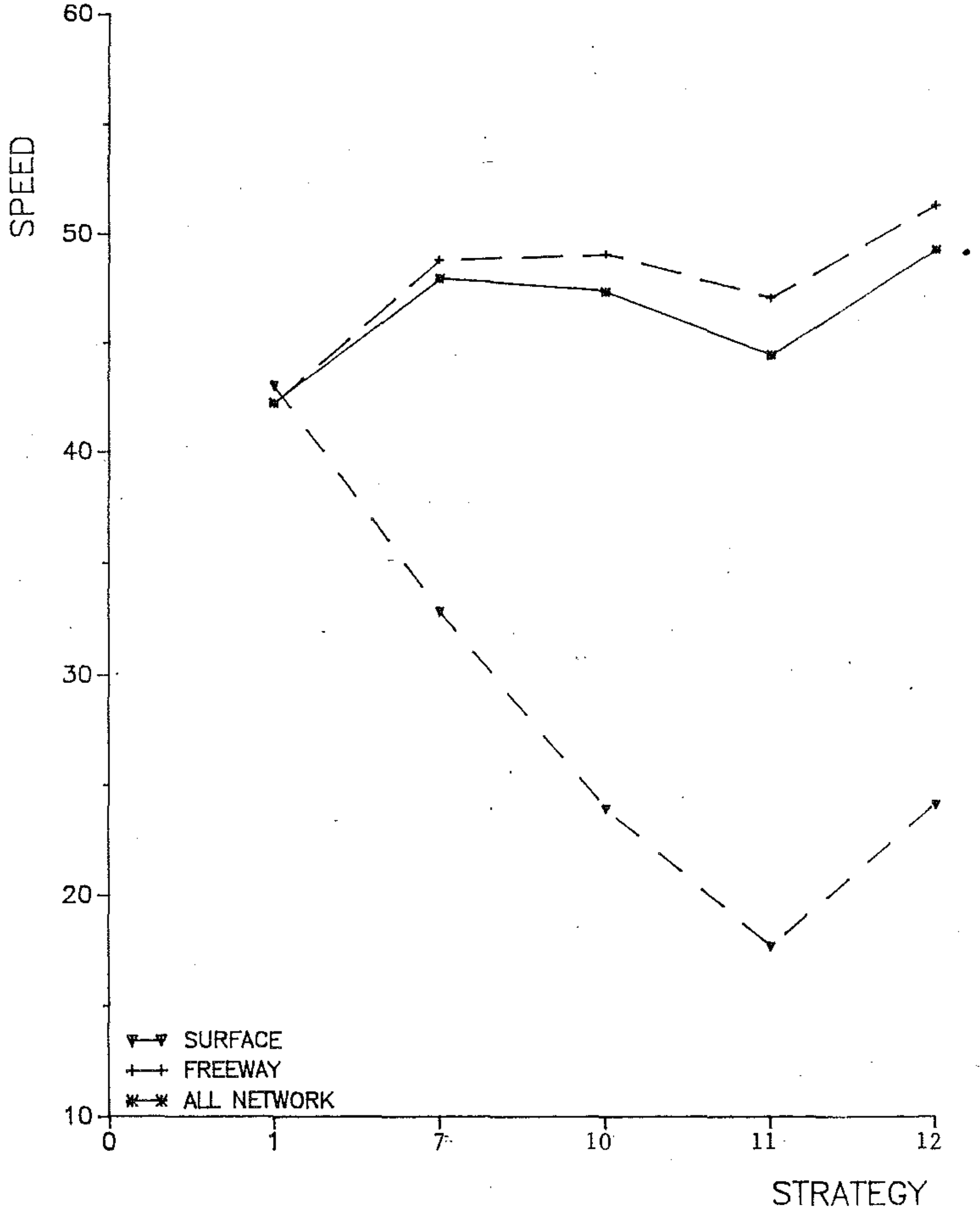


Figure 6.10 Comparing Ave. Speeds Freeway-to Freeway Strategy

The results of the simulation runs show a 9.2 mph, or 22%, increase in the average speed on the main freeway from 42.2 mph without ramp-metering ST#1 to 51.4 mph when applying ST#12. The reduction in vehicle-minutes on the freeway (by applying ST#12) was 17,886 vehicle-minutes (about 300 vehicle-hours), or a 17% reduction of the vehicle-minutes in ST#1. The average speed on the freeway corridor also increased by 7.14 mph, or 17%, from 42.23 mph in ST#1 to 49.37 mph in ST#12. The average speed on the surface links dropped from 43 mph to 24 mph, but that reflected an increase of only 2,990 vehicle-minutes (about 50 vehicle-hours) on the surface links. This means that the final results reflect an overall 14,888 vehicle-minutes (about 250 vehicle-hours) reduction in time spent in the system.

The feasibility of modifying the laneage on the freeway on-ramps depends on the specific design of each on-ramp and the possibility of increasing the length of that ramp or adding another storage lane before the metering signal. In this study, since the focus was on the data from one afternoon peak hour on the eastbound Ford Freeway, there was a need to modify the geometry of the northbound Lodge Freeway on-ramp because of the large volumes on that ramp. The modification was done (on paper) by adding a second lane on the surface road behind the ramp metering signal to accomodate more vehicles waiting to enter the freeway. The existing geometry of this ramp indicates that it is possible to add another storage lane. As a matter of fact, a second lane already exists on almost the entire length of that ramp, but it is marked with yellow stripes to keep vehicles out of that space. Use of this lane could be explored to see if the needed capacity can be gained.

This might not be the case, however, for other situations, such as the traffic on the westbound Ford Freeway or the morning peak-hours. For each case, different procedures or different types of modifications might be needed.

6.11. Summary of Modelling Evaluations

The benefits of the ramp metering strategy currently used in Detroit (i.e., 4 second headway, ST#2) are significant. More than 7,850 vehicle-minutes per peak hour are being saved, about an 8% increase in the average speed on the corridor are noticed, and the ratio of moving time to total trip time has been increased by about 8% (from 0.58 in ST#1 to 0.62 in ST#2).

The results of the optimal control strategy ST#12 show a 9.2 mph, or 22%, increase in the average speed on the main freeway from 42.2 mph without ramp-metering ST#1 to 51.4 mph when applying ST#12. The reduction in vehicle-minutes on the freeway was 17,886 vehicle-minutes (about 300 vehicle-hour), or 17%. The average speed on the freeway corridor also increased by 7.14 mph, or 17%, from 42.23 mph to 49.37 mph. The average speed on the surface links dropped from 43 mph to 24 mph, but that reflected an increase of only 2,990 vehicle-minutes (about 50 vehicle-hours) on the surface links. This means that the final results reflect an overall 14,888 vehicle-minutes (about 250 vehicle-hours) reduction in time spent in the system.

7. ANALYSIS OF SYSTEM FAILURES, ANNUAL COSTS AND BENEFITS

7.1. System Failures

Work orders from 1985 were examined and summarized in order to determine the distribution of maintenance effort among the various SCANDI subsystems. The specific subsystems examined were: the motorist aid telephones (MAT), the TV surveillance system (CCTV), the changeable message sign system (CMS), the ramp metering system, and the cable and sensor systems.

Table 7.1 summarizes the number of hours of work for each sub-system recorded in the work order file. The number of work orders and the percentage of the total hours recorded for each category are also given in the table.

Table 7.1

WORK ORDER SUMMARY 1985

	SYSTEM				
	MAT	CCTV	CMS	CABLE	RAMP METERING
# of Hours	193.6	87.5	210.5	1039.8	410.2
# of Work Orders	63	21	65	404	164
% of Total	10.0%	4.5%	10.8%	53.6%	21.1%

The SCANDI failure log was examined and summarized for 1985 and part of 1986. Tables 7.2 and 7.3 contain the results of the summary.

Table 7.2
FAILURE LOG SUMMARY FOR 1985

	CCTV	CMS	Ramp Metering	Surveillance System
Jan	25	31	358	9487
Feb	76	33	347	13624
March	45	19	147	5797
April	47	11	78	5055
May	58	70	125	10173
June	32	76	284	11903
July	13	56	74	6649
Aug	45	52	91	7210
Sept	67	45	105	7165
Oct	31	28	127	10997
Nov	23	1	20	6065
Dec	18	6	10	6265
Average Number Failures/Day	2.0	2.0	8.0	443
Maximum Possible Failures/Day	8	9	28	1352
Percent Average Daily Failure	25%	22%	29%	33%

Table 7.3

FAILURE LOG SUMMARY FOR 1986
(6 Months)

	CCTV	CMS	Ramp Metering	Surveillance System
Jan	63	26	20	13546
Feb	35	20	18	9261
March	30	21	55	9817
April	89	46	237	16093
May	70	86	93	11859
June	54	23	60	11387
Average Number Failures/Day	2.8	1.8	3.9	585.1
Maximum Possible Failures/Day	10	9	28	1352
Percent Average Daily Failure	28%	20%	19%	43%

7.2 Costs and Benefits

The system was constructed at a cost of $18 million and has an annual operation and maintenance budget of $1,000,000.

7.2.1. Costs and Benefits of MAT System

7.2.1.1 Capital Cost

The capital costs of the motorist aid system (as built) are:

Motorist Aid Call Boxes	$ 151,700
Installation of Call Boxes	19,980
Call Box Connection	178,865
Motorist Aid Communication Support System	596,100
Total Capital Cost	$ 946,645

It should be noted that the cost of the co-axial cable is not included in the total capital cost of the motorist aid system. The reasons for this are that the cable was necessary for the freeway surveillance system and its cost would not be affected by whether or not it was used for the motorist aid telephone system. If the motorist aid telephone system were built by itself, a different linking scheme would have been used and would have to be included in these calculations.

7.2.1.2. Operating and Maintenance Cost

It is reported by SCANDI management that between 13% and 18% of the staff time is spent on the motorist aid system. We used 13% in our calculations. Thus, at $16/hour: staff time = 0.13 x 5 x 2080 x $16 =

$21,600. The SCANDI management estimates that the cost of parts for the motorist aid system is $5000 per year.

Each unit uses 70 watts of power continuously. Using a rate of $.07 per kwh, the annual power cost is estimated to be $2962 or approximately $3000 per year.

Since the system is monitored by the State Police or by MEP volunteers the costs associated with the monitoring of the phones is not included here.

The operating cost of the motorist aid system is approximately $29,600 per year.

7.2.1.3. Cost per call

Assuming a ten-year service life, the average annual capital cost is $94,665. Thus the average annual cost = 29,600 + 94,665 = $124,265.

The system consists of 69 units and it has an average call rate of 11.7 calls per day which gives a cost of $29 per call.

If only operating costs are considered then the cost is $7 per call.

7.2.1.4. Benefits of MAT System

The primary benefit concerns the safety and security aspect of a motorist aid telephone system and is difficult to quantify. About 1000 motorist aid calls a year are made on the SCANDI system at night when traffic is light and danger is the greatest. While there are no records of reduced crime because of the telephones, the State Police report that the system reduces response time to stranded motorists. It is generally believed that the system is like having an extra patrol car and State Trooper patrolling the freeway. The benefits are increased safety and security and better community relations.

7.2.2. Costs and Benefits of CCTV System

7.2.3.1. Capital Cost

The initial cost of one camera, lens, pan tilt, electronics, modulator, pole and installation is $25,000. The total cost of ten cameras and their installation is $250,000. The average lifetime of the camera is estimated to be ten years.

Costs at the control center include:

$18,000 for 12 monitors at $1500 each

$ 5,000 for electronics, switching, and remote control.

The cost of the cable is not included in this calculation. The total capital cost of the CCTV system is approximately $273,000.

7.2.3.2. Operating Cost

Most of the operating cost of the CCTV system comes from the cost of the observers' time and a small portion of the SCANDI staff time.

There are seven half-time employees whose duties include watching the monitors. They are paid $8.70/hour. It is estimated that they spend 28% of their time with the CCTV system.

Therefore, the operating cost is: staff cost = 0.28 x 7 x 1040 x 8.70 = $17,700 per year.

7.2.3.3. Maintenance Cost

The SCANDI Maintenance History Summary shows that 3.3% of the time of the five employees who are paid $16/hour (average rate including fringes and benefits) is spent on the CCTV system. Most of the work is adjusting the cameras, and there are no significant parts costs. The maintenance cost is, therefore:

maintenance costs = 0.033 x 5 x 2080 x $16 = $5,500 per year.

7.2.3.4. Annual Cost for CCTV

Therefore, the annual cost of the CCTV system is approximately $273,000/10 + $17,700 + 5,500. Annual cost = $50,500/year, or $5,000 per camera per year.

7.2.3.5. CCTV Benefits

Benefits of the CCTV system are derived from prompt detection of incidents, the reduction in response time for those incidents where help is required, and the reduction of delay and of secondary accidents. The State Police report that the system is very reliable and enables them to operate more efficiently in dispatching patrol cars and emergency vehicles. The primary quantifiable benefit of the CCTV system is the prompt response to incidents which block traffic and cause delay. It is reported in the literature reviewed that a CCTV system shortens incident duration by 2.5 to 4 minutes per incident (38).

The benefits of the CCTV system were quantified by calculating the reduction in delay due to the shortening of lane-blocking incidents by three minutes. The actual frequency of incidents and the number of lanes blocked were used in the calculation.

The number of vehicle-hours of delay saved was calculated as 5,839, 14,425, 9,772, 11,976, and 18,785 for the years from 1980 through 1985, respectively. When a vehicle-hour is valued at $6.50, the benefits for these five years are: $37,953, $93,762, $63,518, $77,844, and $122,102. Benefits are estimated to average $79,000 per year.

7.2.4. Costs and Benefits of CMS System

7.2.4.1 Capital Cost

The signs cost approximately $100,000 each. Which means that the total capital cost of the CMS system is $900,000.

7.2.4.2 Operating Cost

It is estimated that the observers spend 20% of their time with the signs. Therefore, operational costs for the CMS are estimated at:

0.20 x 7 half-time at $8.70/hour = $12,700/year.

7.2.4.3 Maintenance Cost

Inspection of the 1985 maintenance records indicates that 10.8% of the total SCANDI maintenance was for the CMS. Presently, at 2080 hours per man year, maintenance costs are estimated at:

0.108 x 5 employees at $16/hour = $18,000/year.

So far, approximately 20% of the original elements have been replaced.

7.2.4.4. Annual Cost for CMS

Assuming a ten-year life, the annual cost is approximately $90,000 + 12,700 + 18,000 = $120,700. The annual cost per sign is approximately $13,400.

7.2.5. Costs and Benefits of Ramp Metering System

7.2.5.1. Annual Costs

The approximate cost of the ramp metering portion of the SCANDI system is $18 million less the cost of the other systems or $15,880,000. The average life of the cables and related communication hardware is estimated at 20 years. The anticipated life of the other hardware is 10 years. therefore the average annual capitol cost is approximately

$$14{,}930{,}000/20 + 950{,}000/10,$$

or $841,000 per year.

7.2.5.2. Operating and Maintenance Cost

In 1985, 21.1% of the maintenance work orders were related to the ramp metering system. Therefore, the projected annual maintenance costs are:

$$\text{operating costs} = 0.211 \times 5 \times 2080 \times \$16 = \$35{,}000 \text{ per year.}$$

Of the 1985 work orders, 53.6% were for maintaining the communication cabling. Thus, the estimated operating costs are:

$$\text{Operating cost} = 0.536 \times 5 \times 2080 \times \$16 = \$89{,}000 \text{ per year.}$$

However the total SCANDI operational and maintenance costs are $1,000,000 per year. Therefore the assumed ramp metering operational and maintenance costs are $1,000,000 less the costs related to the other systems or $916,500.

7.2.5.3. Annual Cost of Ramp Metering

The approximate annual cost for providing ramp metering is $916,500 + 841,000. Annual cost = $1,757,500.

7.2.5.4. Annual Benefits of Existing Operation

The value of travel time savings (i.e., reduction in delay) is one of the most important components associated with many freeway improvement projects. A value is commonly placed on travel time savings by selecting a unit value of time, usually expressed in dollars per vehicle hour, and multiplying this unit value by the vehicle time saved.

The average value of automobile travel time savings was shown to approximate $6.67 per vehicle-hour in 1980 (see Gomez-Ibanez and O'Keeffe, 1985). We used a value of $6.50 per vehicle-hour.

Table 6.8 shows one peak hour saving of 7882.49 vehicle-minutes or 131.37 vehicle-hours. Based on that, the annual vehicle hours saved on one direction of the freeway is calculated as given below.

In each weekday in Detroit, there are five peak hours (i.e. two hours in the morning, 7:00-9:00, and three hours in the afternoon, 3:00-6:00). the total peak hours (or ramp-metering operating hours) for one year are PH = 5 * 253 = 1265, where 253 = 365 - 104 weekend days and eight holidays. Accounting for both directions of travel, there are (2 x 1265 = 2530) directional peak hours for the Ford Freeway in one year.

It is reasonable to assume that the tested peak hour represents a typical or an average peak hour in Detroit. Making this assumption, the annual saving (AS) is AS = 2530 * 131.375 = 332,378.75 vehicle-hours, and the user saving, as a result of the time saved (or the reduction in delay), is = AS x $6.50 = $2,160,000.

According to the AASHTO Manual, 1977, the fuel consumption for passenger cars is 650 gallons/1000 hours. In this study, the saving in time was found to be 332,378.75 vehicle hours using the ramp metering, which means that the amount of fuel saved is 650 * 332.379 = 216,046 gallons per year.

Trade journals indicated an average retail price of unleaded gasoline in the first half of 1987 at about $1.00 per gallon, which means that the annual user's saving in fuel consumption is about $216,000.

The total saving in annual user's cost (i.e., saving in time and in fuel) is $2,160,000 + $216,000 = $2,376,000 per year on the Ford Freeway.

A summary of costs and benefits are provided in table 7.4

Table 7.4

Summary of Annual Costs and Benefits

	Capital Costs	Annual Operation Costs	Average Annual Costs	Average Annual Benefits
MAT	$ 946,695	$29,600	$ 98,000	Public Service
CCTV	273,000	23,200	50,000	$ 79,000
CMS	900,000	30,700	121,000	Public Service
Ramp Metering	15,880,355	916,500	1,757,000	$2,376,000
TOTAL	$18,000,000	$1,000,000	$2,026,000	$2,455,000

During the study period, ramp metering was added to the Lodge freeway at a cost of $450,000. The expected incremental increase in average annual costs is estimated to be $55,000. The number of miles and traffic volumes being metered on the Lodge is similar to that studied on the Ford freeway. An incremental increase in the expected average annual benefit may also exceed $2,000,000.

8. CONCLUSIONS AND RECOMMENDATIONS

The four subsystems studied in addition to the loop detectors and communication cabling should not be evaluated as mutually independent. They should be evaluated as a composite freeway management operation. In addition to the estimated annual costs and benefits, each function should be evaluated upon satisfying their intended goals. This study concentrated upon the reduction in delay and savings in fuel as measures of effectiveness. No attempt has been made to evaluate any benefits to the public in additional information, safety, and convenience.

The benefits from ramp metering are more than anticipated and could be even greater with revisions to the metering plan. The television surveillance operation is performing adequately in detecting freeway incidents along critical sections of the Ford Freeway. The motorist aid telephones are used fairly extensively despite their poor condition and limited reliability. The changeable message signs cannot be properly evaluated because of their very poor visibility, but we believe they should play a role of informing the motorist as part of an incident management plan.

It is evident that the continuing need for maintenance is a major burden to the cost effective operation of this project. If the continued operation of this project is to be successful, MDOT should explore the use of current state-of-the-art technology in minimizing maintenance and operational costs.

8.1. Recommendations

It is our conclusion that the SCANDI project, although not without deficiencies, is cost effective. We recommend the following.

8.2. Motorist Aid Telephones

1. The motorist aid telephones are providing a desirable service to motorists on I-94 in the City of Detroit.

2. The reliability of the system must be improved substantially. If a reasonable level of service cannot be provided, then MDOT should consider the removal of the existing system. Maintenance of the motorist aid telephones could possibly be contracted to another governmental or private agency.

3. The motorist aid telephones receive significant use despite their poor condition. Warrants should be developed for determining when and if a motorist aid service should be provided. This service may not be the responsibility of MDOT, nor does this service have to be provided via a telephone system. However, criteria should be developed by MDOT to guide the implementation and operation of a motorist aid service. The following factors should be considered in establishing these criteria:

   a. traffic volumes;
   b. availability an ease of access to public telephones;
   c. depressed freeways and other geometric barriers.

8.3. Changeable Message Signs

It is difficult to make recommendations on the use of changeable message signs. The poor visibility of the SCANDI signs would not necessarily be true of other brands (i.e., those used in Grand Rapids). The justification of changeable message signs should not be determined in isolation of an overall incident management plan. Thus the use and location of changeable message signs should be considered in developing MDOT's incident management plan.

8.4 Television Surveillance

We recommend that the use of TV surveillance as a means of incident detection be continued. However, before any major changes or expansion to this function is implemented, we recommend that MDOT develop warrants or guidelines to govern their installation and operation (i.e., coverage of cameras and duration of surveillance). Factors to be considered in establishing guidelines may be:

a. accident frequency;

b. distribution of traffic volumes;

c. geometric induced conflicts.

The use of detectors for alerting the operators of a possible incident and the subsequent visual inspection via the television system is recommended.

8.5 Ramp Metering

The ramp metering is a cost effective element of the SCANDI operation. The expansion of this function (not necessarily the existing system) throughout the metropolitan Detroit area should be considered. We suggest the following additional considerations.

1. Conduct a study of the possibility of metering the freeway-to-freeway ramps. The existing operation of metering only the local on-ramps significantly limits the effectiveness of this function.

2. An ongoing operational plan should be developed and maintained by MDOT. This plan should include:
   - a. metering strategies that vary for each critical segment (bottleneck) as a function of ramp volumes, flow densities, and velocities; a metering plan similar to that used in San Diego should be tested;
   - b. expand and maintain the use of INTRAS for evaluating emissions and fuel consumption as part of the project objectives;
   - c. standard monthly and/or annual reports to be prepared and released to the public; these reports could be analogous to the Annual Accident Facts Book provided by the Michigan Department of State Police.

3. MDOT should develop warrants or guidelines for governing the installation and operation of ramp metering signals.

8.6. General Comments

1. A maintenance plan should be developed with the goal of minimizing maintenance costs accross the board.

2. Now that MDOT has gained considerable experience in freeway management, changes in the system design and hardware configuration should be made including the following:

   - a. metering logic: we recommend that MDOT not use real time metering; the fixed time process works well and will function with fewer detectors, reduced maintenance and much simpler and less expensive hardware and software;

b. hardware configuration: before expanding the existing operation, we recommend that MDOT develop and evaluate some conceptual hardware designs, which include the following:

  - the feasibility of a simple signal plan with each signal having independent logic, the goal being to provide less expensive hardware;
  - some form of central control which may need to be an independent computer or similar type of standard master controller to monitor the operation and status of the system.
  - a reduction in the number of loop detectors;
  - the need for communication among the systems should be reviewed; an alternative to using coaxial cable should be a major goal.

4. Geometric design changes to improve the ability to divert traffic should be investigated, such as continuous service drives.

9. REFERENCES

1. Pogust, F. et al., **"Means of Locating and Communicating with Disabled Vehicles,"** NCHRP Report 6, 1964.

2. National Cooperative Highway Research Program, **"Motorist Aid Systems,"** Synthesis 7, 1971.

3. Woolman, S. and I.S. Wisepart, **"A New Approach to Motorist Aid?,"** HRR 450, 1968.

4. Committee on Planning and Design, **"An Informational Report on Roadside Telephones and Emergency Communication Devices for Stranded Motorists on Interstate Highways,"** AASHO, 1962.

5. Mammano, F.J. and J. Surti, **"Emergency Call Systems for Distressed Motorists,"** American Highways, Vol. 47, No. 2, April, 1968.

6. Green, D.A. and H. Bregman, **"Northway Emergency Telephone System,"** HRR 358, 1971.

7. Tweedie, R.W. and J.E. Taylor, **"An Evaluation of the Northway Emergency Telephone System,"** HRR 202, 1967.

8. Roth, W.J., **"Rural Freeway Emergency Communications for Stranded Motorists,"** HRR 358, 1971.

9. Roth, W.J., **"Rural Freeway Emergency Communications for Stranded Motorists: Final Phase Report,"** HRR 358, 1971.

10. Goolsby, M.E., W. Smith, and W.R. McCasland, **"Use of an Emergency Call-Box System on an Urban Freeway,"** HRR 358, 1971.

11. McCasland, W.R., **"Experience in Handling Freeway Corridor Incidents,"** TRB Special Report 153, 1975.

12. Signal Communications, Motorist Aid Communication Systems, Woburn, Ma, no date.

13. Subcommittee on Communications and Electronics, **"Guide Specifications for Motorist Aid Systems,"** AASHTO, June 1974.

14. Levin, M., J. Wierer, and J. McDermott, **"Motorist-Aid System on a Rural Freeway: The Illinois Experience"**, HRR 643, 1976.

15. Thompson, R.P. and J.D. Juge, **"Service for the Stranded Motorist Comprehensive Summary,"** Freeway Operations Branch Report No. 78-11, Los Angeles Area Freeway Surveillance and control Project, July, 1978.

16. Committee on Freeway Operations, **"An Inventory of Freeway Surveillance and Operational Control Activities,"** Highway Research Circular 108, Highway Research Board.

17. Michigan Department of Transportation, Traffic Volume Map, 1979.

18. Allen Electronics, **"Motorist Aid System Status Report,"** Prepared for MDOT, 1986.

19. Lindley, J.A., **"Quantification of Urban Freeway Congestion and Analysis of Remedial Measures,"** FHWA, 1986.

20. Cook, A.R., and D.E. Cleveland, **"The Detection of Freeway Capacity Reducing Incidents by Traffic Stream Measurements,"** HSRI, Report No. TrS-1, University of Michigan, 1970.

21. National Safety council, Accident Bulletin, 1984.

22. Interviews with Lt. Holmes, Michigan State Police.

23. Highway Research Board, Highway Research Circular 108, June 1970.

24. Taragin, A., **"A Summary of the John C. Lodge Freeway Research,"** NCHRP Project 20-2C, July 1976.

25. MacCalden, M.S., Feasibility Study of Closed Circuit Television for Traffic Surveillance, April 1973.

26. McCasland, W.R., **"Experience in Handling Freeway Corridor Incidents in Houston,"** TRB Special Report 153, 1975.

27. Bissell, H. and B. Cima, **"Dallas Freeway Corridor Study,"** Public Roads, Vol. 45, No. 3 1981.

28. Case, E.R. and K.M. Williams, **"Queen Elizabeth Way Freeway Surveillance and Control System"**, TRR 682, 1978.

29. Cook, A.R. and D.E. Cleveland, **"The Detection of Freeway Capacity Reducing Incidents by Traffic Stream Measurements,"** HSRI Report No. TrS-1, University of Michigan, 1970.

30. Lindley, J.A. **"Quantification of Urban Freeway Congestion and Analysis of Remedial Measures,"** FHWA 1986.

31. Morales, J.M., **"Analytical procedures for Estimating Freeway Traffic Congestion,"** Public Roads, Vol. 50, No. 2, September, 1986.

32. Aerde, M., Yager, S., Ugge, A., and Case, R., **"A Review of Candidate Freeway/Arterial Corridor Traffic Models,"** 66th Annual Meeting of Transportation Research Board, Washington, D.C., 1987.

33. Buhr, J., Meserole, T., and Drew, R., **"A Digital Simulation Program of A Section of Freeway with Entrance and Exit Ramps,"** Hwy Res Rec 230, 1968, pp. 15-31.

34. Buhr, J., Whitson, R., Brewer, K., and Drew, D., **"Traffic Characteristics for Implementation and Calibration of Freeway Merging Control Systems,"** Hwy Res Rec 279, 1969, pp. 87-106.

35. Drew, D., "**Gap Acceptance Characteristics for Ramp-Freeway Surveillance and Control**," Hwy Res Rec 157, 1967, pp. 108-143.

36. Fonda, D., "**An Analysis of Short-Term Implementation of Ramp Control on the Dan Ryan Expressway**, Hwy Res Rec 279, 1969, p. 157.

37. Gerlough, D., "**Simulation of Traffic Flow**," Highway Research Board, Special Report 79, 1964, pp. 97-188.

38. Gervais, E., "**Optimization of Freeway Traffic by Ramp Control**," Hwy Res Rec 59, 1964, pp. 104-118.

39. Goldblatt, R., "**Development and Testing of INTRAS, A Microscopic Simulation Model**, FHWA-RD-76-78 Vol 2: User's Manual, Final Report, 1980.

40. Goldblatt, R., Hagerty, B., and Laban, T., "**TRAFLO-M Macroscopic Traffic Simulation Model**," Final Report, MDOT, FHWA-MI-RD-85-01, 1984.

41. Gorden, L., "**A Concept of Deterrence Controls for Freeway-to-Freeway Interchanges**," Traffic Engineering, Institute of Traffic Engineers, Vol. 42, no. 11, 1972, pp. 23-27.

42. Highway Research Board, "**Highway Capacity Manual**," Special Report-87, Washington, D.C., 1965.

43. Levy, S., Glickstein, A., and Finley, L., "**Application of Computer Simulation Techniques to Interchange Design Problems**," Highway Research Board Bulletin, No. 291, 1961, pp. 139-162.

44. May, A., "**Experimentation with Manual and Automatic Ramp Control**," Hwy Res Rec 59, 1964, pp. 9-38.

45. Munjal, P., Hsu, Y., and Lawrence, R., "**Prediction and Stability of Freeway Gaps and On-Ramp Merging**," Hwy Res Rec 469, 1973, pp. 26-39.

46. Newman, L., Dunnet, A., and Mies, G., "**An Evaluation of Ramp Control on the Harbor Freeway in Los Angeles**," Hwy Res Rec 279, 1969, pp. 44-55.

47. Payne, H., "**FREFLO: A Macroscopic Simulation Model of Freeway Traffic**," Trans Res Rec 722, 1979, pp. 68-76.

48. Posner, E., "**A Model to Predict Benefits of Priority Lanes on Freeways**," Transportation Science, Vol. 10, No. 2, 1976, pp. 169-204.

49. Ross, P., and Gibson, D., "**Review of Road Traffic Network Simulation Models**," Transportation Research Record 644, 1977, pp. 36-41.

50. Russel, G., "**Ramp Control on Freeways in California**, Hwy Res Rec 279, 1969, pp. 153-154.

51. Sakashita, M., Lu, C., and May, A., "**Evaluation of Freeway Emergency Service Systems Using A Simulation Model**, Hwy Res Rec 358, 1971, pp. 26-45.

52. Sinha, K., and Dawson, R., "**The Development and Validation of a Freeway Traffic Simulator,**" Hwy Res Rec 308, 1970, pp. 34-47.

53. Tignor, S., "**Operational Analysis of Freeway Moving-Merge Systems,**" Transportation Research Board, Trans Res Rec 533, 1975, pp. 1-21.

54. Wattleworth, J., Pinnell, C., McCsland, W., and Drew, D., "**Evaluation of Entrance Ramp Control on A Six-Mile Freeway Section,**" Hwy Res Rec 157, 1967, pp. 22-76.

55. Wattleworth, J., Wallace, C., and Levine, M., "**Development and Evaluation of a Ramp Metering System on the Lodge Freeway,**" Texas Transportation Institute, Research Report 488-3, 1967, pp. 1-46.

56. Wicks, D., and Lieberman, E., "**Development and Testing of INTRAS, A Microscopic Simulation Model,**" FHWA-RD-76-78, Vol. 1: Program Design, Parameter Calibration, and Freeway Dynamics Components Development, Final Report, 1977.