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FHWA Contract Manager - H. H. Bissell (HRS-33)

16. Abstract

The report includes results of two studies of construction zone traffic control. The first study involved analysis of traffic accidents occurring in 79 zones in seven states. Results indicate a before to during accident rate increase of 6.8%. Results also include breakdowns by accident types, severity, light conditions, roadway type, area type, work area roadway type, construction type and state.

The second study was field testing of speed reduction methods. Speeds, erratic maneuvers and conflicts were measured at three sites--an urban freeway, a rural freeway, and an urban street. Results of the urban freeway and rural freeway studies are included in this report. Results of the urban street studies will be included in a special report on taper studies due for completion in August 1977. The field studies examined the effect of the following construction zone parameters on vehicle speeds and safety: sequential flashing arrow boards; speed zoning (advisory and regulatory); enforcement; transverse striping; obliteration of nonappropriate pavement markings; taper length; lane width reduction; and active warning of speed zoning. Recommended guidelines for construction zone traffic controls are also included.

17. Key Words
Construction Zone Accidents
Construction Zone Speeds
Traffic Control Guidelines

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PREFACE

This draft final report was prepared by Midwest Research Institute for the Federal Highway Administration under Contract No. DOT-FH-11-8121. Mr. Howard Bissell of the Office of Research, Federal Highway Administration was the contract manager.

We wish to acknowledge the contributions of seven state highway and transportation departments and individuals who served as principal contacts for the accident study portion of the project: Mr. William E. Tucker of the Colorado Division of Highways, Mr. Arthur Durshimer of the Georgia Department of Transportation, Mr. Robert Addy of the Michigan Department of State Highways and Transportation, Mr. Lyle G. LaFavor of the Minnesota Highway Department, Mr. Donald N. Geoffroy of the New York State Department of Transportation, Mr. Tom Culp of the Ohio Department of Transportation, and Mr. Charles M. Gosney of the Washington Department of Highways. Many other individuals in the states mentioned provided invaluable assistance which is gratefully acknowledged.

We also wish to acknowledge the contributions of the following individuals in the field study portion of the research: Mr. Robert Hunter, Mr. George Satterlee, and Mr. J. Robert Chappell of the Missouri State Highway Commission; Mr. Delbert Karmeier and Mr. Dwight Fox of the Kansas City, Missouri, Transportation Department; Mr. Jim Knez of Knez Construction Company; Mr. Randy German of Tri-City Construction Company; Mr. M. R. Carmack of Safe-T-Flare Rental Company; and Mr. James Thompson of Region 7, Federal Highway Administration.

The work reported herein was carried out in the Economics and Management Science Division under the administrative direction of Mr. Bruce Macy, and Dr. William D. Glauz. Mr. John C. Glennon, Manager, Design and Operations, served as project leader, and Mr. Jerry L. Graham, Associate Traffic Engineer, as the principal investigator.

Messrs. Graham and Glennon, together with Mr. Robert J. Paulsen, Assistance Traffic Engineer, were co-authors of this report. Mr. A. D. St. John, Senior Advisor for Analysis, was the principal contributor to Appendix D. Mr. Michael Sharp, Senior Statistician, performed this analysis of the accident and field study data and contributed to the writing of the analysis results. Other members of the MRI staff who contributed

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[illegible]
to work reported include, Mr. Douglas W. Harwood, Mr. Barry Sanders, Mr. Carl Clark, and Mr. Patrick J. Heenan.

Approved for:

MIDWEST RESEARCH INSTITUTE

Bruce W Macy

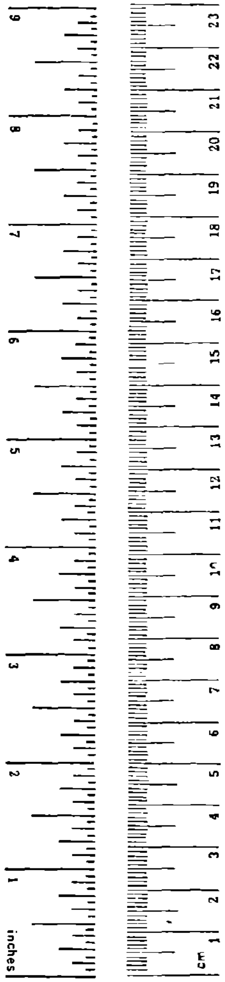
Bruce W. Macy, Director
Economics and Management
Science Division

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

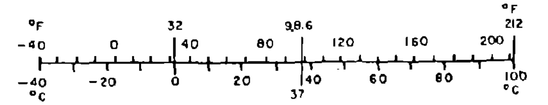


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TABLE OF CONTENTS (Concluded)

I. INTRODUCTION

A. Problem Statement

Today with the building of the interstate highway system nearly complete, there is a shift in the emphasis of the spending of highway monies from the building of new facilities to improving the quality of service of present facilities. This shift in the emphasis of construction projects has made the task of maintaining traffic on highway facilities during construction even more critical. The problem is compounded by generally rising traffic volumes, especially in urban areas.

To accommodate traffic through or around construction zones, the construction activity and the traffic controls must be coordinated to provide safe and expeditious movement of traffic while the construction activity progresses as rapidly, safely, and efficiently as possible. When these two goals come in conflict there are tradeoffs between the safety of traffic and construction workers and the costs of traffic and construction delay.

What the above statement suggests is the need for rigorous management of traffic and construction operations. But this kind of management seems to be generally lacking in many states.

Construction zone traffic controls are often hastily conceived, and seldom reconsidered. Because there is a lack of knowledge about construction zone operations, too often traffic control design is done by simply referring to a typical drawing in a manual. Short transitions and inadequate lateral clearances are often imposed where they could be less restrictive. Barriers are installed in areas where they are not functional, and ineffective barrier systems are used.

Operational management in construction zones is too often haphazard. Traffic control devices having no relationship to the temporal construction activity are often seen, and unsafe actions by construction workers are not uncommon.

Worst of all, the traveling public soon becomes dubious of all traffic control attempts, and may disregard or completely violate the traffic controls in the zone.

The general inability to provide for optimum safety appears to stem from two sources. The first is a general limitation of knowledge on the basic relationships involved in construction zone safety. And the second source, which is probably a by-product of the first, is lack of centralized authority and responsibility for operational safety applied continuously to all activities and changes in activity. At the heart of this second source is the motivational question. It could be that contractors and resident engineers are not motivated correctly because they feel that construction zones are intrinsically hazardous and there is little that anyone can do to change that fact. If this kind of attitude is prevalent, the most promising deterrent would be to develop a more comprehensive base of knowledge on the construction zone factors that relate most to safety.

B. Project Description

This research is part of an ever increasing effort to improve the knowledge of the critical aspects of construction zone safety.

Although the research generally covered all aspects of traffic control in construction zones, its emphasis was on the question of how vehicle speeds affect safety. The NCHRP Synthesis of Practice No. 1[1/]* states:

> "Optimum speeds through work zones need to be determined by further study and research. Current practice suggests that there is a wide range of opinions as to whether or not traffic should be slowed down as it passes work sites or whether continuation at normal highway speeds produce the best performance through work zones."

The research included studies of "before" and "during" accident records of construction zone roadways, and field testing of most speed reduction methods.

The objectives of the accident study were:

1. Determine the consequences of various traffic control strategies in order to specify the optimum speed of vehicles in construction zones for varying construction zone characteristics; and

2. Develop design and operational criteria for use as a set of national guidelines on safe and efficient traffic operations in construction zones.

The objective of the field studies was to determine the operational effects of various speed reduction systems and other construction zone design features on vehicular speeds and accident potential in construction zones. More specifically, the research compared various design and speed control features based on (1) the relationship of approach speeds to speeds in the construction zone, and (2) the safety performance as indicated by traffic conflicts and erratic maneuvers.

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* Numbers in parentheses refer to reference numbers.

A total of 79 projects from seven states were examined in the accident study. Combining the before and during accident numbers shows that over 20,000 accidents were considered. Zones of all types were examined, however, minimum length, duration, and traffic volume criteria were established to avoid studying projects that were not likely to experience enough accidents to be informative.

In the field testing of speed reduction methods, measurements of vehicle speeds and conflict and erratic maneuver counts were made in three construction zones representing rural freeway, urban freeway, and urban street locations. The field studies examined the effect of the following construction zone parameters on vehicle speeds and safety:

1. Taper length;
2. Nonapplicable lane lines;
3. Sequential flashing arrow panel;
4. Advisory speed zoning;
5. Lane width reduction;
6. Transverse striping for speed reduction warning;
7. Active warning of speed zoning; and
8. Enforcement.

After the discussion of construction zone definitions following in this section, the remainder of the report is divided into six sections. Section II - Literature Review, Section III - Construction Zone Accident Studies, Section IV - Field Testing of Speed Reduction Methods, Section V - Conclusions, and Section VI - Guidelines for Recommended Practice.

C. Definition of Construction Zones

Although there are countless combinations of construction zone parameters such as location, construction activity, traffic volume and speed, generally construction zones can be described by defining what highway construction is, by specifying types of work area roadways, and by dividing the zone into areas according to the traffic control requirements and desired driver responses.

1. Definition of highway construction: The term "highway construction" usually implies a work activity aimed at altering a segment of the highway transportation system. As stated in "Traffic Controls for Construction and Maintenance Work Sites"[2] the terms "construction" and "maintenance" are used very broadly and have a variety of meanings. The difference between these two terms is not always clear and may depend on the level of administration that is using the terms. In general, however, the following kinds of distinctions between construction and maintenance can be made:

a. The construction activity will generally involve a contract with a performing company, as opposed to maintenance activities done by highway agency personnel.

b. The construction activity will necessitate an improvement design stage and will be done using improvement plans that specify changes to be made in a highway facility, as opposed to maintenance work that is typically to bring the roadway back to a previous standard condition.

c. Since construction requires more involved work on the highway, the location of the work area will be more permanent than most maintenance activities, especially those such as pavement marking or sweeping.

d. The length of time that the highway is affected by construction activity will be longer than that required for maintenance activities, and therefore will require more permanence in traffic control devices.

These distinctions are made realizing that some activities may be in a "gray area" between maintenance and construction, and that many guidelines for construction zones will also be applicable to maintenance activities. For example, the definition does not encompass what are called "moving sites" or minute sites,[1] however, the use of devices such as sign trailers at construction zones may be very similar to the way they are used in these "maintenance" activities.

2. Types of work area roadways: The primary work area roadway types are identified as lane closure, crossover, temporary bypass, and detour. For a lane closure, the construction in the work area uses one or more lanes of a unidirectional roadway, leaving one or more unidirectional lanes open to traffic. A typical lane closure is shown in Figure 1.

For a crossover, traffic is channeled into one or more lanes of the roadway normally used for traffic in the opposite direction. On divided highways, a temporary or existing connection between the two directional roadways is used to channel traffic to the opposite side. This kind of crossover is shown in Figure 2. On undivided roadways, traffic is channeled across the old

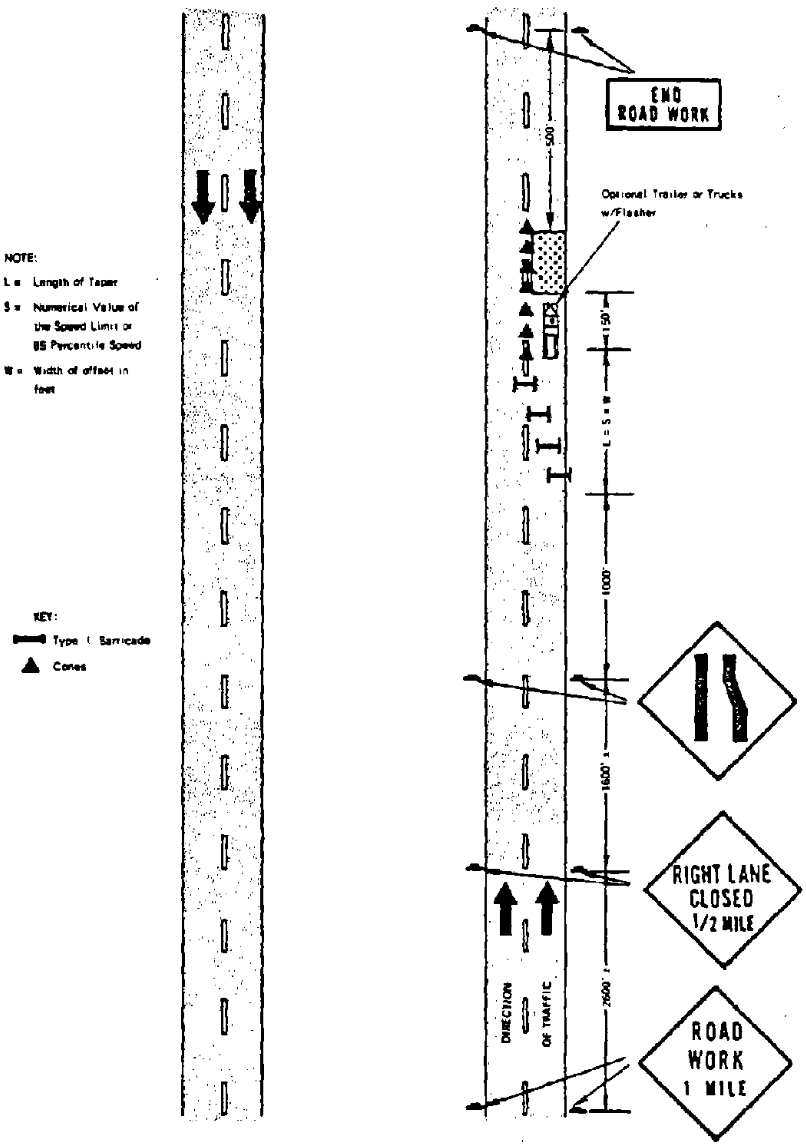

Figure 1 - Typical Lane Closure

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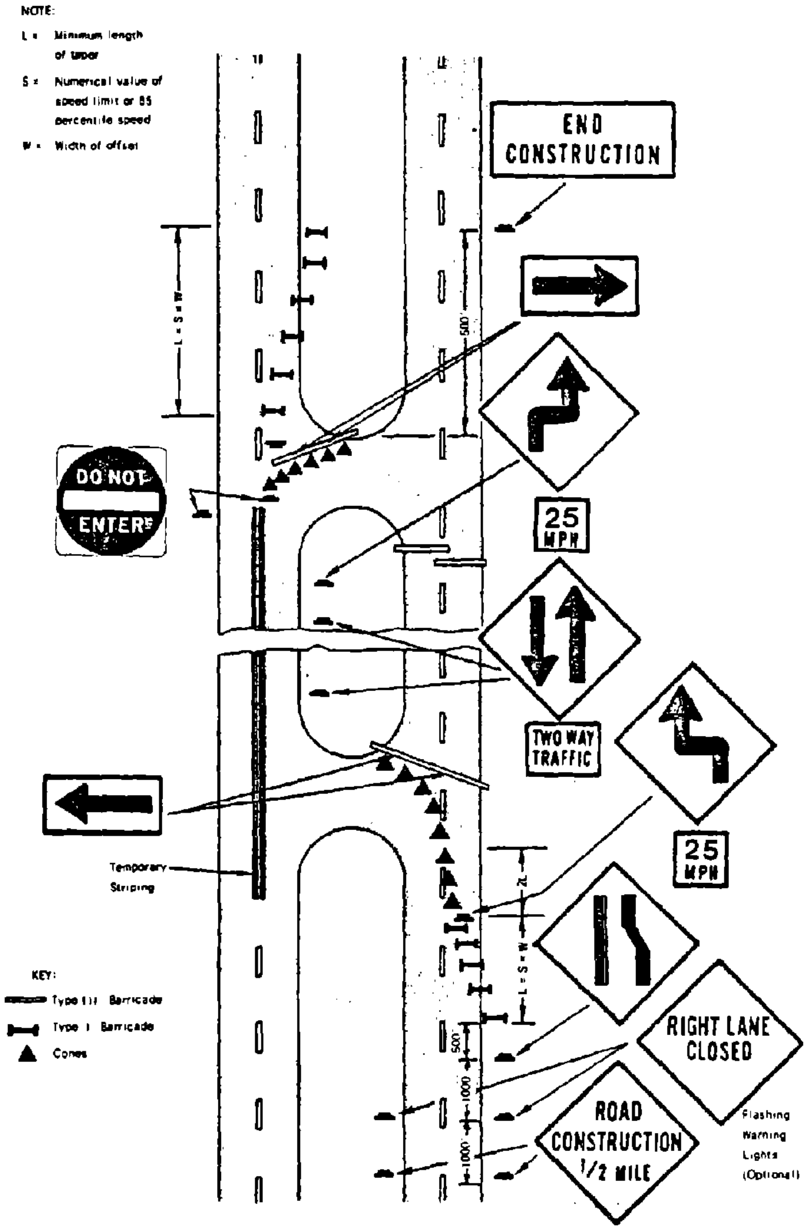

Figure 2 - Typical Crossover Zone or a Divided Roadway

centerline of the roadway so that both directions of traffic are using the same side of the roadway. This kind of crossover is shown in Figure 3.

For a temporary bypass, a temporary road is built to carry traffic around the work area. A typical temporary bypass is shown in Figure 4. The temporary bypass roadway may be either one-way or two-way.

For a detour, the roadway is completely closed for either one or both directions and traffic is rerouted onto alternate routes. An example of a detour is shown in Figure 5.

A fifth type of work area roadway is that in which the existing roadway is utilized but with some restrictions placed on it.

3. Areas within construction zones: It is important to divide construction zones into areas because there are varying traffic control requirements in each area based on driver responses required for safe operation. These areas are common to all types of construction zones. Figure 6 illustrates these areas within a construction zone requiring lane closures at two or more locations.

The term construction zone as shown in Figure 6, refers to an entire construction project. The beginning and end of the zone are called the project limits.

The warning area begins with the first information to the driver that he is approaching a work area. On high-speed expressways, the warning area may begin 1 to 2 miles upstream of the work area.

The approach area begins with the first information to the driver about the actual condition of the roadway ahead and the actions that will be required to travel through the work area. Although no physical restrictions narrow the roadway in the approach area, there are often slowing and merging maneuvers as drivers adjust their speed and position based on their concept of the safe path through the zone.

The entering transition begins at the point where the normal roadway is altered laterally by devices such as cones, barricades, or barriers in order to channelize traffic to the part of the roadway open through the work area. In Figure 6, traffic must move from the right lane into the median lane. In other types of construction zones, the entering transition may lead traffic onto a temporary bypass road or to an alternate route.

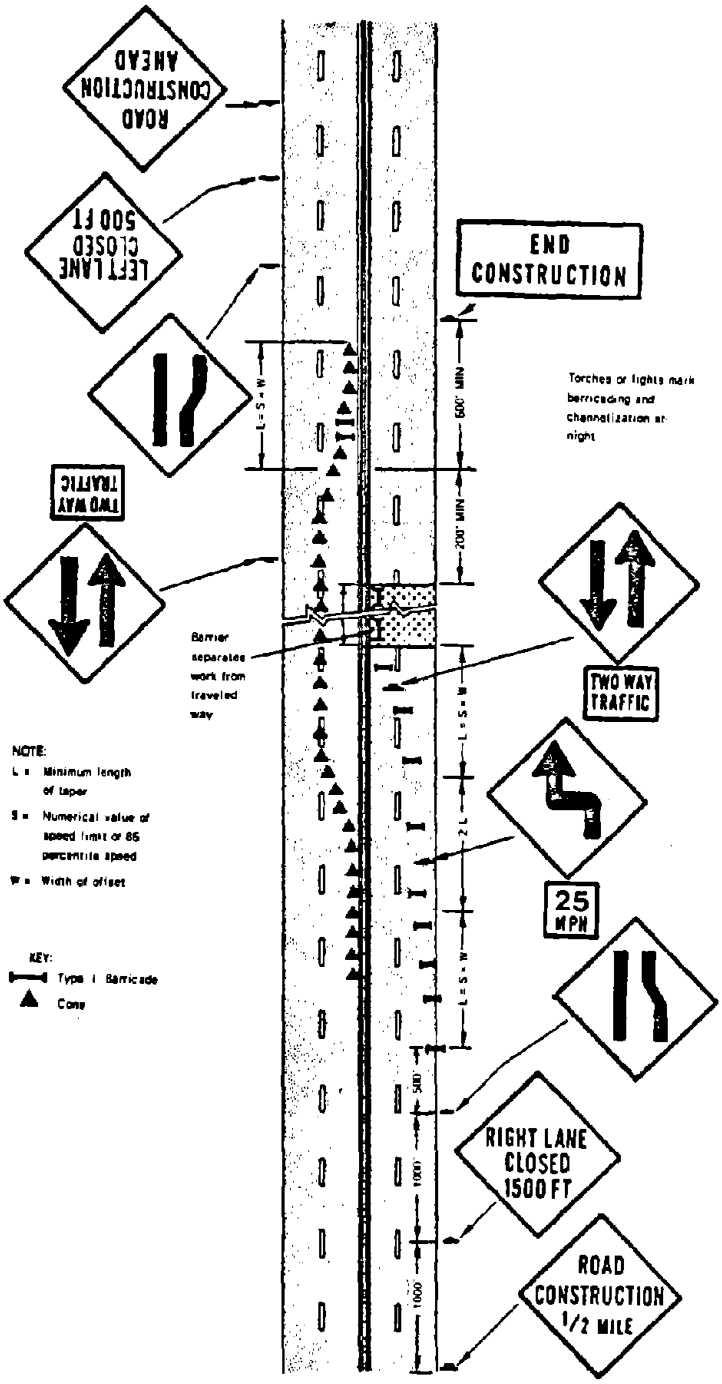

Figure 3 - Typical Crossover Zone on an Undivided Highway

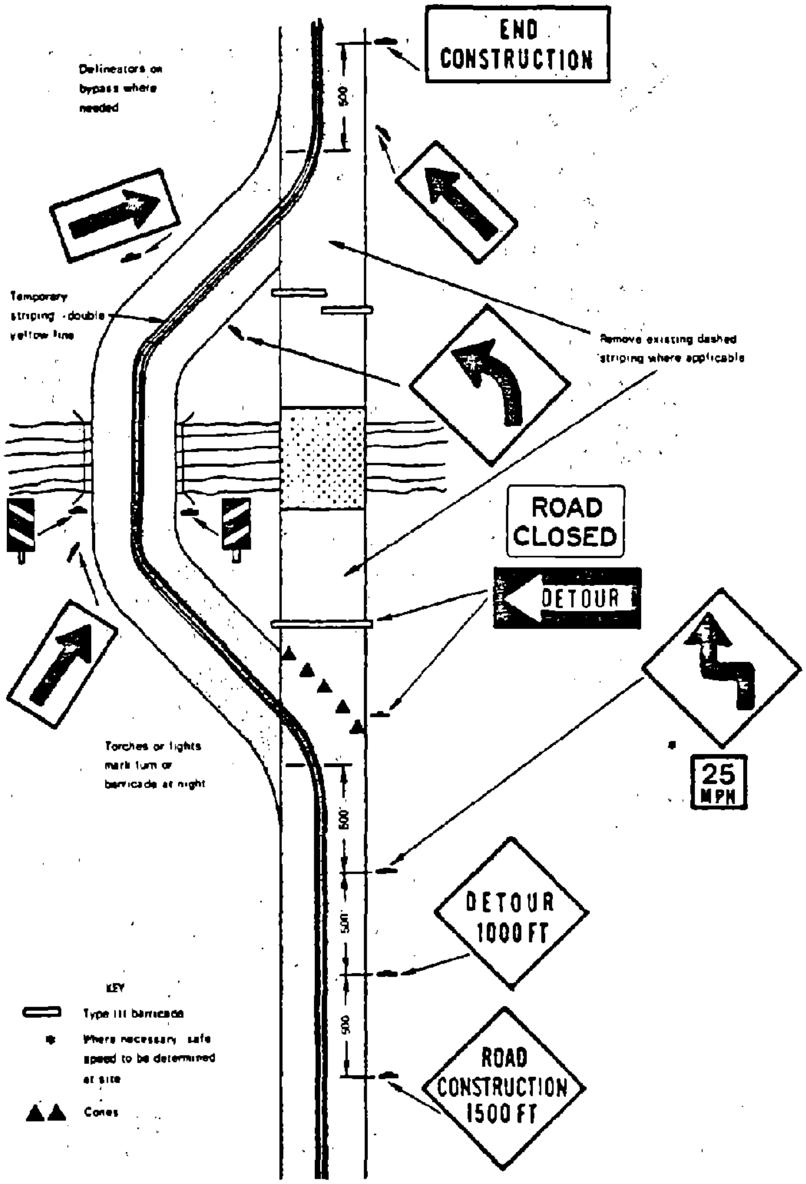

Figure 4 - Typical By-Pass Roadway Zone

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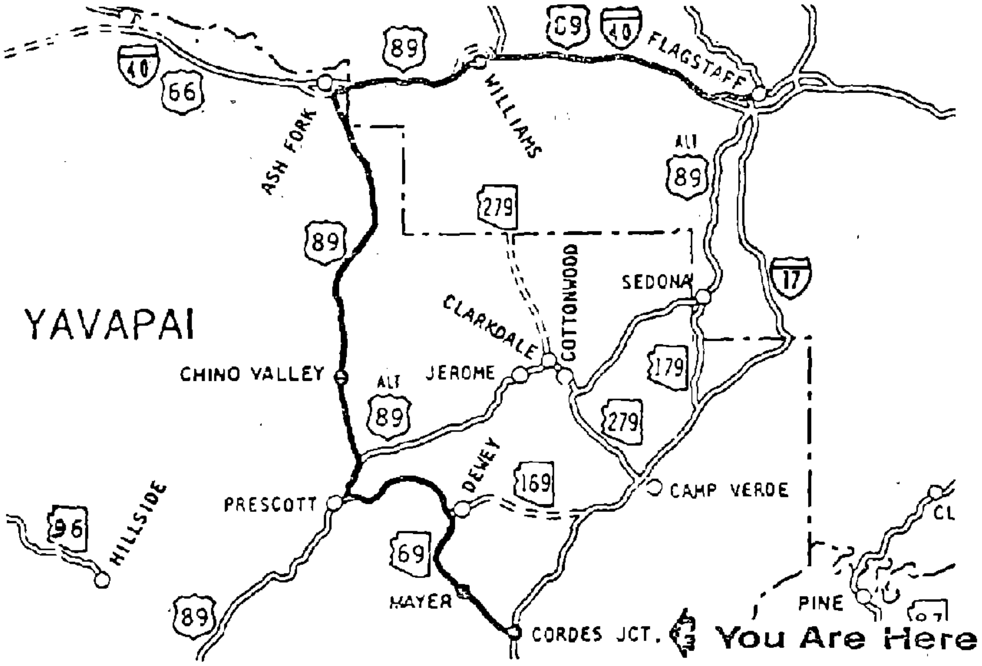

Follow alternate route via Prescott, Ashfork.. 135 miles to Flagstaff. Approximately 2½ to 3 hours driving

Figure 5 - Detour to Alternate Route Zone

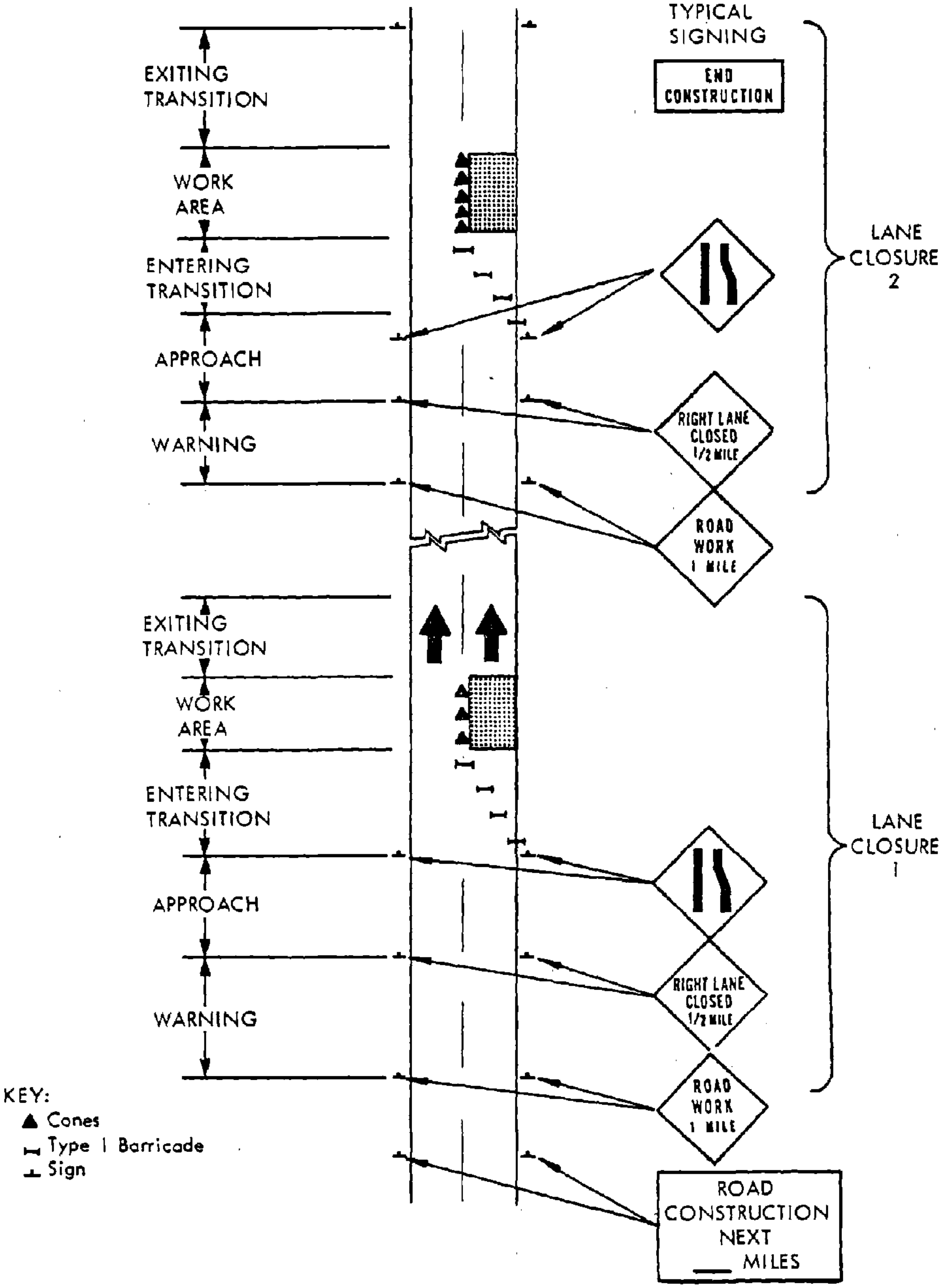

Figure 6 - Areas Within a Construction Zone

The <u>work area</u> is that length of the roadway where work is being done or is going to be done. The work area roadway may be completely closed to traffic, or a portion of the roadway may be open through the work area. If the work area is open to traffic, traffic control should provide for the separation and protection of motorists and construction workers.

The <u>exiting transition</u> is the area downstream from the work area where traffic returns to the normal roadway. In Figure 6, the right lane is reopened in the exit transition. If the work area roadway is closed to traffic the exit transition leads traffic back to the normal roadway. Also in the exit transition area traffic returns to the lanes that were closed and resumes its normal speed. In this area traffic should be informed if no further work areas will be encountered.

II. LITERATURE REVIEW

A. Purpose and Scope

Two HRIS searches were conducted in this task to obtain all available references on traffic controls in construction zones. In all, over 60 published reports were obtained and examined as part of the literature review. As each report was reviewed, important information was classified and grouped with similar data from other reports. The materials were classified by the design and operational elements of construction zone traffic control.

Manuals on traffic control in construction zones from 92 state, city, county, and utility agencies were also obtained and reviewed. Although many of the manuals are patterned closely after the Manual on Uniform Traffic Control Devices,[3/] the review of the manuals was important because they contained specifications for use of timber barricades and other devices used only in one part of the United States.

In addition to the published reports and state manuals which were reviewed, 26 states were contacted by phone to determine if they had additional reports, how they were handling traffic control in construction zones, and their ideas on the major problems in this area. This contact was also the first step in selecting states for the accident study. All references reviewed and reports obtained from the states are given in the reference list at the end of the report.

The information obtained in the review and telephone contacts was synthesized and some recommended improvements to current practices were made in an interim project report. Also, based on the identified problems, recommendations were made on the direction of further research.

B. Findings

1. Problem identification: The first step in evaluating the safety performance of construction zones was to review available construction zone accident data. Only three reports were found. The significant findings of these reports are explained below.

Table 1, which gives the results of a 1965 California accident study of 10 randomly selected construction projects, indicates that the total accident rate increased 21.4% during construction.[8/] Also, noteworthy is that the fatal accident rate increased 132.4% during construction. A later study of 31 construction projects was made in 1970 after many new principles for handling construction zone traffic were put into practice. Table 2 shows the comparison of results for the two California studies, which

TABLE 1

CALIFORNIA 1965 CONSTRUCTION ZONE ACCIDENTS

Proj.	BEFORE CONSTRUCTION									DURING CONSTRUCTION									PERCENT CHANGE							
	Number		Number of Accidents				Accident Rates			Number		Number of Accidents				Accident Rates				Number of Accidents				Accident Rates		
No.	Months	MVM	Tot.	Fat.*	Inj.	PDO	Tot.	F+I	Fatality	Months	MVM	Tot.	Fat.*	Inj.	PDO	Tot.	F+I	Fatality	MVM	Tot.	Fat.*	Inj.	PDO	Tot.	F+I	Fatality
1	12	4.7	10	0	4	6	2.12	0.85	0	12	5.1	16	0	10	6	3.14	1.96	0	+8	+60	0	+150	0	+48	+131	0
2	5	8.7	44	0	21	23	5.07	2.42	0	5	9.2	41	0	18	23	4.45	1.95	0	+6	-7	0	- 14	0	-12	- 19	0
3	12	20.1	33	0	22	11	1.65	1.10	0	12	24.3	54	3(3)	23	28	2.23	1.07	12.50	+21	+64	+ ∞	+ 4	+154	+35	- 3	+ ∞
4	12	62.6	68	4(5)	21	43	1.08	0.40	7.99	12	62.0	118	5(5)	61	52	1.90	1.06	8.06	-1	+59	+25	+190	+ 21	+76	+165	+ 1
5	5	17.3	27	0	13	14	1.57	0.76	0	5	17.4	37	1(1)	27	9	2.13	1.61	5.75	+1	+37	+ ∞	+108	- 36	+36	+112	+ ∞
6	12	28.1	64	0	26	38	2.28	0.93	0	12	27.1	78	0	29	49	2.88	1.07	0	-4	+22	0	+ 12	+ 29	+26	+ 15	0
7	12	4.4	20	1(1)	11	8	4.55	2.73	22.73	9	4.4	25	0	11	14	5.73	2.52	0	0	+25	-∞	0	+ 75	+26	- 8	- ∞
8	12	41.1	65	1(1)	33	31	1.58	0.83	2.44	12	47.2	74	8(9)	29	37	1.57	0.78	19.07	+15	+14	+700	-12	+ 19	- 1	- 6	+681
9	12	54.9	130	4(5)	58	68	2.37	1.13	9.09	12	63.9	188	9(11)	77	102	2.94	1.35	17.18	+16	+45	+125	+33	+ 50	+24	+ 19	+ 89
10	24	36.4	98	1(2)	42	55	2.68	1.18	5.50	12	44.5	114	2(6)	49	63	2.56	1.15	13.63	+26	+16	+100	+17	+ 14	- 4	- 3	+148
Total	118	278.3	559	11(14)	251	297	2.01	0.94	5.03	103	305.1	745	28(35)	334	383	2.44	1.19	11.47	+9.6	+33.3	+154.5	+33.1	+29.0	+21.4	+26.6	+128.0

DURING CONSTRUCTION:

PDO*	accident rate increased	17.8%	(1.07 to 1.26 acc/mvm)
Injury	accident rate increased	21.1%	(0.90 to 1.09 acc/mvm)
Fatal	accident rate increased	132.4%	(3.95 to 9.18 acc/100 mvm)
TOTAL	accident rate increased	21.4%	(2.01 to 2.44 acc/mvm)

**Figures in parenthesis show the number of persons killed.*

---

* Property damage only.

TABLE 2

CALIFORNIA CONSTRUCTION ZONE ACCIDENTS, 1965 AND 1970

	BEFORE CONSTRUCTION									DURING CONSTRUCTION								
	NO. MONTHS	MVM	NUMBER OF ACCIDENTS				ACCIDENT RATES			NO. MONTHS	MVM	NUMBER OF ACCIDENTS				ACCIDENT RATES		
			TOT.	FAT.*	INJ.	PDO	TOT.	F+I	FATALITY			TOT.	FAT.*	INJ.	PDO	TOT.	F+I	FATALITY
10 Construction Zones Studied in 1965	118	278.3	559	11(14)	251	297	2.01	0.94	5.03	103	305.1	745	28(35)	334	383	2.44	1.19	11.47
31 Construction Zones Studied in 1970	415	2393	4242	75(101)	1645	2522	1.77	0.72	4.22	415	2606	4927	83(106)	1954	2890	1.89	0.78	4.07

**Figures in parenthesis show the number of persons killed.*

DURING CONSTRUCTION 1965: PRIOR TO APPLYING NEW PRINCIPLES

PDO* accident rate increased 17.8% (1.07 to 1.26 acc/mvm)
Injury accident rate increased 21.1% (0.90 to 1.09 acc/mvm)
Fatal accident rate increased 132.4% (3.95 to 9.18 acc/100 mvm)
TOTAL accident rate increased 21.4% (2.01 to 2.44 acc/mvm)

DURING CONSTRUCTION 1970: SINCE APPLYING NEW PRINCIPLES

PDO* accident rate increased 5.7% (1.05 to 1.11 acc/mvm)
Injury accident rate increased 8.7% (0.69 to 0.75 acc/mvm)
Fatal accident rate increased 1.6% (3.13 to 3.18 acc/100 mvm)
TOTAL accident rate increased 6.8% (1.77 to 1.89 acc/mvm)

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* Property damage only.

tends to indicate that their new principles may have had some very positive effects. In the second study, the total accident rate increased only 7% and the fatal accident rate increased only 1.6%. Because these two tables represent the total documentation for these studies, however, it is not possible to verify the statistical comparability of these results.

Table 3 shows some construction zone data (unpublished) from another state. These data, which are for 207 resurfacing projects on two-lane highways, indicate a 61% increase in total accidents, a 67% increase in injury accidents, and a 68% increase in fatal accidents during construction. The only conclusion of this analysis is that construction zones for resurfacing projects on two-lane highways appear very hazardous for that one state. What is not resolved is whether these kinds of projects are intrinsically hazardous or whether that state's construction zone traffic control practices are inadequate to meet optimum safety requirements.

A report[4/] by the Virginia Highway and Transportation Research Council regarding the safety practices in the construction zone of I-495 in Northern Virginia indicated a 119% increase in the accident frequency, compared to a preconstruction baseline. As in the 1965 California study,[8/] and the unpublished report, the I-495 construction project experienced a large increase in fatal and injury accident rates (320% and 35%, respectively). However, the distribution of accidents by severity shifted toward more property damage only accidents. The report[4/] also noted that while the frequency of accident occurrence was increased along the entire project length (22.1 miles), interchanges and transitional areas experienced an even higher increase.

2. Description of construction zones: In traversing a construction zone a driver may encounter several different roadway types. These were identified by the project staff as lane closures, crossovers, temporary bypass roadways, detours, and those in which the existing roadway is used, but with some restrictions placed on it. Section I.C gives a detailed review of each work area roadway type. The section also explains the various areas within each roadway type in which particular driver responses are required.

3. Planning and design of construction zones: We feel several types of information are needed to produce a safe and efficient traffic plan for a construction zone. Needed information include construction, roadway, and traffic data.

Required construction data include lateral location, length, and duration. Activities located on the roadway reduce the amount of roadway available for travel. Construction activity taking place off the roadway can also affect travel. Motorists' curiosity tends to slow the traffic stream down while entering any construction area.[2/] Lateral location also affects environmental conditions, especially the amounts of dust and noise.

TABLE 3

RURAL 2-LANE - RESURFACING PROJECTS - FY '74

	NO. PROJECTS	L.N. (MILES)	BEFORE (1 YEAR)							DURING CONSTRUCTION							AFTER (1 YEAR)						
			VEHICLE MILES (10^8)	ACC.	RATE	INJ.	RATE	FAT.	RATE	VEHICLE MILES (10^8)	ACC.	RATE	INJ.	RATE	FAT.	RATE	VEHICLE MILES (10^8)	ACC.	RATE	INJ.	RATE	FAT.	RATE
DISTRICT 1	39	359.95	3.239	896	273.5	389	120.1	30	9.3	0.527	228	432.6	96	182.1	7	13.3	3.239	658	203.1	302	93.2	10	3.1
DISTRICT 2	20	418.37	3.429	1016	296.3	386	112.6	24	7.0	1.328	405	305.0	192	144.6	17	12.8	3.429	683	199.1	369	107.6	21	6.1
DISTRICT 3	34	372.00	3.364	615	182.8	228	67.8	12	3.6	0.855	220	257.3	92	107.6	7	8.2	3.364	507	150.7	190	56.5	7	2.1
DISTRICT 4	23	294.69	1.706	481	281.9	175	102.6	22	12.9	0.426	180	422.5	74	173.7	2	4.7	1.706	338	198.1	114	66.8	13	7.6
DISTRICT 5	36	384.02	3.326	578	173.8	255	76.7	22	6.6	0.769	203	264.5	86	111.8	6	7.8	3.326	457	137.3	186	55.9	19	5.7
DISTRICT 6	41	408.08	4.121	1226	297.7	551	133.7	27	6.6	0.927	355	382.5	140	150.9	10	10.8	4.121	858	208.2	400	97.0	18	4.4
DISTRICT 7	14	88.53	1.556	519	333.5	181	116.3	6	3.9	0.489	200	409.0	74	151.3	1	2.0	1.556	512	329.0	205	131.8	6	3.9
TOTAL	207	2325.64	20.741	5331	257.0	2165	104.4	143	6.9	4.320	1791	414.6	754	174.5	50	11.6	20.741	4113	198.3	1766	85.2	94	4.5
% OF CHANGE OF RATES TO THE BEFORE PERIOD												+61%		+67%		+68%			−23%		−18%		−35%

The length of a construction zone can affect the traffic operations in several ways. If the zone is excessively long, drivers may tend to lose the concentration required to pass through the zone. They may need to be reminded of the conditions repeatedly. Often when the zone is excessively long, there are areas within the zone where no construction work occurs for days or weeks. Drivers are unlikely to maintain reduced speeds when they do not see activity.[5] As the length of zone increases, the probability of a vehicle requiring an emergency stop also increases. If shoulders are eliminated and no other place is provided for emergency stops, the vehicle will be forced to stop in the traffic lane, thus being quite vulnerable to rear-end collisions.[5] The duration of the construction activity can affect both the altertness and respect that drivers have toward traffic control in construction zones.[5] One source indicated motorists usually take a week to become accustomed to different traffic situations.[6] As the duration of activity increases, however, local drivers tend to become so familiar with the new conditions that they become complacent. Motorists often become irritated if construction seems to linger on, and they may lose respect for the traffic control.[2]

Roadway data such as roadway cross-section, number and width of lanes, width of shoulders, lateral clearance to roadside objects, median width, and horizontal and vertical alignment are important in determining the work area, roadway type during construction. For example, alignment and median width are very important in determining the location and geometrics of a crossover.

The normal volume of traffic on the roadway will affect the ability to use various types of traffic control in construction zones. A previous study has developed the following guidelines based on traffic volumes.[2]

For two lane roads (both directions).

- If ADT is less than 1,500 or if the peak hour traffic is less than 150, maintain one lane.
- If ADT is greater than or equal to 1,500 or the peak hour traffic is 150 vehicles or more, maintain two lanes.

For four-lane undivided roads (both directions).

- If ADT is less than 10,000 or peak hour traffic is less than 1,000, maintain one lane each direction.
- If ADT is 10,000 or more or peak hour traffic is 1,000 or more, maintain three lanes (two in heavy direction).

Traffic volumes can also indicate when construction must be suspended due to large volumes, such as morning and evening commuter traffic peaks. Figure 7 shows the effect of closing traffic lanes for construction and the effect on the capacity of the facility. The heavy curved line is the arrival rate, which is determined by counting vehicles when no lanes are closed. The slope of the straight lines is the reduced capacity expected if traffic is funnelled down into two lanes. By moving this sloping line up and down with a parallel ruler, the delay expected if a lane is closed at a certain time of day can be determined.

4. Speed control strategy: Two philosophies are currently in widespread use concerning speed control through construction zones. One says[7/] "Speed in the construction zone should be similar to the speed on the highway before the start of the construction zone" and argues that changes in speed, per se, and large speed differentials, in particular, produce accidents. The second philosophy says[7/] "The speed of traffic should be reduced in construction zones." This philosophy is based on the feeling that construction zones are intrinsically more hazardous than other sections of roadway and therefore traffic speeds should be reduced to provide a reasonable degree of safety for motorists and construction personnel. Conversations with highway officials in several states revealed that while most of these state people realize that speed reductions may be necessary in some cases, several felt that a speed reduction is necessary in almost all construction zones; a smaller number believe that speeds should not be reduced unless conditions dictate such a reduction.[7/]

If the speed control objective is to maintain a normal speed through the construction zone, then a design speed equal to that of the highway preceding the construction should be used. All geometric design elements and traffic control devices must be suitable for this design speed. For example, California specifies that "on roads with high approach speeds detours should be designed to high standards."[8/] This principle would apply to all roads and basically calls for blending the construction zone into the road section with as few differences as possible.

If the safest speed control strategy is to reduce speed in the construction zone, an effective method of speed reduction must be incorporated into the construction zone design. Then a lower design speed can be used in determining geometric design elements and traffic control devices needed. Of course, in some zones on low volume highways, it may be necessary to stop traffic. In these zones it is important that vehicles be brought to a stop safely. Some commonly used speed reduction methods are advisory speed limits, regulatory speed limits, signal control, flagging, traffic pacing, and physical restriction of vehicle speeds, by methods such as "Iowa weave," and reducing lane widths.

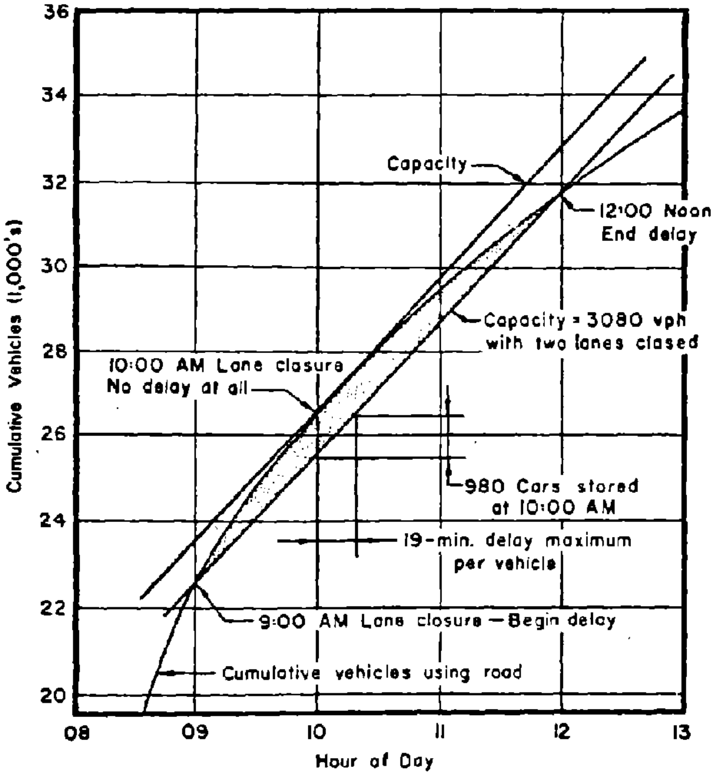

Figure 7 - Effect of Lane Closure on Queue Build-Up [1]

The effectiveness of posting speed limits is regarded as poor. A study of construction zone accidents stated, "It has been proved that posting of a speed limit does not cause traffic to slow to that speed. A majority of traffic behaves according to apparent conditions regardless of the posting."[8] Especially in construction zones with no construction activity, drivers are more likely to disregard reduced speed limits.[5] Two sources indicated that drivers seemed to disregard speed limits unless a patrol car was stationed at the construction zone.[2,7]

5. Geometric design: The geometric design of the roadway passing through or around a construction zone should provide for a safe, efficient traveled-way with as little change from the approach roadway as possible. Any sudden change in geometric standards can result in inefficient and hazardous conditions. Lowering of geometric standards can contribute to increased accident rates.[9] The literature review has identified several principles that should be followed in the geometric design of construction zones:[1,8,10]

- Transition areas must be as nearly like the approach as possible but if there are differences, they must be clearly apparent.[8]
- It is better to use flat diagonal crossovers rather than reverse curves with extensive superelevation.[8]
- Lateral obstructions located closer than 6 ft from the edge of a traffic lane reduce its effective width.[10]
- Reduction of one geometric standard can sometimes be compensated for by improving another[1].
- Tapers for lane drops should not be contiguous with crossover of temporary by-pass roadway transitions.[1]

6. Traffic control devices: Traffic control devices are used in construction zones to alert drivers of the impending conditions, warn them of hazards, and direct them through the proper path. Several references had information concerning the appropriate use of these devices in construction zones. Information concerning the use of signs, pavement markings, and timber barricades follows.

The purpose of using standard signs in construction zones is to assist or direct the driver in making appropriate speed and path decisions. Since a driver can assimilate only a limited amount of information, it is preferable not to use more than two messages per sign.[11] Signs should not clutter the driving environment, and if they must function during darkness they should be as visible as they are during the day.[3]

When construction work makes it necessary to use vehicle paths other than the lanes normally used, appropriate reflectorized pavement markings are required. These markings are used as: lane striping; edge-line striping; channelization striping; pavement arrows; and word messages.

Federal Highway Administration Notice N-5160.21[12] dated May 10, 1976, revised Section 6C-11 of the MUTCD concerning the removal of inappropriate pavement markings. The notice states that the following action is to be taken:

> "The MUTCD, Section 6C-11, is changed by deleting the last sentence of the first paragraph and substituting the following sentence:
>
> > Markings no longer applicable which may create confusion in the minds of motorists shall be removed or obliterated as soon as practicable.
>
> The term 'Practicable' should be interpreted as meaning or implying:
>
> 1. Marking removal equipment should be scheduled for use immediately following any change in laneage.
>
> 2. If darkness or inclement weather interferes with removal operations, such operations should be accomplished during the next daylight period or as soon thereafter as weather conditions permit.
>
> 3. If equipment failures occur such equipment should be repaired, replaced, or leased so that the removal can be accomplished by the following day.
>
> Division Administrators are requested to assure that all future PS&Es adequately provide for complete removal or obliteration."

Timber barricades have been used in some construction zones to serve as both delineation devices and as a positive barrier.[2] They were selected primarily because they take up little room and are supposed to redirect errant vehicles.[4] However, a report by the Virginia Highway and Transportation Research Council concerning the use of these devices for redirection of errant vehicles showed that the timber barricades were ineffective because 73.5% of all vehicles striking the devices either straddled or penetrated them.[4] The report went on to say that portable concrete traffic barriers with the "safety shape" are ideal for use as a protection and redirection device.

FHWA Notice N 5160.27 dated February 2, 1977, also covered the subject of timber barricades, and states " 'Timber Barricades' shall not be approved for use on direct Federal or Federal-aid projects, as a positive barrier at any speed." The notice also states that timber barricades should be used for delineation only in urban areas where operating speeds of 20 mph or less could be expected.

Recently, new devices have been developed to aid in controlling traffic through construction areas. A few of these are described below:

a. Delineator pole made of elastromeric material, set in concrete base, capable of withstanding bumper speeds up to 25 mph.[2/] This device is especially useful in areas where traffic cones are knocked over repeatedly. These delineators also maintain higher reflectivity during rain than conventional posts.

b. Portable, 3 ft x 7 ft changeable matrix message sign with 18 in. characters.[2/] Changeable matrix message signs are very applicable to changing traffic conditions. Portability of these signs allows for the freeing of construction equipment usually required for mounting of these signs.

c. High intensity reflectorized sheeting incorporating diagonal orange strips.[2/] This device is very useful when applied to barricades. The manufacturer claims it is nearly three times as bright as engineer grade material.

d. Equipment to erase unnecessary pavement markings.[2/] Inadequate removal of unnecessary pavement markings can result in very hazardous conditions if they lead the motorist on an inappropriate path. This new equipment removes the markings more effectively and leaves the pavement with as little scarring as possible.

e. Breakaway barricades.[7,13/] This device is assembled without bolts or cement allowing for instant breakaway with parts flying clear of impacting vehicles. Because of breakaway design, most of the parts will not be damaged by collision, and those that are can be easily replaced because of interchangeable parts.

7. Construction Zone Operations: Although it is important that construction zones be well planned and designed, the daily operation of the construction zone is even more important. Lackadaisical or inattentive supervision of the daily operations can negate the most complete and thorough plans. One accident study indicated that more than half of the accidents reported on road construction projects were caused by operational negligence.[14/] An Illinois accident study indicated "Too many accident reports state that the driver was surprised by a barricade across the road or a flagman stopping traffic with no advance signs."[15/]

Invaluable assistance to the traffic control on major facilities can be provided through advance use of public information. Various methods can be used to inform the public of anticipated delays or congestion resulting from construction activities. These methods include public hearings, press releases, special mailings, personal contacts, and special signs.[1,2,6,7] The method and degree to which these techniques are used will vary according to the following project factors: duration, size, season, location, traffic volumes and mix, time of day, day of week, land use, institutional constraints, type of available mediums and expertise, and funding sources.[2] Once the project is completed, mass media articles and letters to affected parties expressing appreciation for cooperation on the project will enhance the operation of future projects.[2]

An important aspect of the operation of a construction zone is the training of personnel who are working in the zone. The resident engineer must be well trained in traffic operation techniques in order to evaluate the effectiveness of the speed control strategy and determine that flagmen and other construction workers are performing in a manner to ensure safety to the public and themselves. Most highway agencies have training programs at the field supervisor level. A notebook entitled, "Traffic Control for Street and Highway Construction and Maintenance Operations," developed by the Department of Transportation is designed to train government and contractor personnel in planning, designing, installing, and maintaining signing and marking installations in construction zones.[16] This 1-week training course presents relevant information and then gives the participants an opportunity to use the information in work sessions. Training films have also been developed for these training sessions.[1]

Traffic control devices must be kept in good condition and in the proper location so that they perform their intended function. Proper maintenance of the devices will help to minimize accident litigation potential, check vandalism, and accommodate adverse environmental conditions.[16]

Maintenance of devices on very large projects can be a substantial part of the construction project. For a construction project on the Dan Ryan freeway in Chicago, the contractors maintained the devices on a continuous 24-hr a day basis using a two-man crew equipped with a two-way radio. This crew replaced an average of 70 to 100 barricades a day.[6] In California, a contractor was required to constantly survey all traffic control devices, 24 hr a day, every day of the week, for the entire length of the project, and to make any necessary temporary repairs.[6] This extensive maintenance effort resulted in a great reduction in the number of accidents that usually accompanied construction projects in that state. Cost of the surveillance was about 2% of the project cost.

Generally, the following general guidelines should be followed in the maintenance of traffic control devices:[2,3,16]

- Replace devices damaged from the weather, traffic, or construction activity.

- Replace missing devices.

- Remove devices no longer needed.

- Replace obsolete devices.

- Clean dirty signs.

- Remove weeds, shrubbery, construction materials or equipment, spoil, etc., that obscures devices.

- Repaint faded pavement markings if they are to be used for an extended period of time.

- Check flasher and delineation light charge levels daily.

- Maintain an adequate inventory of devices.

C. Conclusions of Literature Review

The major conclusions drawn from the literature review in order of importance are:

1. Although several alternative combinations of work area roadway type and construction scheduling are currently used, little or no data are available to determine the safety effect of the choice of any particular alternative.

2. There are two prevailing philosophies on speed control in construction zones. One says that speeds should always be reduced and the other says that normal highway operating speeds should be maintained throughout the zone. Again, there are no data to support the relative safety benefits of either of these philosophies.

3. The application of traffic control devices in construction zones appears to vary widely between agencies and between construction projects. This indicates a general lack of knowledge regarding the safety effectiveness of the various traffic control devices and their locational application.

4. There is a need for a national standard to provide guidance in designing a system for the safe movement of traffic through construction zones. Functional criteria and guidelines are needed for the appropriate use and placement of cones, pylons, barricades, barrels, barriers, and impact attenuators.[4]

5. The high concentrations of accidents at interchanges and transition zones identify those roadway locations where extreme care and meticulous effort must be exercised in the selection, utilization, and maintenance of construction zone traffic control devices.[4]

6. The daily management of traffic operations within a construction zone is an important factor in the safe operation of the zone. Inattentive supervision of the day-to-day operations can often negate the most complete and thorough plans.

7. There is a lack of methods to reduce speeds in construction zones.

8. There is a need for revised traffic control bidding procedures.

9. The use of portable concrete traffic barriers in construction zones should be investigated further.

10. The protection of concrete barrier ends should be investigated further.

III. CONSTRUCTION ZONE ACCIDENT STUDY

The accident study portion of the research looked at the accident experience of construction zone roadways before and during construction. Data from seven states were used in the analysis. Trips were made to each state to obtain data about the construction activity, the roadway, accidents and basic construction and traffic control costs.

The collected data were classified into two major categories--construction data and accident data. The construction data included the type of construction, length, duration, traffic volumes, and type of traffic controls used. Accident data were reduced into several categories such as type, location, time of occurrence, and severity. Forms were developed for recording both types of data to ensure uniformity of the data from each state.

Analysis of the data was done in four stages. The first was a comparison of accident numbers before and during construction. The second stage considered before and during accident rates. The third stage of the analysis was a regression analysis with construction-zone characteristics as independent variables and during accident rates as dependent variables. The fourth stage of the analysis looked at three construction project case studies that included determination of construction-related accidents.

The following sections will detail each part of the accident study from the selection of cooperating states, to the data collection, and finally the analysis of the data.

A. Selection of Cooperating States

States were selected based on five criteria.

- Concern about construction zone problems;
- Variation of speed control methods;
- Ease and cost of obtaining reliable accident records;
- Availability of specific data on construction zones; and
- Variation of geographical area.

Of these five criteria the third and fifth were the most useful in choosing one state over another. All states contacted were concerned about construction zone problems, and there was little variation in speed control methods or availability of construction zone data.

Table 4 lists the 26 states that were contacted. When the states had been ranked by the above criteria, they were contacted in order, and asked to cooperate. The seven states selected were Colorado, Georgia, Michigan, Minnesota, New York, Ohio, and Washington.

TABLE 4

STATES CONTACTED

1. Arizona
2. California
3. Colorado
4. Connecticut
5. Florida
6. Georgia
7. Idaho
8. Illinois
9. Indiana
10. Iowa
11. Kansas
12. Maryland
13. Michigan
14. Minnesota
15. Nebraska
16. New Jersey
17. New York
18. Ohio
19. Oklahoma
20. Oregon
21. Pennsylvania
22. Tennessee
23. Texas
24. Utah
25. Virginia
26. Washington

B. Data Collection and Reduction

Data were collected by project staff during visits to the highway department of each cooperating state. The data collection effort was planned as two visits to each state. On the first visit data were gathered on a group of current or recently completed construction projects. The second visit was scheduled for about 1 month later, and was for the purpose of collecting accident data for each of the projects. All seven states were visited at least once. In some states accident data were obtained by mail rather than a second visit.

A data collection plan was developed prior to the state visits. In order to choose projects that would provide a reasonable number of accidents, project selection criteria were developed that specified a minimum product that should be obtained when the length (in miles) and the duration (years) were multiplied. These criteria, were developed from typical accident rates given in a report entitled "Interstate System, Accident Research

Study - 1."[17/] The criteria were tested by comparing in-house accident data on actual highway sections. A project worksheet was developed to record data about length, duration, and ADT for each section.

A data collection checklist was also developed to ensure a comprehensive data collection effort. Data were divided into categories of general data, project selection data, construction zone data, accident data, and cost data. Project selection criteria, the project worksheet, a data collection checklist, and accident rate computation data are shown in Appendix A.

The collection of project data on the initial visit to a state usually required trips to district highway department offices. In most visits current projects were visited and photographed to obtain a perspective on the relationship of controls shown on the traffic control plans and controls that were being used in the field.

Accident data for the period of construction and 1 year before construction began was requested for each suitable project. Where possible, hard copy accident reports were requested for the during period, and computer printout line summaries for before periods. In some states, only hard copies of construction related accidents were available or the state could only furnish hard copies on two or three projects. Detailed accounts of each state visit are given in Appendix B.

As construction and accident data were received from each of the seven states the data were organized by projects. In some cases, original projects were divided or combined with other projects to simplify the analysis.

When construction and accident data had been divided into projects, the data for each project was recorded in a format common to all states. Forms were used to ensure uniformity. Construction data were recorded on the Construction Data Worksheet, and accident data were recorded on the Accident Summary Worksheet. These forms are also shown in Appendix A.

Table 5 summarizes the data collected. The data included 79 projects of which 11 were on six- or eight-lane interstate highways, 24 on four-lane divided interstates, 18 on four-lane divided noninterstate, 3 on five-lane undivided, 4 on four-lane undivided and 19 were on two-lane roadways. There were 31 urban projects and 48 rural projects.

Cost data were also collected in the state visits. Traffic control cost data are given in Appendix C. Appendix D gives the computation methods for determining user costs due to construction. This appendix was developed in conjunction with project DOT-FH-11-8120, "Effectiveness of Alternative Skid Reduction Measures."

TABLE 5

COLLECTED DATA SUMMARY

Project	Area Type	Normal Roadway Type	Construction Roadway Type	Length (mi)	Duration (days)
1	Rural	4-lane divided Noninterstate	4-lane divided reduced to 1 lane each direction	11.97	234
2	Urban	4-lane divided Interstate	4-lane divided reduced to 1 lane each direction	7.12	219
3	Urban	4-lane divided Interstate	4-lane divided reduced to 1 lane each direction	4.25	315
4	Urban	6 or 8-lane Interstate	6 or 8-lane divided reduced to 2 lanes each direction	3.87	113
5	Urban	6 or 8-lane Interstate	6 or 8-lane divided reduced to 2 lanes each direction	8.77	85
6	Urban	6 or 8-lane Interstate	6 or 8-lane divided reduced to 2 lanes each direction	6.90	92
7	Urban	4-lane undivided	4-lane undivided reduced to 2 lanes	2.99	270
8	Urban	4-lane divided Interstate	4-lane divided reduced to 1 lane each direction	1.76	231
9	Urban	4-lane divided Noninterstate	4-lane divided, but on new alignment	3.79	219
10	Rural	4-lane divided Noninterstate	4-lane divided, but on new alignment	5.56	227
11	Rural	4-lane divided Noninterstate	4-lane divided, but on new alignment	8.29	539
12	Rural	2-lane	2-lane on new alignment	4.94	181
13	Rural	2-lane	2-lane on new alignment	6.59	274
14	Rural	2-lane	2-lane on new alignment	4.28	153
15	Rural	2-lane	2-lane on new alignment	5.03	191
16	Rural	2-lane	2-lane on new alignment	5.44	220
17	Rural	4-lane divided Interstate	4-lane divided reduced to 1 lane each direction	11.72	655
18	Urban	2-lane	2-lane on new alignment	3.07	610
19	Urban	4-lane undivided	4-lane undivided reduced to 2 lanes	1.00	285

TABLE 5 (continued)

Project	Area Type	Normal Roadway Type	Construction Roadway Type	Length (mi)	Duration (days)
20	Rural	2-lane	2-way 2-lane reduced to 1 lane	8.60	100
21	Rural	2-lane	2-way 2-lane reduced to 1 lane	3.85	313
22	Rural	2-lane	2-way 2-lane reduced to 1 lane	4.55	239
23	Rural	4-lane divided Interstate	4-lane divided reduced to 2-way 2-lane	5.70	39
24	Rural	2-lane	2-lane on new alignment	2.90	100
25	Urban	5-lane undivided w/TWLTL	4-lane undivided reduced to 2 lane	3.48	186
26	Urban	4-lane divided Interstate	4-lane divided reduced to 1 lane each direction	6.18	271
27	Urban	6 or 8-lane Interstate	6 or 8-lane divided reduced to 2 lanes each direction	8.57	122
28	Urban	6 or 8-lane Interstate	6 or 8-lane divided reduced to 2 lanes each direction	3.48	47
29	Urban	2-lane	2-way, 2-lane reduced to 1 lane	2.86	294
30	Rural	4-lane divided Interstate	4-lane divided reduced to 1 lane each direction	10.10	215
31	Urban	4-lane divided Noninterstate	4-lane divided reduced to 1 lane each direction	10.68	212
32	Urban	6 or 8-lane Interstate	6 or 8-lane divided reduced to 2 lanes each direction	5.25	464
33	Urban	4-lane divided Interstate	4-lane divided reduced to 1 lane each direction	8.43	201
34	Urban	6 or 8-lane Interstate	6 or 8-lane divided reduced to 2 lanes each direction	9.06	209
35	Rural	2-lane	2-lane on new alignment	8.04	452
36	Rural	2-lane	2-way, 2-lane reduced to 1 lane	15.79	194
37	Urban	6 or 8-lane Interstate	6 or 8-lane divided reduced to 1 lane each direction	15.09	55

NOT REPRODUCIBLE

TABLE 5 (continued)

Project	Area Type	Normal Roadway Type	Construction Roadway Type	Length (mi)	Duration (days)
38	Urban	4-lane divided Noninterstate	4-lane divided reduced to 2-way, 2-lane	0.59	121
39	Rural	2-lane	2-lane on new alignment	4.25	983
40	Urban	6 or 8-lane Interstate	6 or 8-lane divided reduced to 1 lane each direction	7.61	67
41	Rural	4-lane divided Noninterstate	6-lane divided reduced to 2-way, 2-lane	2.86	122
42	Urban	2-lane	2-way, 2-lane reduced to 1 lane	3.17	241
43	Rural	2-lane	2-lane on new alignment	13.39	241
44	Rural	4-lane divided Noninterstate	4-lane divided on new alignment	9.73	241
45	Urban	4-lane divided Noninterstate	4-lane divided on new alignment	0.72	365
46	Urban	6 or 8-lane Interstate	6 or 8-lane divided reduced to 1 lane each direction	6.09	89
47	Urban	5-lane undivided w/two-way left-turn lane (TWLTL)	5-lane undivided w/TWLTL reduced to 2 lanes	7.58	79
48	Rural	4-lane divided Noninterstate	4-lane divided reduced to 2-way, 2 lane	2.04	267
49	Rural	2-lane	2-way, 2-lane reduced to 1 lane	8.18	443
50	Rural	2-lane	2 lane on new alignment	0.80	673
51	Rural	2-lane	2 lane on new alignment	4.32	297
52	Rural	4-lane divided Noninterstate	4-lane divided reduced to 1 lane each direction	25.06	192
53	Rural	4-lane divided Noninterstate	4-lane divided reduced to 2-way, 2-lane	6.20	999
54	Urban	4-lane divided Noninterstate	4-lane divided reduced to 1 lane each direction	6.19	304
55	Urban	6 or 8-lane Interstate	6 or 8-lane divided reduced to 2 lanes each direction	9.80	386
56	Rural	4-lane divided Interstate	4-lane divided reduced to 2-way, 2-lane	10.30	659
57	Rural	4-lane divided Interstate	4-lane divided reduced to 1 lane each direction	14.74	507

TABLE 5 (continued)

Project	Area Type	Normal Roadway Type	Construction Roadway Type	Length (mi)	Duration (days)
58	Rural	4-lane divided Interstate	4-lane divided reduced to 1 lane each direction	5.90	273
59	Rural	4-lane divided Interstate	4-lane divided reduced to 1 lane each direction	14.48	167
60	Rural	4-lane divided Interstate	4-lane divided reduced to 1 lane each direction	9.63	395
61	Rural	4-lane divided Interstate	4-lane divided reduced to 1 lane each direction	7.94	273
62	Rural	4-lane divided Interstate	4-lane divided reduced to 1 lane each direction	14.48	250
63	Rural	4-lane divided Interstate	4-lane divided reduced to 1 lane each direction	8.20	619
64	Rural	4-lane divided Interstate	4-lane divided reduced to 1 lane each direction	10.59	370
65	Rural	4-lane divided Interstate	4-lane divided reduced to 1 lane each direction	7.94	244
66	Rural	4-lane divided Interstate	4-lane divided reduced to 1 lane each direction	8.91	285
67	Rural	4-lane divided Interstate	4-lane divided reduced to 1 lane each direction	36.46	215
68	Rural	4-lane divided Interstate	4-lane divided reduced to 1 lane each direction	16.10	470
69	Rural	4-lane divided Interstate	4-lane divided reduced to 1 lane each direction	6.60	574
70	Rural	4-lane divided Interstate	4-lane divided reduced to 1 lane each direction	23.18	514
71	Rural	4-lane divided Interstate	4-lane divided reduced to 1 lane each direction	10.20	165

TABLE 5 (concluded)

Project	Area Type	Normal Road Type	Construction Road Type	Length (mi)	Duration (days)
72	Urban	4-lane undivided	4-lane undivided reduced to 2 lanes	1.57	989
73	Rural	4-lane undivided	4-lane undivided reduced to 2 lanes	2.64	187
74	Rural	4-lane divided Noninterstate	4-lane divided reduced to 2-way, 2 lanes	3.45	356
75	Rural	4-lane divided Noninterstate	4-lane divided on new alignment	4.20	105
76	Urban	5-lane undivided w/TWLTL	5-lane undivided w/TWLTL reduced to 2 lanes	2.93	114
77	Urban	4-lane divided Noninterstate	4-lane divided reduced to 1 lane each direction	1.44	60
78	Rural	4-lane divided Noninterstate	4-lane divided reduced to 1 lane each direction	5.84	379
79	Rural	4-lane divided Noninterstate	4-lane divided reduced to 1 lane each direction	6.03	134

C. Data Analysis

1. Analysis of Before-During Accident Numbers: The first stage of the analysis compared the number of accidents occurring during construction with the number of accidents occurring in the year before the construction began.

The before-during accident number comparison was made in the following manner. For those projects where the construction period was 1 year or less, the before-during comparison was performed simply on a month-to-month correspondence. For example, if a construction project lasted from April 1, 1975, to November 15, 1975, the number of accidents in that period was compared to a before period of April 1, 1974, to November 15, 1974.

For those projects where the construction period exceeded 1 year, the before accident numbers were expanded by the ratio of the duration of construction to the duration of the before period. For example, if a construction project lasted from March 1, 1975, to June 1, 1976, (457 days) and the requested before period was from March 1, 1974, to February 28, 1975 (365 days), the before accident number would be multiplied by the ratio 457/365.

One drawback to this expansion is that it ignores the effect that seasons of the year have on accident types, severity, surface condition, percentage of night accidents, and total accident numbers. However, since only 27% of the projects are affected by the expansion, we assumed that the seasonal effects were minimal when the total accident set was analyzed.

Table 6 illustrates the number of before accidents, during accidents, and percent change for all projects. Similar tables for each state are shown in Appendix E. Each table includes the total number of accidents by night, day, severity, type, surface condition, and area.

Table 6 shows a 7.5% increase in construction accidents. Fixed object, rear-end, head-on, and turning accidents experienced large increases while ran-off-road accidents declined substantially.

The number of night accidents rose by 9.4%. However, the night accidents percentage of total accidents remained 30% both before and during construction. Accident severity had similar results. Although the number of fatal or injury accidents rose by a combined rate of approximately 5%, the percentage of these accidents to the total number of accidents remained a constant 29% both before and during construction. Also, rural accidents showed a slightly higher increase than urban accidents.

TABLE 6

TOTAL CONSTRUCTION ZONE ACCIDENTS

	Before	During	Change (%)
Total Accidents	8,172	8,785	+7.5
Night Accidents	2,454*	2,685*	+9.4
Severity			
Property-Damage-Only	4,718*	5,226*	+10.7
Injury	2,369*	2,488*	+5.0
Fatal	62*	58*	-6.5
	7,149*	7,772*	
Accident Type			
Right Angle	720	585	-18.8
Rear End	2,614	3,048	+16.6
Side Swipe	939	850	-9.6
Head On	99	114	+15.2
Turning	480	552	+15.0
Ran-Off-Road	706	520	-26.3
Roll	204	225	+10.3
Animal	84	102	+21.4
Fixed Object	941	1,307	+38.9
Fixed Object (Construction Equipment)	--	120	N/A
Other	1,385	1,362	-1.7
	8,172	8,785	
Surface			
Dry	4,190*	4,870*	+16.2
Wet	1,467*	1,443*	-1.6
Ice/Snow	706*	548*	-22.4
Unknown	786*	911*	+15.6
	7,149*	7,772*	
Area			
Urban	4,873	5,149	+6
Rural	3,299	3,636	+10
	8,172	8,785	

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* Does not include State 2 data.

Ranking the states by the percent increase in before-to-during accidents shows the following results:

State*	% Increase in Accidents Before Period to During Period	Ranking
6	-3.4	1
2	-1.0	2
5	+9.6	3
1	+9.9	4
3	+11.6	5
4	+21.0	6
7	+37.6	7

Thus, in two states, the accident numbers actually decreased slightly during construction, however the percentage increase in accident numbers is very sensitive to the type of projects in the state, and the number of before accidents that are considered. The state ranking is re-evaluated later in the analysis.

The before-during accident numbers were further analyzed by doing a time trend analysis of the month-by-month accident totals.

For each project, the monthly difference between accidents during construction and those in the corresponding months in the year prior to construction were totaled. The month-by-month accident differentials were used to determine if there is a time-trend effect in the construction zone accident experience. Since only 1 year of before accident data was collected, a maximum of 12 monthly differentials were analyzed. For projects that lasted more than 1 year, data after the first 12 months of construction were not considered.

Most of the projects began or ended at a time other than the first or last day of the month, and since uniformity in the duration of each monthly period was necessary for our time-trend analysis, the following scheme was used: if the partial month was less than 10 days, then the accident number in both the before and during periods was placed in the succeeding or preceding month, depending on whether it was the beginning or ending of the period. If the partial month was 10 days or more, then that monthly accident number was expanded by the ratio of the total number of days in the month to the number of days affected by construction. This procedure was used for both the before and during periods.

In addition to the time-trend, the monthly differentials were also analyzed to determine the variability of construction zone accidents between states, area types (urban-rural), and levels of speed reduction (speed reduction--no speed reduction).

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* State numbers are used instead of names to keep the state identity anonymous.

Only 65 of the 79 projects studied were used in this analysis, because the "before" data in State 2 was not broken down on a month-by-month basis.

The natural framework for the data is the (hierarchial) Analysis of Variance (AOV) model. Since some cells of this framework are missing, and since the sample sizes are unbalanced throughout, the AOV required is complicated. In order to produce working estimates of variable effects with a minimum of effort, an approximate AOV was executed in phases as described below.

The AOV considers monthly responses as replicates, i.e., independent duplicate observations of accident differential. In practice, the sequence of monthly observations within any project might be correlated to time if, for example, the effect of construction is relatively immediate but tapers off after a few months.

Therefore, prior to the AOV, an examination of the monthly accident differential versus time (in months) was undertaken. The Spearman rank correlation coefficient, r_s, was computed for every project ($N = 65$) with the result that no significant trends were observed. Only five of the 65 r_s's were statistically significant at $\alpha = 0.05$, and of these three were positive and two were negative. Also, the overall incidence of positive and negative r_s's was not significantly different from an equal partition ($X^2(1) = 2.46$). These computations indicate no general or long-term association between construction effect and time after construction. Also, a comparison of the first month response to their expected rank under the hypothesis of no significant short-term effect yielded an unsignificant test statistic ($Z = 0.57$).

The residual variance σ_e^2 (month-to-month within a zone) and project variance σ_p^2 were both estimated in the normal (pooled) manner, with the results $\sigma_e^2 = 51.445$, $\sigma_p^2 = 8.042$. The state (S), area (A), and speed reduction (R) effects were approximated with one-way AOV (each) to yield $\sigma_S^2 = 10.664$, $\sigma_A^2 = 9.596$, $\sigma_R^2 = 11.351$. Thus, in the accident data, state, area type, speed reduction level, and project variability contribute roughly equal to the response; and the residual variation is larger than the sum of the identifiable components.

The overall average accident differential of +1.60 is significantly greater than zero ($t = 4.75$, $p < 0.01$). That is to day, on the average the construction zone "caused" a significant increase of 1.60 accidents/month.

The increase is greater in zones <u>with</u> a speed reduction (5.58 versus 1.11), and also greater in urban locations (6.22 versus 1.19).

State 5 had by far the worst record (9.21), State 3 is next (3.09), and the other four states are less (0.58 to 1.37). No state exhibited a negative accident differential, although States 1 and 6 are not significantly different from zero.

The average <u>monthly</u> accident differential was 1.60, but the average accident differential by <u>project</u> was 2.11. Apparently, the shorter duration construction zones caused more incremental accidents than the projects that lasted 1 year or more.

2. Analysis of Before-During Accident Rates: Although comparative analysis using accident numbers provides us with some very useful information, the determination of the change in accident rates from the before to the during construction period is a more meaningful measure of the effects of construction. Although we were able to obtain the necessary data to compute accident rates for the before period (length, duration, accident number, and traffic volumes), with the exception of two projects, we were unable to obtain traffic volumes during construction. The states studied simply did not have this data available.

Two factors are of primary concern in estimating construction traffic volumes based on before-period data. One is the expected annual increase in ADT on the subject projects. The other is the expected decrease in traffic volumes during construction caused by a reduction in the number of lanes, by a decrease in average speed, by a general annoyance to the traveling public, or a combination of all three.

Most of the sampled construction projects occurred in either 1974 or 1975. Therefore, the before periods were 1973 and 1974, respectively. National statistics have shown that traffic volumes for these years were quite similar due to the energy crisis. Statistics from State 3 for 1973 and 1974 bear this out. Thus, on many projects the reduction effect of construction probably outweighed the annual increase in traffic volumes, resulting in an overall drop in traffic volumes. Many of these projects consisted of closing at least one lane of an urban freeway. Also, some of the project notes specify that ramp entrances were closed, further indicating a drop in traffic volumes.

Two projects were studied that had during traffic volume data. Both projects were six-lane urban freeways where two lanes were closed in each direction. Also, several entrance ramps were closed on each project. These projects experienced traffic reductions of 60 and 35%. Although these projects were unique in having two lanes closed, they do indicate that on similar projects there were probably significant decreases in traffic volumes.

Two-lane resurfacing and rural interstate projects were also a significant percent of the total number of projects we analyzed. It is doubtful that these projects experienced any significant drop in traffic volumes. State 6 consisted entirely of rural interstate projects taking place in 1972. Traffic volumes from 1971 through 1973 in this state increased 10% annually. For this state, we feel the accident rate increase may be overstated.

In conclusion, we assume that overall, the construction projects had lower traffic volumes than in their respective before periods. Thus, the increase in construction accident rates is probably greater than our results indicate.

Although the lack of construction period traffic volumes forced us to compute construction accident rates using before traffic volumes, analysis using accident rates did provide us with a method of comparing before to during accidents using only documented accident data, not expanded numbers. Accident rate computation data is shown in Appendix A. "Before" data used were; (1) 1-year prior to construction for projects of 1-year or longer and (2) corresponding before months for projects shorter than 1-year.

The following pages and tables provide comparisons of accident rates for several different classifications. Since four of the 79 projects had no before data, only the 75 projects with before and during data were used.

To get an overall view of how the construction zone accident rate varied among the states, they were ranked from lowest to highest:

State	Number of Projects	Mean Construction Accident Rate (100 MVM)	Rank
6	15	116.72	1
2	9	206.94	2
5	10	217.52	3
7	5	287.37	4
1	16	290.69	5
3	10	309.18	6
4	10	427.06	7

However, this ranking is not necessarily an indication of how good or bad each states' construction zones are. State 6 had the lowest accident rate, but all of its construction projects involved rural interstates. These types of projects experience relatively low accident rates in all seven states. State 4 was at the bottom because a large proportion of its accidents were on urban interstate routes.

A better ranking of the states' construction zone experience compares before to during accident rates. Table 7 ranks the states according to least increase in construction accident rate. This table is very similar to the listing of the increase in accident numbers on page 37, but does show some change in the rankings. Probably the most interesting result is the large increase in accident rate experienced by State 4.

Since roadway type is such an important factor in accident rates, Table 8 was constructed to illustrate the variance of accident rates among road types before and during construction. It shows that in the before period, four-lane undivided roadways had the worst accident experience followed by two-lane and five-lane undivided w/TWLTL roadways, respectively. During construction, five-lane undivided w/TWLTL roadways reduced to two-lane experienced the highest accident rate followed by four-lane undivided reduced to two-lane, two-lane on new alignment, and six- or eight-lane interstate reduced to one-lane each direction.

TABLE 7

STATE RANKING BY INCREASE IN MEAN ACCIDENT RATE

State	No. Projects	Mean Accident Rate (100 MVM) Before	During	% Change	Rank
2	9	227.55	206.94	-9.1	1
6	15	120.22	116.72	-2.9	2
1	16	268.24	290.69	+8.4	3
3	10	279.95	309.18	+10.4	4
5	10	189.29	217.52	+28.2	5
7	5	208.79	287.37	+37.6	6
4	10	265.25	428.41	+163.16	7
	75				

TABLE 8

MEAN ROAD TYPE ACCIDENT RATES, BEFORE AND DURING CONSTRUCTION

Before Road Type	No. Projects	Mean Accident Rate (100 MVM)
6 or 8-lane divided (Interstate)	11	198.88
4-lane divided (Interstate)	24	130.61
4-lane divided (Noninterstate)	16	277.58
4-lane undivided	3	801.46
5-lane undivided w/TWLTL	3	488.25
2-lane	18	529.51
	75	

During Construction Road Type	No. Projects	Mean Accident Rate (100 MVM)
6 or 8-lane Interstate reduced to 2 lanes each direction	8	204.23
6 or 8-lane Interstate reduced to 1 lane each direction	3	489.22
4-lane divided Interstate reduced to 1 lane each direction	22	229.55
4-lane divided Interstate reduced to 2-lane, 2-way	2	100.58
4-lane divided (Noninterstate) reduced to 1 lane each direction	5	361.46
4-lane divided (Noninterstate) reduced to 2-lane, 2-way	5	205.16
4-lane divided (Noninterstate) on new alignment	6	200.52
4-lane undivided reduced to 2 lane	3	761.99
5-lane undivided w/TWLTL reduced to 2-lane	3	776.14
2-lane reduced to 1 lane	7	475.73
2-lane on new alignment	11	545.55
	75	

However, a better indication of how the degradation of a road type affects accident rates is by comparing the percent increase in accident rate from the before to the during construction period. Table 9 shows this, and some interesting results appear.

For example: it shows that six- or eight-lane divided roadways that were reduced to one lane in each direction experienced a rate increase of 114.6% while those reduced to two lanes in each direction experienced only a 5.3% increase. Five-lane undivided W/TWLTL reduced to two-lane had a 59% increase. Two-lane highways reduced to one lane had a 30.7% rate increase, while those shifted to a new alignment had a 14.3% decrease. And finally, four-lane divided interstate highways reduced to two-lane, two-way experienced an increase of 147.2% during construction, while those in which one lane was closed in each direction experienced a 68.6% increase in their accident rate. Unfortunately there were only two projects reduced to two-lane, two-way, so the reliability of these data are questionable.

Table 10 illustrates the mean accident rates for the various work area roadway types. Lane closures with temporary bypass roadways experienced the highest accident rate followed by temporary bypass roadways with detours. However, further investigation showed that the lane closure with temporary bypass roadway type had a before mean accident rate of 725.18, thus its during accident rate decreased by 30%. Also, the temporary bypass with detour work area roadway type had a before accident rate of 111.48, thus its construction accident rate went up substantially. However, since the work area roadway types were so disportionally distributed with over 60% being lane closure, no major conclusions can be drawn from this analysis.

Table 11 illustrates the mean accident rates for the various types of construction. The construction types were distributed relatively even with bridge work and reconstruction of existing roadways experiencing the highest percentage accident rate increases. The former had a substantial increase in raw accident rate of 97.99.

Table 12 illustrates the percent increase in accident rates comparing urban to rural projects. This analysis shows that urban projects experienced a slightly higher percentage increase in accident rates. Also, their increase in accident numbers (31.16) was higher than rural projects (14.14).

Table 13 illustrates the severity rate experienced by state and by the total data set. States 4 and 7 experienced the largest increases in injury accident rates. State 2 was not available. Overall, the PDO accident rate increased at a slightly higher percentage than the injury rate, while the fatal accident rate decreased.

TABLE 9

EFFECT OF DEGRADING VARIOUS ROAD TYPES

Roadway Type	No. Projects	Original Roadway Mean Accident Rate (100 MVM)	Construction Roadway Mean Accident Rate (100 MVM)	% Change
6 or 8-lane Interstate reduced to 2 lanes each direction	8	193.96	204.23	+5.3
6 or 8-lane Interstate reduced to 1 lane each direction	3	227.91	489.22	+114.6
4-lane Interstate reduced to 1-lane each direction	22	136.16	229.55	+68.6
4-lane Interstate reduced to 2-lane, 2-way	2	40.68	100.58	+147.2
4-lane divided reduced to 1-lane each direction	5	314.73	361.46	+14.8
4-lane divided reduced to 2-lane, 2-way	5	177.09	205.16	+15.9
4-lane divided on new alignment	6	249.08	200.52	-19.5
4-lane undivided reduced to 2-lanes	3	801.46	761.99	-4.9
5-lane undivided w/TWLTL reduced to 2-lanes	3	488.25	776.14	+59.0
2-lane reduced to 1-lane	7	363.99	475.73	+30.7
2-lane on new alignment	11	636.77	545.55	-14.3
	75			

TABLE 10

MEAN ACCIDENT RATE BY WORK AREA ROADWAY TYPE

Work Area Roadway Type	No. Projects	Mean Accident Rate (100 MVM)
Lane Closure	48	204.23
Cross-Over	4	215.28
Temp. By Pass	0	--
Detour	0	--
LC and Cross Over	5	144.29
LC and Temp. By Pass	4	507.91
LC and Detour	10	286.67
Cross Over and Detour	3	154.08
Temp. By Pass and Detour	1	419.35
	75	

TABLE 11

MEAN ACCIDENT RATE BY TYPE OF CONSTRUCTION (100 MVM)

Type of Construction	No. Projects	Mean Accident Rate Before Construction	Mean Accident Rate During Construction	% Change
Resurfacing, Pavement Patching	26	147.73	159.04	+7.7
Bridge Work	5	88.27	132.47	+50.1
Median Barrier Work	15	187.16	203.87	+8.9
Widening of Existing Roadway	12	577.10	593.21	+2.8
Upgrading to Interstate Standards	9	167.65	194.65	+16.1
Reconstruction of Existing Roadway	2	278.98	371.97	+33.3
Construction of New Roadway (New Alignment)	5	213.49	214.27	+0.4
Other	1	137.36	137.36	0.0
	75			

TABLE 12

MEAN ACCIDENT RATE BY AREA TYPE

Area Type	Mean Accident Rate (100 MVM) Before	During	% Change
Urban	273.54	304.70	+11.4
Rural	140.45	154.59	+10.1

TABLE 13

MEAN ACCIDENT SEVERITY RATES BY STATES (100 MVM)

	No.	PDO			Injury			Fatal		
State	Projects	Before	During	% Δ	Before	During	% Δ	Before	During	% Δ
1	16	213.52	234.76	+9.9	53.03	55.11	+3.9	1.68	0.81	-51.8
2		NA	NA	NA	NA	NA	NA	NA	NA	NA
3	10	186.04	203.39	+9.3	95.00	104.40	+9.9	1.51	1.39	-7.9
4	10	195.76	320.47	+63.7	67.96	90.41	+33.0	1.52	0.67	-55.9
5	10	107.36	126.10	+17.4	79.67	88.69	+11.3	2.27	2.73	+20.3
6	15	81.56	78.65	-3.6	37.01	36.65	-1.0	1.64	1.42	-13.4
7	5	148.18	202.05	+36.4	60.62	85.91	+41.7	0	0	0
Total	66	122.90	129.01	+5.0	59.31	61.57	+3.8	1.58	1.44	-8.9

Accident rate comparisons were made for those projects that had reduced lane widths vs. the projects which maintained normal lane widths. The six projects with reduced lane widths during construction experienced a 17.6% increase in before to during accident rates while the 69 projects with normal lane widths experienced a 6.6% increase in before to during accident rates.

Also projects with and without speed reductions were compared. Urban projects showed a 14.0% increase without speed reductions and a 6.0% increase with speed reductions. Rural projects however, showed a 2.6% increase without speed reductions and a 16.4% increase with speed reductions.

3. <u>Regression Analysis</u>: The third stage of the analysis involved multiple regression analysis of the data using 17 independent variables and computing their relationship to 17 various during accident rates (dependent variables). Table 14 shows the list of independent and dependent variables used in the first multiple regressions.

The initial screening regression run indicated strong correlations between many of the dependent variables. For this reason, several dependent variables were eliminated from further regressions. Also several of the independent variables were moderately correlated. This correlation of independent variables was largely due to the way the independent variables were chosen, and changes in the classification of the variables for later regressions were made based on these results.

Table 15 shows the independent-independent and dependent-dependent correlations that were obtained from the regressions. Pairs of variables with correlation coefficients (R) of 0.71 or greater were classified as being strongly correlated. Those of which had correlation coefficients at 0.31 to 0.71 were classified as moderately correlated.

Table 16 gives the correlations between independent-dependent variables that were obtained in the multiple regressions. The correlation coefficients for each pair of variables is also given. Fifteen of the 30 highest independent-dependent correlations involved normal speed limit or area type correlations with dependent variables. These two independent variables were also moderately correlated ($R = +0.477$). There were four road type correlations among the 30 highest.

The 17 dependent variables listed in Table 14 accounted for about 38% of the variability of the total accident rate (adjusted $R^2 = 0.385$). Adjusted R^2 values for the other response variables are shown in Table 17.

TABLE 14

MULTIPLE REGRESSION VARIABLES

Independent Variables

1. **State**

   1-7

2. **Project**

   1-79

3. **Length**

   Length in hundreths

4. **Duration**

   Number of Days

5. **Road Type**

   1. 6 or 8-lane Interstate
   2. 4-lane Interstate
   3. 4-lane divided
   4. 4-lane undivided
   5. 5-lane undivided w/TWLTL
   6. 4-lane Comb. divided and undivided
   7. 2-lane

6. **Construction Road Type** (Primary)

1. 2-way 2-lane reduced to 1-lane
2. 4-lane divided reduced to 1-lane each direction
3. 4-lane divided reduced to 2-way, 2-lane
4. 6 or 8-lane divided reduced to 2-lanes each direction
5. 6 or 8-lane divided reduced to 1-lane each direction
6. 4-lane undivided reduced to 2-lanes
7. 4-lane divided maintained, but on new alignment or mainline shift
8. 2-lane highway maintained, but on new alignment or mainline shift
9. 5-lane undivided w/TWLTL reduced to 2-lanes

7. **Construction Road Type** (Secondary)

   Same as 'Primary' but add '10' for NA

TABLE 14 (continued)

8. Primary Work Area Roadway Type

1-Lane closure
2-Cross over
3-Temp. By pass
4-Detour

9. Secondary Work Area Roadway Type

1-Lane closure
2-Cross over
3-Temp. By pass
4-Detour
5-None

10. Type of Construction

1-Resurfacing and pavement patching and general improvements
2-Bridge work
3-Median barrier work
4-Widening of existing roadway
5-Upgrading to interstate stds.
6-Reconstruction of existing roadway
7-Construction of new or separate roadway and shift in traffic (except interstate)
8-Other

11. Area

1-Urban
2-Rural

12. Normal Speed Limit

Actual Number

13. Speed Reduction

1-No speed reduction anytime
2-Reduced: Regulatory throughout
3-Reduced: Advisory throughout
4-Advisory at high-hazard locations
5-Reduced: Regulatory during working hours only

TABLE 14 (continued)

14. Daily Traffic Effect

1-24 hours
2-Daylight only
3-Daylight--no peak hour work

15. Control Status

1-Stationary
2-Temp. (moving weekly or monthly)
3-Temp. (moving hourly or daily)

16. Lane Width

1-Normal
2-Reduced

Traffic Control Devices and Methods

1. No special devices or methods
2. Flagmen slowing traffic
3. Flagmen stopping traffic
4. PCMB (portable concrete median barrier)
5. Sequential Arrow Board
6. Timber curbing or Timber Barricades
7. Pacing Vehicles
8. Enforcement
9. Barrel-mounted guardrail and flagging
10. Hydrocell
11. 2 and 5
12. 2, 4, and 5
13. 2 and 4
14. 3 and 7
15. 3 and 5
16. 3, 4, and 5
17. 2 and 6
18. 3 and 6
19. 6 and 8
20. 5 and 8

TABLE 14 (concluded)

Dependent Variables

Y_1 - Total Accident Rate*
Y_2 - Night Accident Rate
Y_3 - PDO Accident Rate
Y_4 - Injury Accident Rate
Y_5 - Fatal Accident Rate
Y_6 - Nonreportable Accident Rate
Y_7 - Right-Angle Accident Rate
Y_8 - Rear-End Accident Rate
Y_9 - Side-Swipe Accident Rate
Y_{10} - Head-On Accident Rate
Y_{11} - Turning Accident Rate
Y_{12} - Ran-Off-Road Accident Rate
Y_{13} - Overturning Accident Rate
Y_{14} - Animal Accident Rate
Y_{15} - Fixed Object Accident Rate
Y_{16} - Fixed Object (Construction Device) Accident Rate
Y_{17} - Other Accident Rate

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* Accident rates were for "during data only."

TABLE 15

INDEPENDENT - INDEPENDENT AND DEPENDENT - DEPENDENT CORRELATIONS

Independent - Independent
Strongly Correlated (R ≥ 0.71)

State and Project Number
Primary and Secondary Zone Type

Moderately Correlated (0.71 > R≥0.31)

Daily Traffic Effect and Control Status
Construction Road Type (Primary) and Primary Zone Type
Construction Road Type (Primary) and Type of Construction
State and Construction Road Type (Primary)
State and Speed Reduction
State and Daily Traffic Effect
State and Control Status
Speed Reduction and Control Status
Project and Speed Reduction
Project and Daily Traffic Effect
Project and Control Status
Length and Type of Construction
Length and Normal Speed Limit
Length and Daily Traffic Effect
Length and Control Status
Road Type and Construction Road Type (Primary)
Road Type and Primary Zone Type
Road Type and Secondary Zone Type
Road Type and Type of Construction
Construction Road Type (Primary) and Area Type
Construction Road Type (Primary) and Speed Reduction
Construction Road Type (Primary) and Daily Traffic Effect
Construction Road Type (Primary) and Control Status
Primary Zone Type and Type of Construction
Primary Zone Type and Daily Traffic Effect
Primary Zone Type and Control Status
Secondary Zone Type and Type of Construction
Secondary Zone Type and Control Status

Dependent - Dependent
Strongly Correlated (R ≥ 0.7)

Total and Night Accident Rates
Total and PDO Accident Rates
Total and Injury Accident Rates
Total and Right Angle Accident Rates
Total and Rear End Accident Rates
Night and PDO Accident Rates
PDO and Rear End Accident Rates
Night and Injury Accident Rates
Rear End and Side Swipe Accident Rates
Total and Turning Accident Rates
Night and Right Angle Accident Rates
PDO and Right Angle Accident Rates

Moderately Correlated (0.71 > R ≥ 0.31)

Total and Side Swipe Accident Rates
Night and Head On Accident Rates
PDO and Side Swipe Accident Rates
PDO and Injury Accident Rates
Injury and Right Angle Accident Rates
Injury and Head On Accident Rates
Right Angle and Rear End Accident Rates
Total and Head On Accident Rates
Night and Side Swipe Accident Rates
Right Angle and Side Swipe Accident Rates
Right Angle and Head On Accident Rates
Total and Other Accident Rates
PDO and Head On Accident Rates
Injury and Side Swipe Accident Rates
Fatal and Right Angle Accident Rates
Turning and Other Accident Rates
Overturn and Animal Accident Rates
Fixed Object and Other Accident Rates

TABLE 15 (concluded)

Independent - Independent
Moderately Correlated

Type of Construction and Normal Speed Limit
Type of Construction and Speed Reduction
Type of Construction and Daily Traffic Effect
Type of Construction and Control Status
Area Type and Normal Speed Limit
Normal Speed Limit and Daily Traffic Effect
Normal Speed Limit and Control Status
Speed Reduction and Control Status

Dependent - Dependent
Moderately Correlated

Total and Fixed Object Accident Rates
Fatal and Turning Accident Rates

TABLE 16

INDEPENDENT - DEPENDENT CORRELATION COEFFICIENTS

Variables	Correlation Coefficient
Area Type and Rear End Accident Rate	-0.55
Normal Speed Limit and Rear End Accident Rate	-0.51
State and Overturning Accident Rate	-0.48
Normal Speed Limit and Total Accident Rate	-0.47
Length and Animal Accident Rate	+0.46
Project and Overturn Accident Rate	-0.44
Normal Speed Limit and Side Swipe Accident Rate	-0.43
Normal Speed Limit and Right Angle Accident Rate	-0.42
Normal Speed Limit and Turning Accident Rate	-0.42
Normal Speed Limit and Animal Accident Rate	+0.42
Area Type and Total Accident Rate	-0.41
Road Type and Right Angle Accident Rate	+0.40
Road Type and Turning Accident Rate	+0.40
Type of Construction and Overturning Accident Rate	+0.40
Speed Reduction and Overturning Accident Rate	+0.40
Area Type and Side Swipe Accident Rate	-0.39
Normal Speed Limit and Night Accident Rate	-0.38
Primary Zone Type and Construction Object Accident Rate	+0.37
Control Status and Construction Object Accident Rate	-0.37
Area Type and Night Accident Rate	-0.36
Area Type and PDO Accident Rate	-0.36
Area Type and Animal Accident Rate	+0.36
Normal Speed Limit and PDO Accident Rate	-0.35
Construction Road Type (Primary) and Fixed Object Accident Rate	-0.35
Type of Construction and Fixed Object Accident Rate	-0.35
Road Type and Fatal Accident Rate	+0.34
Road Type and Head On Accident Rate	+0.34
Normal Speed Limit and Injury Accident Rate	-0.34
Secondary Zone Type and Fixed Object Accident Rate	+0.32
Project and PDO Accident Rate	+0.31
Project (Revised Numbers) and Overturn Accident Rate	+0.31

TABLE 17

FIRST MULTIPLE REGRESSION - ADJUSTED R^2 VALUES

Dependent Variables	Adjusted R^2
Total Accident Rate	0.385
Night Accident Rate	0.276
PDO Accident Rate	0.215
Injury Accident Rate	0.276
Fatal Accident Rate	0.081
Nonreported Accident Rate	0.400
Right Angle Accident Rate	0.276
Rear End Accident Rate	0.379
Side Swipe Accident Rate	0.207
Head On Accident Rate	0.238
Turning Accident Rate	0.322
Ran Off Road Accident Rate	0.065
Overturn Accident Rate	0.296
Animal Accident Rate	0.239
Fixed Object Accident Rate	0.275
Construction Object Accident Rate	0.204
Other Accident Rate	0.150

Based on the initial regression, it was apparent that many of the dependent variables were highly correlated and therefore a subset of the variables could be used in further investigations. This regression also revealed some problems of moderately correlated independent variables. For these reasons another set of regressions were run, using only total accident rate and other dependent variables that seemed to differ radically from total accident rate. The independent variables were adjusted to remove those that were significantly correlated.

Table 18 shows the general results of the second multiple regression. For the regression of total accident rate the original 17 variables were reduced to 6. However, the adjusted R^2 value only changed from 0.385 to 0.236. The order of the independent variables indicates that normal speed limit accounts for the largest portion of the variability of total accident rate, and that construction road type (primary) accounts for the least portion of the variability of the six independent variables.

NOT REPRODUCIBLE

TABLE 18

SECOND MULTIPLE REGRESSION

Dependent Variables	Adjusted R^2	Independent Variables Most to Least Important
Total Accident Rate	0.236	Normal Speed Limit, Area Type, Zone Type, State, Project, Construction Road Type (Primary)
Fatal Accident Rate	0.000	State, Construction Road Type (Primary), Project
Overturn Accident Rate	0.342	State, Type of Construction, Project
Animal Accident Rate	0.214	Length, Project, State
Fixed Object Accident Rate	0.225	Construction Road Type (Primary), Control Status, Type of Construction, Project, State
Construction Object Accident Rate	0.273	Control Status, Project, Traffic Control Devices and Methods, Daily Traffic Effect, State
Other Accident Rate	0.000	Zone Type, Construction Road Type (Primary), State,Project

The prediction of the fatal accident rate and other accident rate were both very poor, indicating the lack of relationships between the construction zone variables and fatal accident rate. Two other accident rates in Table 18 are of particular interest. They are the fixed object accident rate and the construction object accident rate. The control status variable which refers to the way the work area moves within the construction zone is an important contributor to both types of fixed object accident rates.

Further investigations were made by conducting linear regressions of both length and duration versus the total accident rate. A regression was done on the total project set and for each road type and construction road type and also by urban and rural projects. The results of the regressions are shown in Table 19.

In general, both the length and duration regression lines had negative slopes indicating that the long length and duration projects normally had lower accident rates. Many of the regressions broken down by road type and construction road type were hampered by small sample sizes.

TABLE 19

LINEAR REGRESSION RESULTS

Regression	b	a	r^2	n
Length vs Total Accident Rate (All projects)	-10.87	376.20	0.06	79
Duration vs Total Accident Rate (All projects)	-0.23	362.28	0.03	79
Length vs Total Accident Rate				
1. 6 or 8-lane Interstate	12.38	241.40	0.05	12
2. 4-lane Interstate	-4.39	197.65	0.22	24
3. 4-lane divided	7.26	200.61	0.07	15
4. 4-lane undivided	373.37	-21.37	1.00	2*
5. 5-lane undivided w/TWLTL	-148.14	1572.50	0.84	3
6. 4-lane comb. divided and undivided	20.13	76.81	0.33	4
7. 2-lane	-23.80	520.93	0.08	19
Duration vs Total Accident Rate				
1. 6 or 8-lane Interstate	-0.78	460.76	0.29	12
2. 4-lane Interstate	-0.14	197.00	0.13	24
3. 4-lane divided	-0.10	280.95	0.02	15
4. 4-lane undivided	-49.53	14469.0	1.00	2*
5. 5-lane undivided w/TWLTL	6.89	11.62	0.84	3
6. 4-lane comb. divided and undivided	-0.07	166.14	0.73	4
7. 2-lane	0.10	353.80	0.01	19
Length vs Total Accident Rate				
1. 2-way, 2-lane reduced to 1 lane	-38.52	750.79	0.29	7
2. 4-lane divided reduced to 1 lane each direction	0.11	171.42	0.00	29
3. 4-lane divided reduced to 2-lanes each direction	-19.38	314.25	0.17	7
4. 6 or 8-lane divided reduced to 2-lanes each direction	-1.26	290.47	0.00	8
5. 6 or 8-lane divided reduced to 1 lane each direction	-4.00	536.77	0.04	3
6. 4-lane undivided reduced to 2-lanes	386.00	-313.71	0.55	5
7. 4-lane divided maintained, but on new alignment or mainline shift	-20.22	325.33	0.32	6
8. 2-lane highway maintained, but on new alignment or mainline shift	-20.10	425.81	0.05	12
9. 5-lane undivided w/WLTL reduced to 2-lanes	-119.57	1335.34	1.00	2*

TABLE 19 (concluded)

Duration vs Total Accident Rate	b	a	r^2	n
1. 2-way, 2-lane reduced to 1 lane	0.48	367.51	0.02	7
2. 4-lane divided reduced to 1-lane each direction	-0.21	237.40	0.07	29
3. 4-lane divided reduced to 2-way, 2-lane	-0.15	281.10	0.14	7
4. 6 or 8-lane divided reduced to 2-lanes each direction	-0.56	388.74	0.17	8
5. 6 or 8-lane divided reduced to 1-lane each direction	-1.68	616.53	0.10	3
6. 4-lane undivided reduced to 2-lanes	-0.79	891.10	0.25	5
7. 4-lane divided maintained, but no new alignment or mainline shift	0.13	180.58	0.03	6
8. 2-lane highway maintained, but on new alignment or mainline shift	0.17	261.63	0.03	12
9. 5-lane undivided w/TWLTL reduced to 2-lanes	15.89	-825.97	1.00	2*
Length vs Total Accident Rate				
Urban	-10.78	485.66	0.01	31
Rural	-4.77	251.30	0.03	48
Duration vs Total Accident Rate				
Urban	-0.25	486.75	0.02	31
Rural	-0.05	226.14	0.00	48

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* Inadequate sample size.

4. Construction Project Case Studies: Three case studies of selected construction zone projects are given in Appendices F, G, and H. Each of the case studies presents findings about the particular project. This section presents some of the common findings and general conclusions that could be made based on the case studies.

The projects were not selected randomly. Hard copy accident reports were briefly reviewed and the projects chosen were those that demonstrated a reasonable number of construction-related accidents. The projects were chosen this way because this stage of the analysis was aimed at getting an idea of why accidents happen in construction zones.

Table 20 gives the results of the three case studies. Each study experienced an above average increase in the before to during number of accidents. Also the report of night accidents decreased in all three cases. The percentage of the types of accidents varied between the three studies. In all of the studies the percent of PDO accidents increased during construction. And as stated before, all of the projects studied had a large proportion of accidents that were construction related.

The determination of construction-related accidents was a central part of the case studies. The accident was judged as being construction-related by reading the accident report and asking "Was the accident precipitated or affected by the construction?" Or from the opposite point of view, "Would the accident have happened and been as severe if there were no construction underway?" Although judgment was involved it should be stressed that the judgments were made by experienced traffic safety personnel after thorough familiarization with the project.

In each of the projects, the number of construction-related accidents was at least equal to the increase in accidents from the before to during period. In Case Study 2, the construction related number is high because of a high number of rear-end accidents that occurred when queues formed during the construction. Even if the rear-end accidents had not been classified as construction-related, the other 29 construction-related accidents would be near the increase in accidents comparing the before and during periods.

The general impression gained from the case studies was that the accident experience of a roadway is not only increased during construction but also the overall characteristics of the accident histories are different from the before to during periods.

In the first two case studies, there was a definite predominate accident type, that if remedied could have reduced the number of accidents occurring in the zone. In the first case study, accidents involving timber

TABLE 20

CASE STUDY SUMMARIES

Case Study 1 Results	Case Study 2 Results	Case Study 3 Results
Accidents increased 42% B-D Night Accidents 50% B-44% D Rear End Accidents 40% B - 21 % D	Accident number increased 49% (B-D) Night Accidents 43% B - 28% D Rear End Accidents 33% B - 50% D	Accidents increased 180% B-D Night Accidents 60% B - 50% D Rear End and Side Swipe Accidents 60% B - 14% D
FO Accidents 15% B 38% During HO Accidents 0% B - 2% During	FO Accidents 16% B - 9% D	FO Accidents 0% B - 44% D HO Accidents 0% B - 21% D
Severity	Severity	Severity
Before: PDO 38% I 60% F 2%	Before: PDO 68% I 32%	Before: PDO 60% I 40%
During: PDO 57% I 40% F 3%	During: PDO 79% I 21%	During: PDO 86% I 14%
Before Accident Rate = 54 acc/100 MVM During Accident Rate = 76 acc/100 MVM Before fatality rate = 1.35 acc/100 MVM During fatality rate = 2.25 acc/ 100 MVM 36 of 102 during accidents judged to be construction related.	Before Accident Rate 187 acc/100 MVM During Accident Rate 432 acc/100 MVM 78 of 103 during accidents judged to be construction related	Before rate = 186 acc/100 MVM During rate = 523 acc/100 MVM 8 of 14 during accidents were judged to be construction-related

FO = Fixed Object
HO = Head On
PDO = Property Damage Only
I = Injury
F = Fatal
100 MVM = 100 million vehicle miles

barricades were prevalent throughout the construction period. In the second case study the rear-end accident was predominant. Two types of accidents (fixed object and head-on or sideswipe) were nearly the entire set of construction-related accidents in the third case study.

D. Accident Studies Summary

Accidents occurring both before and during construction were analyzed using several methods. These included analysis of the time-trend effect of monthly accident differentials, total accident numbers analysis, accident rate analysis, and case studies of individual projects. In addition, regression analysis was performed on the construction accident rates. The results of these analyses follow.

The time-trend analysis showed that construction zones caused an average increase of 1.60 accidents per month. The total number of accidents increased by 7.5% and the accident rate increased by 6.8%. Thirty-one percent of the projects studied experienced decreases in accidents during construction, while 24% experienced rate increases of more than 50%. The percent differences may be understated, because of the lack of during traffic volume data. The analyses assumed that before and during traffic volumes were equal; however, for many projects, the traffic volumes during construction were probably lower than the before volumes. Three case studies of zones experiencing large increases in accident rate revealed that most of the increase from the before to during period was due to construction-related accidents.

The accident experience of each state was also analyzed. Time-trend analysis (State 2 not included) indicated State 5 had the largest increase in accidents followed by State 3. In States 1 and 6, the increase in construction accidents was not significant. However, since this analysis uses accident differentials, states with high accident numbers in both the before and during period were possibly unfairly ranked as poor, even though their accident differential percentage was not greater than states with smaller accident samples. Accident number analysis ranked the states by least percent increase in number of accidents. States 6 and 2 had decreases in the number of construction accidents. State 7 experienced the worst percentage increase in accidents with State 4 only slightly better. The accident rate analysis yielded similar results. State 2 had the lowest percentage accident rate increase followed closely by State 6, while State 4 had the highest percentage increase with State 7 next.

Both the accident number and accident rate analyses showed very little difference in the distribution of accident severity types in the before to during comparison. However, there was a slight shift in both analysis toward property-damage-only accidents. Both analyses show a great degree of variability in the number and rate of fatal accidents. This was supported by the regression analysis, in which there was very little correlation between the construction zone variables and the fatal accident rate.

The proportion of night accidents to the total number of accidents remained relatively constant in both the accident number and accident rate analyses. Again this was supported by a relatively high degree of correlation between night accident rates and total accident rates in the regression analysis. The linear regression analysis also indicated a strong correlation between traffic control devices and construction fixed object accidents, and a poor correlation between construction zone variables and ran-off-road accidents. Accident number analysis showed a substantial increase in fixed object, head-on, and rear-end accidents, with a decrease in ran-off-road and side-swipe accidents.

The time-trend analysis showed that projects with reduced speeds (by regulatory or advisory signing) had higher monthly accident differentials than those without speed reductions. The accident rate analysis also showed that those with speed reductions had a slightly higher percentage accident rate increase. According to the linear regression analysis the project speed limit, which is highly correlated with area type, accounts for the largest portion of the total accident rate variability.

Road types accounted for 4 of the 30 highest correlations between construction zone and accident variables in the linear regression analysis. Accident rate analysis resulted in some interesting results concerning road types. Six- or eight-lane interstate projects reduced to one-lane in each direction had accident rate increases of over 100% while those reduced to two lanes in each direction had increases of only 5%. The case studies showed that the one-lane projects experience a great number of rear-end accidents. Four-lane divided interstate projects reduced to two-lane, two-way had percentage increases more than double those in which the roadway was simply reduced to one lane each direction. Five-lane undivided highways with two-way left-turn lanes reduced to two-lanes during construction experienced the largest accident rate increase of all road types. And finally, two-lane roads reduced to one-way alternating operations experienced worse construction accident rates than those placed on new alignment during construction.

The time-trend analysis indicated a much higher monthly increase in accidents in urban areas. However, since urban areas normally have higher accident numbers, this does not necessarily mean their construction accident experience is any worse. The linear regression analysis indicated a moderately high correlation between area type and total accident rate. The accident number and accident rate analyses both showed that construction accidents went up a similar percent in urban and rural areas.

The time-trend analysis showed that the first month after construction begins is not significantly different than the other months of construction and that construction zones do not necessarily have better accident experiences over time. The linear regression analysis showed that there is a negative correlation between the length and duration of projects and the accident rate. Thus, the longer a project (both in time and space), the lower the accident rate.

The accident rate analysis indicated that bridge work, followed by reconstruction of existing roadway (on the same alignment) experienced the largest percentage accident rate increases. Case studies of projects with large before-during rate increases showed a definite predominate accident type for each of the studies.

IV. TESTING OF SPEED REDUCTION METHODS

A. Purpose and Scope

Because the projects employed in the accident study were often completed before the state visits, it was not possible to obtain two types of important operational data about the projects.

The first type of operational data needed was vehicle operating speeds. The only way to really judge the effectiveness of construction zone speed reduction methods was to measure vehicle speeds upstream from and within the various areas of the zone.

The second type of operational data needed was erratic maneuver and conflict counts in the approach and transition areas of the zone. These counts were needed to indicate how safe various speed reduction methods were. These counts were also valuable because they can be made in conjunction with speed measurements, unlike accidents that are rare occurrences that must be sampled over long periods of time.

Because of the need for these types of data, the accident study was supplemented by field testing of several speed reduction methods. This testing was done so that vehicle speeds could be measured in various parts of the construction zone. Also all speed reduction methods of interest could be studied, and it was possible to control and record the operational management of the zone more completely than was possible in the accident study.

B. Site Description

Three sites were studied. The sites represented zones on an urban street, an urban freeway, and a rural freeway. The studies were also planned for a rural two-lane highway, but were cancelled because of problems with the question of liability during the studies. The sites were in or near the Kansas City metropolitan area, and were chosen from current construction projects in the area. Figure 9 shows each of the sites. Photos A and B are from the urban freeway project, photo C is from the rural freeway project, and photo D is from the urban street project.

The urban street site was located on a four-lane undivided arterial highway. The construction involved complete renovation of a bridge deck and resurfacing of the approaches to the bridge. Traffic in each direction was channeled into a single lane, then detoured onto an adjacent two-lane street. The normal speed limit on the highway was 40 mph. During construction, the posted speed limit was reduced to 30 mph.

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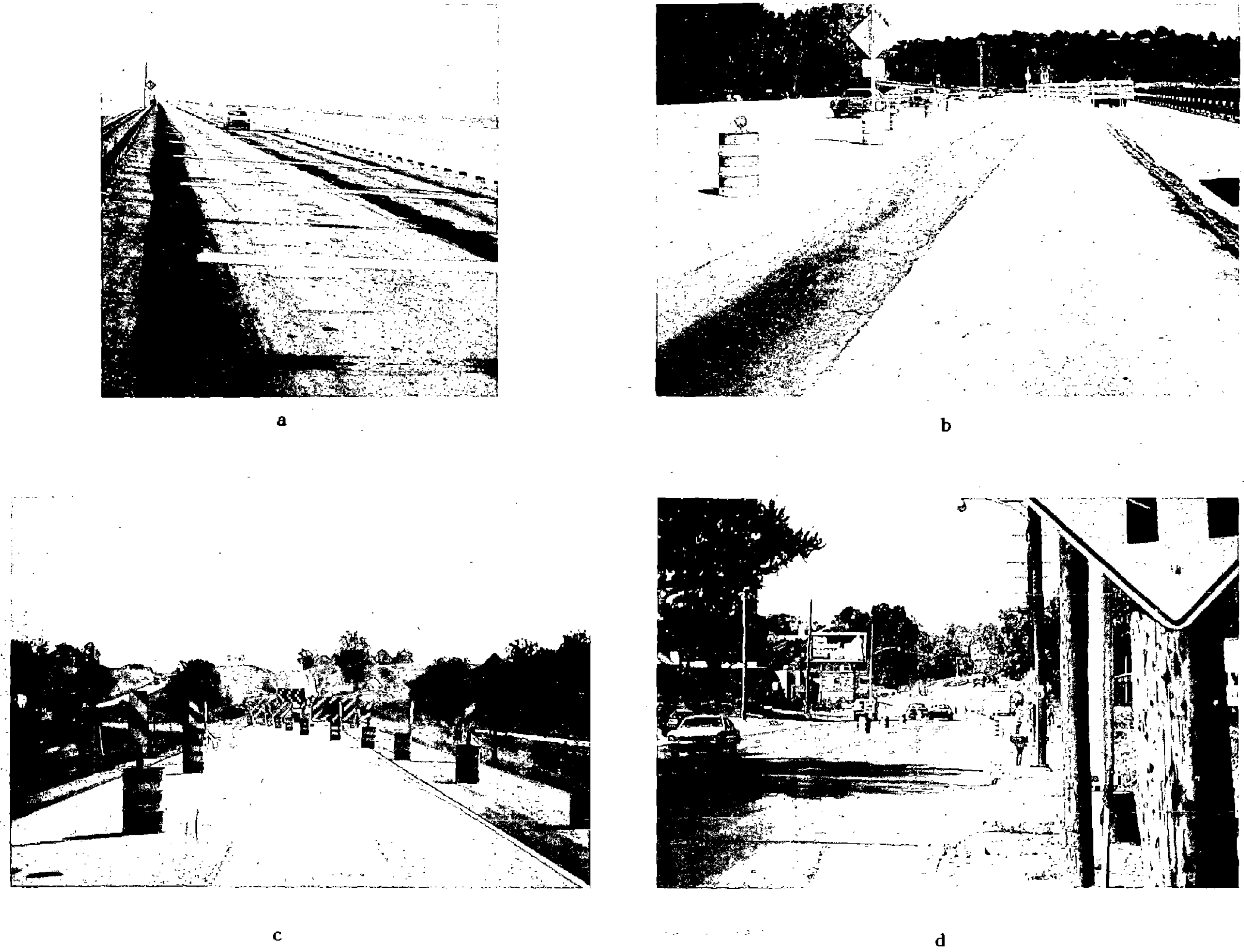

Figure 9 - Field Testing Sites.

The urban freeway site was located on a four-lane divided, controlled access highway. The construction involved resurfacing and widening of a bridge. In this zone, northbound traffic was reduced to one lane and shifted onto the opposing roadway where traffic operated as two-lane two way. The normal speed limit on the roadway was 55 mph. During construction, a 45-mph advisory plate was placed upstream of the zone, and a 35-mph advisory plate placed at the lane taper.

The rural freeway site was located on a four-lane interstate highway. The construction project involved renovation of a river bridge. As in the urban freeway project the traffic was reduced to one lane then shifted by means of a crossover roadway to one lane of the opposing roadway. The speed limit on the roadway was 55 mph. A 40 mph advisory plate was in place at the crossover of the zone.

C. Experimental Design

Methods tested in the studies were of two basic types; speed control methods and design features to accommodate speeds. The speed control methods included advisory speed zoning, regulatory speed zoning, active speed reduction warning devices, funneling and lane width reduction, and transverse striping for speed reduction warning. The design features to accommodate speeds included lane taper formulas, sequential flashing arrows, and obliteration of nonapplicable lane lines.

A set of experiments was designed for each site to test the effect of each method alone, and in combination with other methods. Those methods most applicable to one type of roadway were tested at that location. Others were arbitrarily subdivided among the sites based on the construction schedule.

The construction scheduling allowed for a maximum of 12 experiments at the urban street location, 4 experiments at the urban freeway location and 12 experiments at the rural freeway location. Because of the constraint on the number of experiments, a fractional factorial design was used to determine a set of experiments for each location. Another consideration was that traffic controls at a site were not lessened or made less safe. For example, there were no advisory speed tests on the urban street because a lower regulatory speed limit had been posted.

Table 21 gives the experimental design for the studies conducted on the urban street. The methods studied were taper length formulas, and funneling and lane width reduction.

TABLE 21

URBAN STREET EXPERIMENTS

Experiment[a]	Treatment	Level
Experiment US1-	Taper length	New formula
	Funneling and lane width reduction	Not present
Experiment US3-	Taper length	New formula
	Funneling and lane width reduction	Present
Experiment US5-	Taper length	Old formula
	Funneling and lane width reduction	Not present
Experiment US6-	Taper length	Old formula
	Funneling and lane width reduction	Present

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a/ All experiments done both day and night.

Table 22 gives the experimental design for the studies conducted on an urban freeway. The methods studied were nonapplicable lane lines, transverse pavement striping, and advisory and regulatory speed zoning.

Table 23 Gives the experimental design for the studies conducted on a rural freeway. The methods studied were sequential arrow panel, advisory and regulatory speed zoning, speed zoning enforcement and active warning of speed zoning (through use of high-intensity flashing lights).

Once the experiments were designed, the existing traffic control plan was obtained. This plan was used as a base for the plan for each experiment. Each experiment plan showed the traffic control changes to be made, the location of all speed measuring equipment, and observers. The entire set of experimental plans is shown in Appendix I.

Prior to conducting the experiment, the experimental plan was approved by the construction contractor and the state highway department.

TABLE 22

URBAN FREEWAY EXPERIMENTS

Experiment[a]	Treatment	Level
Experiment UF1-	Nonapplicable lane lines	Nonobliterated
	Transverse striping for speed reduction warning	Not present
	Speed zoning	Advisory
Experiment UF2-	Nonapplicable lane lines	Nonobliterated
	Transverse striping for speed reduction warning	Present
	Speed zoning	Regulatory
Experiment UF3-	Nonapplicable lane lines	Obliterated
	Transverse striping for speed reduction warning	Present
	Speed zoning	Advisory
Experiment UF4-	Nonapplicable lane lines	Obliterated
	Transverse striping for speed reduction warning	Not present
	Speed zoning	Regulatory

---

[a] All experiments done both day and night.

TABLE 23

RURAL FREEWAY EXPERIMENTS

Experiment[a]	Treatment	Level
Experiment RF1- (base conditions)	Sequential arrow panel	Not present
	Speed zoning (approach)	None
	Enforcement	Not present
	Active warning of speed zoning	Not present
Experiment RF2-	Sequential arrow panel	Not present
	Speed zoning (approach)	Advisory
	Enforcement	Not present
	Active warning of speed zoning	Not present
Experiment RF3-	Sequential arrow panel	Not present
	Speed zoning (approach)	Regulatory
	Enforcement	Not present
	Active warning of speed zoning	Not present
Experiment RF4-	Sequential arrow panel	Present
	Speed zoning (approach)	None
	Enforcement	Present without speed zoning
	Active warning of speed zoning	Not present
Experiment RF5-	Sequential arrow panel	Present
	Speed zoning (approach)	Advisory
	Enforcement	Present with speed zoning
	Active warning of speed zoning	Not present
Experiment RF6-	Sequential arrow panel	Present
	Speed zoning (approach)	Regulatory
	Enforcement	Present with speed zoning
	Active warning of speed zoning	Not present

---

a/ All experiments done both day and night.

TABLE 23 (concluded)

Experiment[a]	Treatment	Level
Experiment RF8-	Sequential arrow panel	Present
	Speed zoning (approach)	Advisory
	Enforcement	Not present
	Active warning of speed zoning	Present
Experiment RF9-	Sequential arrow panel	Present
	Speed zoning (approach)	Regulatory
	Enforcement	Not present
	Active warning of speed zoning	Present
Experiment RF11-	Sequential arrow panel	Not present
	Speed zoning (approach)	Advisory
	Enforcement	Present with speed zoning
	Active warning of speed zoning	Present
Experiment RF12-	Sequential arrow panel	Not present
	Speed zoning (approach)	Regulatory
	Enforcement	Present with speed zoning
	Active warning of speed zoning	Present

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[a] All experiments done both day and night.

D. Field Study Procedure

After the experiment plan had been approved, changes were made in traffic control. In most cases, the traffic control changes were made by the project staff. Subcontractors were hired to paint transverse pavement striping and remove nonapplicable pavement markings.

The next step in the field study was to install speed measuring equipment. The basic mode of data collection used a series of tape switches connected to a 20-channel event recorder. Pairs of tape switches 100 feet apart were placed in each lane at two or three locations in the zone. The areas of the zone where speed measurements were made were upstream of the zone, on the approach to the transition area, in the transition area, and in the work area.

The switches were connected by wire to the event recorder. When a vehicle crossed the switch, the circuit was closed and the vehicle passage was recorded on paper charts used in the event recorder. Connecting the switches to the recorder required almost 2 miles of wire. To reduce the quantity of wire required, speeds in one area of the zone were measured by radar.

Ten-foot tape switches placed perpendicular to the lane were used to record lane volumes, speeds, and headways. In the transition area of each zone, two-foot switches laid end to end were used to record information on the lateral placement of vehicles.

The tapeswitches were installed by the project crew. During installation of the switches, traffic was controlled by a flagman and a sequential flashing arrow trailer. The switches were in general secured to the pavement by 4 inch duct tape.

When switches were in place and had been tested, the study began. Each experiment was conducted for both day and night conditions. For the urban street and rural freeway studies, the daytime experiments were conducted from 2 to 5 PM. The urban freeway experiments were conducted between 7 and 11 AM on Saturday morning to avoid interfering with construction operations. Night studies at all three sites were conducted between 7 PM and 12 AM.

Two observers were present during each of the experiments. One of the observers made the radar speed measurements. The other observer was stationed in the transition area of the zone and recorded vehicle conflicts and erratic maneuvers. The erratic maneuver and conflict counts and the radar speed measurements were made for 15 minute periods. The length of each experiment (day or night) was 2-1/2 to 3 hours. This was sufficient time to obtain at least ten 15-minute periods of conflict data. This 2-1/2 hours of conflicts data is equivalent to the conventional sample of intersectional conflicts counting. This length of time was more than sufficient to collect a significant number of speed measurements.

Details of the field studies at each site are given in Appendix J.

At the urban freeway site the effects of the advisory and regulatory speed zoning, transverse striping for speed reduction warning and obliteration of nonapplicable pavement markings were tested. Transverse striping was installed in the approach area, using specifications established by the Michigan Department of Transportation. Nonapplicable pavement markings in the transition area were removed by sand blasting.

At the rural freeway site the effects of advisory and regulatory speed zoning, enforcement, sequential flashing arrows, and active warning of speed zoning were tested. Enforcement was provided by highway patrol or the county sheriff stationed on the roadside on the approach to the zone. The sequential flashing arrow replaced alternating flashing beacons on the barricades at the crossover. The active warning of speed zoning consisted of high intensity flashing lights mounted on the regulatory or advisory speed zone signs.

At the urban street site the effects of lane taper formula changes and funneling and lane width reduction were tested. The formulas of $L=WS$ and $L=WS^2/60$ were compared where L = length of the lane change taper, W = lane width in feet, and S was the posted speed limit in mph (30). The lane width was reduced by placing 55 gallon drums along the centerline of the highway. Minimum distance between the drums on the centerline and those in the lane taper was 14 feet.

E. Field Data Reduction

The first step in analyzing the field data was to mark times on the event recorder chart. Times at the beginning and end of each chart had been recorded in the field, and they were used to check that the event recorder had been operating at a constant speed. Speed data on two rural freeway night experiments were lost because the event recorder speed varied during the study period.

When the times had been marked on the recorder chart, the 15 minute volumes of 4 or 5 switches were counted. It was possible to count the number of axles of vehicles actuating the switches so the vehicles were classified as trucks (three or more axles) and passenger vehicles. Trucks were counted only at the rural freeway and urban street sites, the urban freeway roadway was virtually closed to trucks.

As the switch volumes were being counted, the free flowing vehicles (those with headways of 5 seconds or greater) were chosen for the speed readings. Where possible one vehicle was measured at three speed trap locations as it traversed the zone. This was not possible at the urban street site because an intersection was located between two of the switch pairs and vehicles leaving and entering the traffic stream, made it impossible to trace one vehicle through both traps. When a vehicle trace was chosen for speed reading, it was circled and numbered.

The speed measurements from the event recorder charts were made by projecting the chart image on a rear-projection screen with an overhead opaque projector. This enlarged the image of the switch closures four times and permitted more accurate determination of vehicle speeds. The tape switch speeds were grouped in 15-minute periods to correspond to the radar and conflicts data.

After all the event recorder charts had been read, the speed data were analyzed to determine the mean speed and variance of the speed distribution for each experiment. All speed and conflicts data were then recorded on one form to facilitate further analysis of the data.

F. Field Data Analysis and Results

This section presents the findings of the field data experiments at the rural freeway and urban freeway sites. The results of the urban street experiments will be presented in a special report on lane taper formulas scheduled for completion in August 1977.

1. Rural Freeway: The analysis of mean speeds at the rural freeway site consists basically of an analysis of variance involving the following factors:

a. t = time
  t1 = day
  t2 = night

b. L = location (used in speed analysis only)
  L1 = radar, 2,000 ft before lane closure
  L2 = 1,000 ft before lane closure
  L3 = beginning of lane closure
  L4 = beginning of detour

c. A = arrow panel
  A1 = not present
  A2 = present

d. Z = speed zoning (approach)
Z1 = none
Z2 = advisory
Z3 = regulatory

e. W = warning of speed zoning
W1 = not present
W2 = present

f. E = enforcement
E1 = not present
E2 = present

The interactions of L and t with all other factors (and themselves) are retrievable, but interactions among A, Z, W, and E are not directly estimable from the data due to the fractionated nature of the analysis of variance design and due to the incidence of missing values.* Since (an average of) 153 speed measurements/cell were taken, it is possible to estimate a direct residual. Thus, a "residue" term composed of all A, Z, W, E (and higher-order) interactions is retrievable. This residue mean square was not statistically significant, indicating that none of the unestimated interactions are likely to be significant.

The AOV is given in Table 24. Four factors were statistically significant (at the $\alpha = 0.05$ level):

a. <u>Time</u>: The average nighttime speed on the rural freeway is 1.22 mph lower than the average daytime speed. This effect does not significantly interact with any other variable.

b. <u>Location</u>: Mean speeds vary according to location, although L1 and L2 are not distinguishable. On the average, L4 exhibits the lowest mean speed (47.18 mph), followed by L3 (52.06 mph) and L2, L1 (56.77 mph, 56.60 mph). This general pattern does vary, however, according to the level of enforcement as discussed below.

c. <u>Enforcement</u>: The presence of enforcement depresses mean speed by 2.77 mph. This effect, however, depends on location as discussed below.

d. <u>Location x Enforcement</u>: There was no enforcement effect at L1 (since the enforcement vehicle was not visible at this location) but the presence of enforcement did reduce mean speeds at the other locations. The L2 reduction is 3.7 mph, the L3 reduction 4.9 mph, and the L1 reduction was 2.5 mph, as shown below.

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* Replaced via minimization of residual variation. See, for example, "Statistics and Experimental Design in Engineering and the Physical Sciences," Volume II, N. L. Johnson and F. C. Leone, John Wiley and Sons, 1964, 13.16.2, pp. 70-72.

TABLE 24

ANALYSIS OF VARIANCE OF RURAL FREEWAY SPEEDS

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F Ratio
time (t)	1	35.77	35.77	5.85*
Location (L)	3	1,484.50	494.83	80.99*
Arrow (A)	1	18.38	18.38	3.01
Zoning (Z)	2	1.11	0.56	<1
Warning (W)	1	1.45	1.45	<1
Enforcement (E)	1	183.71	183.71	30.07*
Lt	3	11.47	3.82	<1
LA	3	28.71	9.57	1.57
tA	1	4.51	4.51	<1
LZ	6	53.62	8.94	1.46
tZ	2	6.42	3.21	<1
LW	3	54.37	18.12	2.97*
tW	1	1.36	1.26	<1
LE	3	81.36	27.12	4.44*
tE	1	0.28	0.28	<1
Residual	37	226.24	6.11	

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* Statistically significant @ $\alpha = 0.05$.

	L1 (mph)	L2 (mph)	L3 (mph)	L4 (mph)
E1 (no enforcement)	56.6	58.6	54.5	48.4
E2 (enforcement)	56.6	54.9	49.6	45.9
	0.0	-3.7	-4.9	-2.5

If we let $\alpha = 0.10$ instead of 0.05, the arrow panel effect is also significant--namely, the presence of the arrow panel reduces mean speed by 0.87 mph on the average (from 53.59 to 52.72 mph). At L4 the presence of the arrow panel reduced mean speeds by 2.7 mph (48.53 to 45.83).

There was no significant effect of speed zoning (regulatory or advisory) on mean speeds.

The rural freeway analysis of variance framework was also examined with erratic maneuver rate and slow-moving conflict rate as responses. An erratic manuever is defined as a single vehicle suddenly swerving or braking on approaching the transition area. A slow-moving conflict is defined as vehicle swerving or braking to avoid a slower vehicle in front. For convenience, conflict rate is treated as 100 x number of conflicts/volume; i.e., the response is number of conflicts/100 vehicles. The complete analyses of variance results are found in Tables 25 and 26; the discussion will consist only of the significant effects.

The overall average erratic maneuver rate was 8.48 (8.48 erratic maneuvers/100 vehicles). All of the main effects, except Z, have a significant effect on erratic maneuver rate as follows:

a. Time of Day (t): The nighttime erratic maneuver rate is almost four times as great as the daytime response (13.36 versus 3.59). This time effect, however, does not interact with any of the experimental variables.

b. Arrow Panel (A): The presence of an arrow panel reduces erratic maneuver rate by about 25% (9.59 to 7.36).

c. Warning of Speed Zoning (W): The presence of active warning reduces erratic maneuver rate by about 30% (10.02 to 6.94).

d. Enforcement (E): The presence of enforcement reduces erratic maneuver rate by 25% (9.76 to 7.20).

The overall slow moving conflict rate was 5.61; all experimental factors were at least marginally significant ($\alpha < 0.10$), but time of day was not. No interactions were significant.

a. Arrow Panel (A): The presence of an arrow panel increased slow moving conflict rate by about 20% (4.87 to 6.35).

TABLE 25

ANALYSIS OF VARIANCE FOR ERRATIC MANEUVER RATE

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F Ratio
Time (t)	1	573.01	573.01	124.16*
Arrow (A)	1	29.77	29.77	6.45*
Warning (W)	1	57.07	57.07	12.37*
Zoning (Z)	2	4.90	2.45	<1
Enforcement (E)	1	39.40	39.40	8.54*
tA	1	0.17	0.17	<1
tW	1	11.61	11.61	2.51
tZ	2	11.60	5.80	1.26
tE	1	9.41	9.41	2.04
Residual	12	55.38	4.62	

$F(1, 12) = 3.18\ (\alpha = 0.10),\ 4.75\ (\alpha = 0.05),\ 9.33\ (\alpha = 0.01)$

$F(2, 12) = 2.81\ (\alpha = 0.10),\ 3.89\ (\alpha = 0.05),\ 6.93\ (\alpha = 0.01)$

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* Statistically significant at $\alpha = 0.05$.

TABLE 26

ANALYSIS OF VARIANCE FOR SLOW MOVING CONFLICT RATE

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F Ratio
t	1	6.584	6.584	2.44
A	1	13.069	13.069	4.85*
W	1	11.440	11.440	4.25
Z	2	27.634	13.817	5.13*
E	1	10.574	10.574	3.93
tA	1	0.018	0.018	<1
tW	1	0.870	0.870	<1
tZ	2	0.040	0.020	<1
tE	1	2.071	2.071	<1
Residual	12	32.323	2.694	

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* Statistically significant at $\alpha = 0.05$.

b. Warning of Speed Zoning (W): The presence of a warning increases slow moving conflict rate by about 20% (4.92 to 6.30).

c. Speed Zoning (Z): Speed zoning (either advisory or regulatory) increases slow moving conflict rate 35% versus no speed zoning (6.56 and 6.16 versus 4.11).

d. Enforcement (E): The presence of enforcement reduces slow moving conflict rate by about 20% (6.27 versus 4.94).

Thus, enforcement reduces both kinds of conflict rates, but the arrow panel and warning of speed zoning have trade-off effects. In particular, the presence of the arrow panel or warning of speed zoning reduces the erratic conflicts but increases the slow moving conflicts (by comparable amounts). The only significant speed zoning effect discovered was to increase the slow moving conflict rate by 35%.

2. Urban Freeway: The mean speeds, erratic maneuver rates and previous conflict rates at the urban freeway location were examined by an analysis of variance framework consisting of the following factors:

a. Experiment
    UF1 = first urban freeway experiment
    UF2 = second urban freeway experiment
    UF3 = third urban freeway experiment

b. Time
    Day
    Night

c. Location (used only in speed analysis)
    L1 = 1,000 ft before taper
    L2 = 400 ft from taper
    L3 = in taper
    L4 = in work area, radar

Erratic maneuvers are defined as in the rural freeway experiments. Previous conflicts occur when an erratic maneuver or other conflict causes a following vehicle to swerve or brake. Erratic maneuver and previous conflict rates were computed as in the rural freeway analysis, number of conflicts/100 vehicles.

The original intent was to perform an analysis of variance explicitly identifying the experiment treatments of speed zoning, transverse striping for speed reduction warning, and nonapplicable lane lines. This was impossible due to the loss of the UF4 experiment; therefore, the statistical analysis retains only the ability to discriminate between experiments, but not to determine the effect of any of the experimental treatments.

The analysis of variance of mean speeds indicated a significant location effect [$F\ (3, \infty) = 102.2$, $p < 0.01$], a significant experiment effect [$F\ (2, \infty) = 21.4$, $p < 0.01$], a significant time effect [$F\ (1, \infty) = 94.4$, $p < 0.01$], and a significant experiment location interaction [$F\ (6, \infty) = 2.67$, $p < 0.05$].

The time effect arises because the day mean speeds averaged 3.97 mph greater than night mean speeds. This differential is not affected significantly by location or experiment so subsequent discussion will use overall speed for comparisons.

Although speeds in all experiments decrease while traversing L1 to L4, this decrease is greater in magnitude in experiment UF2 than elsewhere. Specifically, the L1 mean speed for UF2 is significantly higher than UF1, UF2, but for L4, all three mean speeds are indistinguishable.

	L1	L2	L3	L4
Experiment UF1	54.7	52.4	51.6	45.7
Experiment UF2	60.4	54.7	53.0	46.4
Experiment UF3	53.6	50.7	51.2	46.7

Due to unequal sample sizes and the small number of cells involved (2 times x 3 experiments = 6), the individual means of the erratic maneuver and the previous conflict rates were separated here directly (via Fisher's LSD test).

The UF1 erratic maneuver night rate is the highest such value; the other two night rates <u>and</u> the UF2 day rate form the next group, and the other two day rates are the lowest. In other words, although night rates are generally higher, UF2 also had a high day rate, and the UF1 night erratic maneuver rate is the largest of all.

UF1, night = 16.05	UF3, night = 9.94 UF2, night = 9.38 UF2, day = 8.40	UF3, day = 1.58 UF1, day = 1.51

The previous conflict rate is significantly greater at night than during the day, and in part all three night values are statistically indistinguishable. However, the daytime previous conflict rates are all distinguishable; in descending order they are UF3, UF2, and UF1.

UF2, night = 5.83 UF1, night = 5.67 UF3, night = 5.45	UF3, day = 3.48	UF2, day = 1.31	UF1, day = 0.22

The slow-moving conflict rate was not significant at the urban freeway location.

G. Summary of Results

1. Speeds: At both the rural freeway and urban freeway locations, speeds were lower at night; also at both locations vehicles slowed as they traversed the zone.

Speed zoning on the rural freeway had no effect on speeds. Likewise, the effect of zoning could not be statistically determined at the urban freeway location, however, speeds at location L1 on the urban freeway were ≃ 5 mph higher under the UF2 experimental conditions than for either UF1 or UF3. This was true for both day and night speeds.

The only experimental condition that was the same for UF1 and UF3 and different for UF2 was advisory speeds under UF1 and UF3 and regulatory speeds for UF2. The advisory signing was well in advance of the speed measurement locations, the regulatory signing, however, was between L1 and L2. Therefore, it seems likely that the location of the signing did have an effect on speeds. The speed in the work area did not vary between the three UF experiments.

The effect of enforcement was to reduce the mean vehicle speed by 2.77 mph. However, the speed reduction was greatest near the position of the enforcement vehicle.

The arrow panel reduced speeds most significantly near where it was located at the beginning of the crossover.

The active warning of speed zoning did not affect speeds.

No effect on speeds from the transverse striping or nonapplicable lane lines could be determined or inferred from the field studies.

2. Erratic Maneuvers: At both sites erratic maneuver rates were higher at night. The arrow panel, warning of speed zoning and enforcement reduced the erratic maneuver rate significantly.

The UF2 erratic maneuver rate was high for both night and day conditions. In this experiment the speed reduction from the approach area through the transition area was also greater than in UF1 or UF3. From this we can infer that the speed reduction over a shorter length of roadway produced a higher erratic maneuver rate.

Speed zoning had no effect on erratic maneuver rate, and no effect from the transverse striping or obliteration of pavement markings could be determined or inferred.

3. Slow-Moving Conflicts: There was no significant difference between the day and night slow-moving conflict rate. The arrow panel speed zoning and warning of speed zoning increased the slow-moving conflict rate. Only enforcement reduced the slow-moving conflict rate.

4. Previous Conflict Rate: The previous conflict rate was higher at night at the urban freeway location.

V. CONCLUSIONS

1. The 79 construction zones that were studied experience an average increase in accidents of about 7%, however, 31% of the projects studied experienced decreased accident rates during construction (assuming that before and during traffic volumes are equal). Twenty-four percent of the projects experienced rate increases of 50% or more.

2. Based on detailed analyses of three construction zones with increased accident rates during construction, the increase in accidents were highly related to the construction.

3. Short duration and short length construction projects experience higher accident rates.

4. Bridge work and roadway reconstruction are the two types of construction that experience the largest increases in accidents.

5. Some construction roadway types, such as 6- or 8-lane freeways reduced to 1-lane in each direction, experience very high increases in accidents.

6. Although the construction zone accident rate is higher for urban projects, the percent increase in accident rates is nearly equal for rural and urban projects. Accident rates for rural projects do, however, vary more than for urban projects.

7. The number of night accidents increased during construction, but the proportion of night accidents to total accidents remained the same.

8. The proportion of fatal and injury accidents in construction zones is nearly equal to the accident experience before construction, with a slight shift toward less severe accidents during construction.

9. Fatal accident rate is not related to any of the construction zone characteristics studied.

10. The presence of construction zones is most likely to increase fixed-object, rear-end, and head-on accidents, while decreasing right-angle, turning, and ran-off-road accidents.

11. The fixed-object accident rate is higher in stationary construction zones than in zones where traffic controls are moved periodically (daily, weekly, monthly).

12. Construction zones with reduced speed limits do not experience lower accident rates than other zones. Field studies indicate that speed zoning does not reduce mean vehicle speed and does increase conflicts in the transition area.

13. Enforcement patrols and lighted sequential arrow panels decrease vehicle speeds near where they are installed, but their speed reduction effect is only effective over a short length of highway.

14. Based on time-trend analyses, the initial period of construction zone traffic control is not more hazardous than later periods.

15. Drivers adjust speed and position based on the environment (geometrics of zone, lateral clearance and devices) more than on signing.

16. Basic national standards for traffic control layouts in work areas are often violated.

VI. RECOMMENDED GUIDELINES

A. Introduction

Work-area traffic controls must be current, clear and appropriate. For the controls to be adequate, a concerted effort is needed starting with the Federal Highway Administration and the officials of each state highway department and extending to resident engineers, contractors, and workmen. The responsibilities of each level are certainly different, but each level of organization should know the duties it must perform, and have guidelines to chart its performance.

This section presents the recommendations formulated during the research project. Each recommendation fits into the process of developing standards and policies, planning the construction zone, designing the traffic controls, or operating the zone. This process has been outlined (as shown in Table 27) and serves as the framework of this section. Obviously, not enough information is available to fill in the outline entirely. The gaps point to the areas covered in the recommended research.

Recommendations are ranked by their degree of objectivity. Recommendations ranked "R1" are based on the direct findings of the project. Page numbers following the "R1" refer to the page in the report where the project finding is discussed. Recommendations ranked "R2" are based on project synthesis. Findings in several areas considered together may lead to these recommendations, or they are derived from the literature review, if so the reference number is given, or they may have been developed as a collolary of a recommendation based on the project findings. Recommendations ranked "R3" are based on the project staff's observation of practice in the field, and from discussions with many individuals responsible for planning, design, and operation of construction zones.

B. General Needs

1. Communications

- Part VI of the Manual on Uniform Traffic Control Devices should be revised (R2). There are two possibilities: (1) the present Part VI could be expanded to show more examples and new devices; or (2) Part VI could be shortened by deleting typical drawings and only including standards for devices and their use. A separate document could then be developed to recommend and guide design of traffic control systems for construction zones. Alternative (2) is recommended to improve communications with resident engineers and contractors.

TABLE 27

OUTLINE OF RECOMMENDED GUIDELINES

A. Introduction

B. General Needs

  1. Communications (with Contractors, State Engineers, Workers)
  2. Training

C. Planning, Design and Management of Traffic Control

  1. Decision Process
  2. Construction Zone Planning

    a. Determination of Basic Requirements (checklist)
    b. Basic Zone Type Selection and Scheduling

  3. Construction Zone Design and Installation

    a. Speed Control Strategy
    b. Geometrics
    c. Devices

      (1) Signs (warning, regulatory, information)
      (2) Delineation
      (3) Barricades
      (4) Barriers
      (5) Active Displays
      (6) Signals
      (7) Lighting

    d. Traffic Control Plan
    e. Site Preparation

TABLE 27 (Concluded)

4. Traffic Management
   - a. Public Information
   - b. Initial Inspection
   - c. Operational Procedures for Changing Traffic Controls
   - d. Maintenance of Traffic Control Devices
   - e. Temporal Changes in Traffic Control
   - f. Accident Consideration
   - g. Interrupted Flow Operations
     - (1) Flagging
     - (2) Pacing (Pilot Vehicle)
     - (3) Closures
     - (4) Motorist Information
   - h. Special Considerations

4. Post-Evaluation of Traffic Control Operations

2. Training

- People placing and using construction zone traffic control devices must be better educated as to standards for using devices, and why these standards are important (R3). Controls are no better than what the man in the field makes them. Lackadaisical or unattentive supervision of the daily operations of the construction zone can negate the most complete and thorough plans.

- The person in direct charge of traffic control in a construction zone should have traffic engineering and traffic safety education (R3). Too often resident engineers are very aware of construction management needs and not very aware of traffic control management needs, and therefore spend most of their time managing construction activities.

C. Planning, Design, and Management of Traffic Control

1. Decision Process

To adequately plan and design traffic controls for construction zones, several kinds of information should be known. This information is used in a logical process to produce the safest and most efficient traffic control plan possible. Following is a recommended decision process for construction zone traffic control. Although this distinct process is not found in practice, it is viewed as an orderly and complete procedure for making the correct traffic control decisions.

The recommended decision process has five steps (R2):

a. Determine basic conditions including construction, roadway, and traffic data.

b. Select the work-area roadway type and scheduling.

c. Formulate speed control strategy.

d. Determine geometric design elements.

e. Select traffic control devices and methods.

Each of these steps is discussed briefly below. The decision process also serves as the outline for the next two sections (construction zone planning and construction zone design and installation), that contain many recommendations related to each step.

Before decisions about the traffic control plan can be finalized, it is necessary first to identify the basic conditions that will exist in the construction zone. Three categories of data are needed. These are construction data, roadway data, and traffic data. The kinds of data in each of these categories are shown below.

BASIC CONDITIONS

I. Construction Data

   A. Location
   B. Length
   C. Duration

II. Roadway Data

   A. Cross-section
   B. Horizontal and Vertical Alignment
   C. Existing Traffic Control Devices
   D. Importance of the Roadway to the Surrounding Area
   E. Roadway Operational Data

III. Traffic Data

   A. Volume
   B. Composition
   C. Pedestrians
   D. Speed
   E. Accidents

The second step in planning and design of construction zones is to elect the basic work-area roadway type and scheduling. Logically, the choice of work-area roadway type and the scheduling of construction activities are the first decisions to be made about the construction zone. The fundamental problem addressed in this step is the separation of traffic and construction activities on the roadway. These activities can be separated in either space, or time, or both. Separation in space is accomplished by one of the work-area roadway types of lane closure, crossover, temporary bypass, and detour. Separation in time is accomplished by restricting the time that either the traffic or construction activity can occupy a specific section of road. Common scheduling alternatives are: restriction of construction during hours of peak traffic flow, night construction, and stopping of traffic for short periods.

Once the types of work-area roadway and scheduling are determined, the next step is the formulation of the speed control strategy, which results in determination of the design speed and control methods to be used.

The fourth step in the decision process is to determine geometric design elements. The work area traveled-way should be designed consistent with the geometric design standards required for the design speed.

The last step in the design process is to select traffic control devices and methods that can be used for the work-area roadway, scheduling, speed control strategy, and geometric design elements chosen. The traffic control devices are used to alert drivers of impending conditions, warn them of hazards, and direct them to the proper path.

2. Construction Zone Planning

a. Determination of Basic Conditions

- A recommended Basic Condition Checklist is given in Table 28 (R3). This information should be obtained for use in the planning process. The length and duration of the project should be established based on construction requirements, so that the maximum required length and duration will be known. The construction zone controls must be blended into the existing roadway, so it is important that existing traffic controls are known.

- In planning a construction zone look at the current accident data, taking into account that the construction effect may change the accident picture (R1, p. 59).* The accident experience before construction is very important in predicting accident problems during construction. Before-during studies show a strong relationship between the before and during accident experience, however in zones with high ($\geq$ 50%) increase in accident rates the accident experience may be greatly altered from the before to during period.

b. Basic Zone Type Selection and Scheduling

- When staging construction for extended lengths of roadway, minimize the number of construction zones (R1, p. 56). Study results indicate construction zones with longer duration and lengths experience lower accident rates. For example, work zones separated by short distances should be combined into one construction zone.

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* Page numbers following "R1" refer to the page in the report where the project finding is discussed.

TABLE 28

BASIC CONDITION CHECKLIST

Construction Data

What type or types of construction are required?
What is the lateral location of each construction type or types?
What length of roadway will be affected by the construction?
How long should the project last?

Roadway Data

Number and width of lanes
Width of shoulders
Lateral clearance to roadside objects
Median width
Length of tangent sections
Location and degree of horizontal curves
Location and length of vertical curves
Percent and length of roadway grades
Existing traffic control devices
Functional classification
Access Control

Traffic Data

ADT and peak hour volumes
Percent buses and trucks in traffic flow
Speed limit and operating speeds
Advisory speeds
Accidents

- When widening a roadway, only excavate along traveled lanes for that length of roadway that can be constructed in a single day (R2). California experience shows fewer accidents on widening projects using this approach. Also examination of accident reports showed some accidents occurred when a vehicle dropped off the edge of the pavement and lost control.

- Do not reduce 6- or 8-lane roadways to 1-lane in each direction (R1, p. 43). Accident data shows this alternative as much more hazardous than leaving two lanes open.

- Where possible, reduce a 4-lane freeway to one lane in each direction rather than reducing the roadway to a 2-lane, 2-way roadway (R1, p. 43). Accident data indicate than 2-lane, 2-way construction roadways had more than twice the increase of construction roadways with one lane in each direction. However, only two projects of the 2-lane, 2-way type were studied. (See recommended research.)

- Where possible, route traffic from 2-lane highways onto a new alignment rather than using one lane of alternating traffic (R1, p. 43). Two-lane roads reduced to one-way alternating operation experienced a 31% increase in accident rates during construction. Those two-lane highways placed on new alignment experienced a 14% decrease in accident rates.

3. Construction Zone Deisgn and Installation

a. Speed Control Strategy

- Select design speed equal to or greater than the normal posted speed limit (R1, p. 38, 62). Accident studies indicate that the construction zones with reduced speed limits do not experience lower accident rates than other zones. Field studies indicate that speed zoning does not reduce mean vehicle speed and does increase conflicts in transition areas.

- Do not use reduced regulatory speed zoning or advisory speed zoning throughout the entire zone, especially in rural areas (R1, p. 47). Projects with this strategy have higher percentage accident rate increases than those with either no speed reduction or speed reduction through advisory signing.

- Use enforcement as a speed control method at short sections where speed reductions are absolutely necessary (R1, pp. 74-78). Field studies indicated that an enforcement unit is the only speed control method studied that reduces mean speeds, erratic maneuvers, and traffic conflicts.

b. Geometrics

- Normal lane width should be maintained whenever possible (R1, p. 47). Those projects with lane width reductions show a greater accident rate increase than those without.

- Horizontal and vertical curves must be consistent with the selected design speed (R2).[8/][*]

- Use flat diagonal crossovers rather than reverse curves with extensive superrelevation (R2).[8/]

- Successive lane-drop tapers or lane-drop and crossover tapers should not be contiguous (R1, p. J-2). A large number of severe erratic maneuvers were observed in field studies where sucessive tapers were contiguous.

- Lane closures should be readily visible to the driver--not over a crest or around a curve (R2).[8/]

- Subsequent special reports will provide information on taper formulas, the effect of lateral clearance on vehicle speeds and operations, and the effect of reducing the distance between successive tapers.

c. Devices

(1) Signs

- The condition the message conveys must be real (R3).

- When construction regulatory signs are used, then the devices they supercede must be removed or covered (R2).[6/]

- Special consideration should be given to nonlocal motorists in the installation of guide signs to assist them in locating alternate routes (R2).

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[*] Numbers refer to reference numbers.

- If conditions prevent a reflectorized sign from being located where headlights can effectively illuminate it, then face-lighted nonreflectorized signs should be considered (R3).

- Whenever night construction is necessary, a supplementary sign--"Night Construction Ahead"--should be used (R2).[8/] This sign should be removed during the day.

(2) Delineation

- When crossovers are constructed using AC, the transition PC abutting the AC should be overlayed to match the AC (R2).[8/]

- When a multilane divided roadway is reduced to a 2-lane, 2-way roadway, centerline delineators (such as the new delineator poles made of elastromeric material) should be used to remind drivers not to cross into the opposing traffic lane (R3). Ohio and Minnesota use this practice.

(3) Barricades

- The number of barricades should be minimized to reduce fixed-object accidents (R1, p. 35, 61). Accident studies show that fixed-object accidents increase in construction zones, and the less cluttered the zone is, the better.

- Barricades should be used as warning devices rather than barriers (R2).[4/] Barricades offer little or no resistance when struck, but can inflict damage to colliding vehicles and injury to the occupant.

- Barricades should not be placed where no hazard exists (R2).[4/] By placing a barricade where no hazard exists, a hazard (barricade) is created.

(4) Barriers

- Do not use timber curbing or timber barricades as barriers (R1, p. F5 and F11).

- Positive barriers such as portable concrete traffic barriers should be used when necessary on projects where timber curbing or timber barricades were previously used as barriers (R2).[4/] Those projects using timber curbing or barriers evidently needed protection devices. Virginia experience shows that 90% of all vehicles pentrating the timber barricade would have been redirected by the concrete traffic barrier, and the difference in cost (of the barrier) is small.

(5) Active Displays

- Active displays are very effective in conveying real-time information and are especially applicable in zones where work is intermittent (R3).

- Standards should be adopted for the size and use of lighted, flashing arrow panels (R3).

- New devices, such as the variable, vehicle roof-mounted, message systems, legible at 1,800 feet in direct sunlight, show promise as being very useful on urban freeways where construction may cause large queues of traffic (R2).[2/]

(6) Signals

- Motorists are more accustomed to seeing a traffic signal than a flagman, resulting in more respect for the signal, and also a greater tendency to obey it. This should be taken into consideration when choosing between signals and flagging (R2).[6/]

(7) Lighting

- Flagman stations should be illuminated by flood lighting at night (R2).[3/]

d. Traffic Control Plans

- Detailed traffic control plans should be designed and recorded for all stationary construction zones (R3).

- Detailed traffic control plans should be designed and evaluated to meet site-specific conditions, rather than force-fitting conditions to a "Typical" plan (R3).

- Construction zones in which the traffic control requirements change frequently require emphasis on traffic management, rather than on the preparation of a detailed traffic control plan (R3). Large projects may require both.

- If possible, the traffic control plan should provide options where conditions might change (R3).

e. Site Preparation

- Installation of temporary pavements and traffic control devices are similar to common maintenance activities and temporary traffic control should be handled with due care accordingly (R3). Full consideration should be given to using active real-time warning devices such as lighted flashing arrow panels.

- All inappropriate signs and pavement parkings should be removed, covered, or obliterated (R3).

- If sandblasting is used to obliterate inappropriate pavement markings, due care should be taken to shield the operation from passing motorists (R3). Unshielded sandblasting operations for field studies caused severe erratic maneuvers and subsequent traffic conflicts.

4. Traffic Management

a. Public Information

- Public information through mass media, billboards, and handouts is recommended for road closures, detours, and high-volume highways (R3).

b. Initial Inspection

- Traffic control plans, no matter how detailed, will probably need some field modification (R3).

- After the traffic control devices have been installed, the zone should be driven (both day and night) to ensure all hazards are adequately protected and delineated, the proper path is well defined, and signs are well positioned for adequate reflectivity (R3).

- Observation of erratic maneuvers, conflicts, speed differentials, delays, damaged control devices, and skid marks should be performed by the person in charge of traffic control to diagnose signs of inefficient traffic movement through the zone (R2). By observing the traffic for short periods (approximately 1 hour) most inefficiencies will show up.

- Any observed inefficiency that could likely cause an accident should be remedied immediately, even at night (R3).

- Any inefficiency that will not directly cause an accident should be remedied the next day if inefficiency is spotted at night (R3).

- The person responsible for traffic controls on the project must have the authority to make changes in the traffic controls if operational deficiencies arise (R3).

- Any change in the traffic control should be documented (R3).

d. Maintaining Traffic Control Devices

- Low-volume projects should be driven through daily, and high-volume projects driven more often to observe and correct traffic control devices that are out of place (R3).

e. Temporal Changes in Traffic Control

- If a change in traffic control is required, then it must be documented and inappropriate devices removed or covered (R3). Light-weight burlap is not an effective cover at night. Plywood is an effective cover.

f. Accident Consideration

- If accidents occur, the traffic control supervisor must work directly with the police officers to ensure additional accidents do not occur (R3).

- Copies of all accident reports should be reviewed immediately by the traffic control supervisor to determine if the traffic controls contributed to the accident, and then appropriate remedial action should be taken (R3).

g. Interrupted Flow Operations

- Use high mounted warning devices for flagging operations--especially where long queues can be expected (R2). Accident studies show a prevalence of rear-end accidents where long queues are experienced.

- Flaggers should note operational difficulties and notify their supervisors as soon as possible (R3).

h. Special Considerations

- Flagmen should be informed on how to handle emergency vehicles (R3).

- Some construction workers have little regard for traffic. For example, workers have been observed pulling out in front of oncoming vehicles and taking unsafe paths through the zone. The highway department inspectors should note these maneuvers, and the contractor should be cautioned (R3).

- Night construction may require floodlights to aid both the construction worker and the traffic. If flood lights are used, care must be taken to ensure they don't cause glare. The best way to ensure this is to drive through the zone right after the lights are installed (R3).

- Special care should be given to highway sections where normally one-way traffic is converted to two-way. Drivers need to be reminded continuously that they are on a two-way section; especially those who are in their normal lane. In this situation a double line consisting of two solid yellow lines should be used (R3).

- Unless the zone operations are continually moving, the location of devices should be documented daily. This will not only ensure the proper placement of the devices, but will be useful in court cases, should accidents occur (R3). Photographs can also be helpful.

5. Post-Evaluation of Traffic Control Operations

- States should continuously evaluate zones to determine the cost and safety effectiveness of various control strategies (R1, p. 61-63). The before-during accident comparison revealed some types of control strategies that were much more hazardous than their alternatives. The case studies also showed that there is often a predominate accident type associated with various control strategies.

- There is a need for new traffic control bidding procedures following bid item guidelines. Specifications should include timing of use of devices (R3). Knowing the actual cost of various control strategies is vital to evaluation of control alternatives.

D. Recommendations for Further Research

- More before-during accident data should be collected for four-lane interstate highways that are reduced to 2-lane, 2-way operation (R1, p. 43). This construction road type had high increases in accident rates from the before to during period. However, only two projects of this type were studied.

- More research should be done concerning the treatment of exposed concrete barrier ends (R2).[4]

- Standards must be established for the size and use of lighted flashing arrow panels (R3).

- More research should be done on using CB radios to inform drivers of special construction situations (R2).

E. Major Recommendation

A major goal in construction zone operations is to plan, design, and operate traffic controls to maintain the construction zone accident rate equal to or below the accident rate before construction (R2). Accident studies show that 31% of the projects investigated experienced decreased accident rates during construction. Figure 10 is a graphical representation of the accident rate changes experienced by the 79 studied projects.

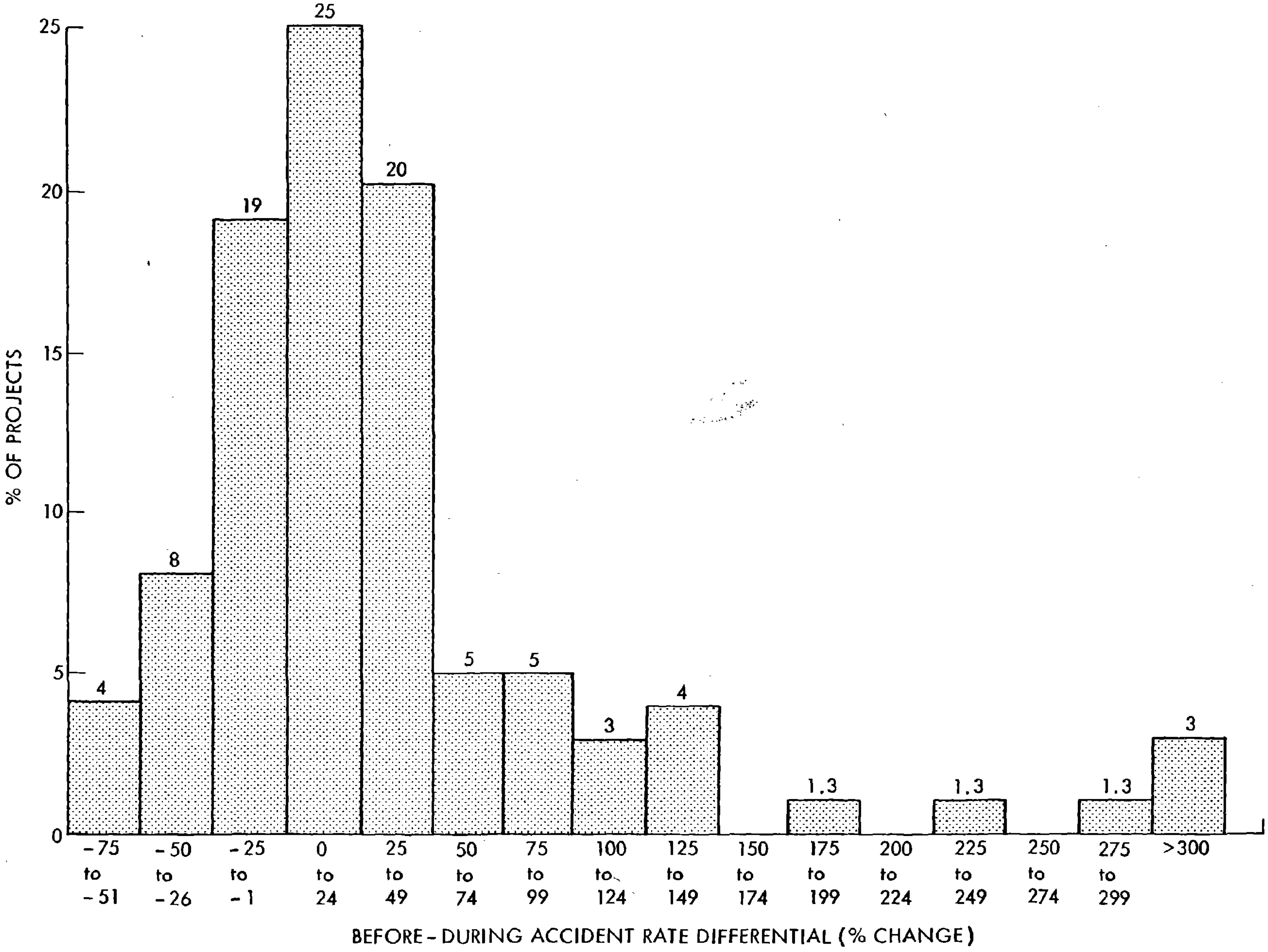

Figure 10 - Project Accident Rate Change

REFERENCES

1. National Cooperative Highway Research Program, Synthesis of Highway Practice No. 1: Traffic Control for Freeway Maintenance. Highway Research Board, Division of Engineering, National Research Council, National Academy of Science - National Academy of Engineering (1969).

2. "Traffic Controls for Construction and Maintenance Worksites," Report No. FHWA-RD-75, Three Volumes, American Public Works Association, December 1975.

3. "Manual on Uniform Traffic Control Devices for Streets and Highways," Federal Highway Administration, U.S. Department of Transportation (1971).

4. Liste, Frank N., Bernard J. Reilly and Melvin D. Beale, "Evaluation of Timber Barricades and Precast Concreter Traffic Barriers for Use in Highway Construction Areas," Virginia Highway and Transportation Research Council, September 1976.

5. Center for Auto Safety, "Safe Traffic Control Through Highway Work Areas," Presentation to the attendees at the 55th Annual Meeting, Transportation Research Board, January 1976.

6. Highway Focus, Volume 6, No. 4, Federal Highway Administration, U.S. Department of Transportation, December 1974.

7. Conversations with highway agency personnel in States of Arizona, California, Colorado, Connecticut, Florida, Georgia, Idaho, Illinois, Indiana, Iowa, Kansas, Maryland, Michigan, Minnesota, Nebraska, New Jersey, New York, Ohio, Oklahoma, Oregon, Pennsylvania, Tennessee, Texas, Utah, Virginia, and Washington.

8. "Construction Zone, Detour and Temporary Connection Accidents," Division of Highways, Department of Public Works, State of California Business and Transportation Agency, June 1972.

9. Kihlberg, Jaakko K., and K. J. Tharp, "Accident Rates as Related to Design Elements of Rural Highways," National Cooperative Highway Research Program Report 47 (1968).

10. Highway Research Board, Special Report 87, "Highway Capacity Manual," (1965).

11. Hulbert, Slade F., "Human Factors and Traffic Engineering," Traffic Engineering, September 1968.

12. FHWA Notice N5160.21, May 10, 1976.

13. "Federally Coordinated Program of Highway Research and Development," Office of Research and Development, Federal Highway Administration, U.S. Department of Transportation (1975).

14. "It pays to Minimize Traffic Hazards During Road Construction," Public Works, October 1963.

15. Frick, W. A., "Traffic Protection for Highway Work Areas," Indiana Road School, 58th Annual Road School, April 3-6, 1972, Engineering Bulletin of Purdue University, Engineering Extension Series No. 139.

16. "Traffic Control for Street and Highway Construction and Maintenance Operations," National Highway Institute, Federal Highway Administration, U.S. Department of Transportation, September 1975.

17. Fee, Julie Anna, et al., "Interstate System Accident Research Study--1," U.S. Department of Transportation, October 1970.

BIBLIOGRAPHY

1. Alexander, Gerson J., and Harold Lunenfeld, Positive Guidance in Traffic Control, Office of Traffic Operations, Féderal Highway Administration, U.S. Department of Transportation, April 1975.

2. "Appendix B, Minnesota Manual on Uniform Traffic Control Devices," Minnesota Department of Highways, January 1, 1974.

3. Baerwald, J. E., Traffic Engineering Handbook, Third Edition, Institute of Traffic Engineers (1965).

4. Baerwald, J. E., Transportation and Traffic Engineering Handbook, Institute of Traffic Engineers (1976).

5. Bender, Louis, "What Should You Do About Detours?" American City, February 1972.

6. Biggs, R. G., "Traffic Handling Around Maintenance Activities on Freeways," Special Study No. 5.3, Transportation Planning Division, Texas State Department of Highway and Public Transportation, July 1975.

7. Butler, B. C., "The Effect of Traffic Lane Closures on the Highway Motorists," Better Use of Existing Transportation Facilities, Transportation Research Board, National Research Council, Special Report No. 153 (1975).

8. "California Report On Construction Area Accidents," FHWA Bulletin, Federal Highway Administration, U.S. Department of Transportation, November 1975.

9. Cummings, Jerome V., "Traffic Requirements for Construction Projects," Traffic Engineering, November 1967.

10. Drew, Donald R., Traffic Flow Theory and Control, McGraw-Hill, Inc., 1968.

11. Executive Committee of the Construction Section, National Safety Council, "Data Sheet 239--Revision B (Extensive): Barricades and Warning Devices for Highway Construction Work," National Safety News, March 1974.

12. Fitzpatrick, James F., Michael N. Sohn, Thomas E. Silfen, and Robert H. Wood, The Law and Roadside Hazards, Michie Company (1975).

13. "Five-Deep Signs Protect Repair Crews," Rural and Urban Roads, April 1972.

14. "Flagging Handbook," Division of Highways, State Department of Highways, State of Colorado.

15. Forbes, T. W., ed., Human Factors in Highway Traffic Safety Research, Wiley-Interscience, 1972.

16. Gilbach, William, "The Contractors Problems in Design and Construction of Urban Highways," Highway Research Record 372 (1971).

17. Gillis, Lyman R., "The Feasibility of Night Maintenance and Construction," Public Works, April 1969.

18. Goodwin, D. N., "Investigation of Freeway Lane Drops," NCHRP Final Report, Project 3-16, System Development Corporation, October 1973.

19. Hatton, Roger L., "Traffic Controls for Maintenance Operations," Public Works, November 1970.

20. Heimbach, Clinton L., and Harold D. Vick, "Relating Change of Highway Speed per Unit of Time to Motor Vehicle Accident Rates," Highway Research Record 225 (1968).

21. "Highway Design and Operational Practices Related to Highway Safety," American Association of State Highway and Transportation Officials, Second Edition (1974).

22. "Highway Design, Construction, and Maintenance," Highway Safety Program Manual No. 12, Federal Highway Administration, U.S. Department of Transportation, February 1974.

23. "ITE Standard for Flashing and Steady-Burn Barricade Warning Lights," Traffic Engineering, August 1971.

24. "Jobsite Protection - Good Enough's," Rural and Urban Roads, September 1974.

25. Lee, Calvin D., "Nighttime Construction Work on Urban Freeways," Traffic Engineering, March 1969.

26. Lukken, E. C., "Portable Precast Concrete Safety Barriers," Public Works, December 1973.

27. Lundy, Richard A., "Effect of Traffic Volumes and Number of Lanes on Freeway Accident Rates," Highway Research Record 99 (1965).

28. McGarry, Thomas F., "Prescription for Safety: Sincere Consideration," Public Works, March 1967.

29. McInerney, Henry B., and Stephen G. Peterson, "Intersection Capacity Measurement Through Critical Movement Summations: A Planning Tool," Traffic Engineering, January 1971.

30. "Manual of Uniform Traffic Control Devices," Traffic and Safety Division, New York State Department of Transportation, July 1, 1974.

31. Moore, John O., "A Preliminary Study of Speed as Related to Injury-Producing Automobile Accidents," Highway Research Board Bulletin 142, 1956.

32. National Advisory Committee on Uniform Traffic Control Devices, Traffic Control Devices Handbook: An Operating Guide, Federal Highway Administration, U.S. Department of Transportation, December 1974.

33. "The Obliteration of Pavement Markings," FHWA Notice N 5160.14, Federal Highway Administration, U.S. Department of Transportation.

34. "Plan Cuts Project-Area Accidents," Rural and Urban Roads, May 1970.

35. Resurfacing Projects Data Sheet, Fiscal Year 1974, Georgia Department of Transportation.

36. "Speed Signs Change with the School Day," American City, August 1969.

37. Stevenson, J. L., "How Utah Trains Its Flagmen," Traffic Safety, July 1974.

38. "Supplemental Specifications for Traffic Controls for Street and Highway Construction and Maintenance Operations," Iowa State Highway Commission, July 1972.

39. Tamburri, Thomas N., and Richard N. Smith, "The Safety Index: A Method of Evaluating and Rating Safety Benefits," Highway Research Record 332 (1970).

40. "Traffic Barricade Manual," Traffic Engineering Department, City of Phoenix, Arizona, Revised, July 1974.

41. "Traffic Protection for Highway Work Areas," Rural and Urban Roads, October 1972.

42. Transportation Research Board, "Crash Cushion Trailer Protects Workers, Doubles Production Through Added Security," Highway Research News, Spring 1974.

43. "Typical Traffic Control for Work Area Protection," Virginia Department of Highways and Transportation, January 1975.

44. "Utah Manual for Construction and Maintenance Traffic Control," Utah Department of Highways, March 1972.

APPENDIX A

ACCIDENT STUDY DATA FORMS

3825-E PROJECT WORKSHEET

Project	District and County	Route	M.P. Limits and (Length)	Dates of Work and (Duration)	L x D (Miles) x (Years)	Roadway Type	Area Type	ADT (Year)	Selection Criteria	O. K. for Analysis?	Construction Data	Accident Data	Cost Data

3825-E DATA COLLECTION CHECKLIST

Before First Visit

1. Find out about the state's system for locating zones, accidents, ADT counts, etc. If we do not have information in-house, inform the state contact that we will need this data in order to select zones.

2. Review the state's manual on construction zones. Note unusual or innovative practices.

3. If possible get map of district, counties. etc. Find out if there is a control section log or similar record that would be useful in selecting projects.

Desirable General Data

1. Average yearly proportion of each type of construction zone.

2. Methods used to record traffic control activities.

3. Distribution of construction zone lengths.

4. Distribution of duration of construction activity. (Regular construction season, etc.).

5. Projects using traffic surveillance teams.

6. Methods used to evaluate construction zone operations.

7. Speed studies in construction zones.

Project Selection

1. Information needed for completing the project worksheet are length of the project (are mile posts listed for limits of work area or entire zone?), duration of project (traffic control), and the ADT and road types.

2. Project selection should be done at headquarters office if at all possible. If it must be done at district level go to district with large urban areas, or follow advice of state people.

3. Use projects done during 1975 first, then most recent years possible.

4. After all project have been examined to determine their suitability, there should be at least 10 projects. If there are not, some projects that did not meet the criteria will have to be used. Try to choose projects of varying length, duration, zone type, and area.

5. If there are more than 10 suitable projects, it is alright to have as many as meet the criteria. However, if the district offices must be visited it would be beneficial to exclude projects that are in districts with very small numbers of projects.

6. Try to insure that some two-lane and some freeway projects are considered in each state.

Required Construction Zone Data

1. Length of zone (be sure we know what length means).

2. Type of zone.

3. Duration--stage by stage.

4. Scheduling--including stages.

5. Traffic control plan or standard plan including traffic control methods used.

6. Type of construction.

7. Speed limit and type of speed control.

8. Length of transition and warning areas.

9. Delineation techniques and roadside clearance to barriers or construction workers.

10. Intersections within the zone including access points for construction workers.

Desirable Construction Zone Data

1. Project diary entries or traffic control logs.

2. Traffic management plan.

3. Information on construction zone design considerations.

4. Data on nonreported accidents.

5. Design quality and pavement type.

6. Try to observe a construction zone.

Accident Data

1. Statewide accident rates on each type of road and in construction zones, (especially statewide rates for 1973 and 1974 if 74 projects are used).

2. Get hard copy reports for all warning and transition sections of each zone.

3. Make sure accident summaries include:

Location in zone;
Time of day;
Accident severity;
Accident type;
Speed;
Highway geometrics involved;
Contributing circumstances;
Accidents involving construction vehicles;
Pavement conditions;
Environmental conditions; and
Driver factors.

4. Find out if there are any current problems with accident system such as delay in putting records in the system or historical data in different format, etc.

Cost Data

1. Find out if traffic control is a bid item.

2. What percent of project funds are spent on traffic control?

3. How much does restrictive scheduling add to the cost of the project?

4. What are the costs of crossover roadways and temporary bypass routes.

5. Get all available information on costs to install, operate and maintain traffic in zone.

6. Find out if there is any information on road user delay costs.

7. Get total of project costs.

3825-E ACCIDENT SUMMARIES

	Mile Post Limits	Dates	Total Accidents		Accident Type											Severity			Surface			Accidents by Month																
							RA	RE	SS	HO			FO	FO (Constr)	Other	PDO	Injury	Fatal	Dry	Wet	Icy																	
Proj.____ Before																																						
During																																						
Proj.____ Before																																						
During																																						
Proj.____ Before																																						
During																																						
Proj.____ Before																																						
During																																						

3825-E PROJECT WORKSHEET

PROJECT: ______________________

Route ____________

District/County ______/______

Area Type ____________

Roadway Type ____________

ADT - Before (Year)/During ______/______

General Description: ______________________

	M.P. Limits (& Length)	Dates of Work	Zone Type	Speed Limit		Speed Control	Traffic Control Strategy	Lane Width	Delineation Techniques (Markings, Cones)	Protection Techniques (Barricades, Barriers)	Notes
				Before	During						
General Data -											
Traffic Control Intent Zone Parts (Approaches, Transitions)											

NOT REPRODUCIBLE

ACCIDENT RATE CALCULATIONS

Project Number	Number of Accidents	100 Million	/	(ADT)	Section Length	Duration	=	Accident Rate in ACC/100 MVM
1 Before	(56)	(100,000,000)	/	(16,600)	(11.97)	(234)	=	120.44
1 During	(96)	(100,000,000)	/	(16,600)	(11.97)	(234)	=	206.47
2 Before	(80)	(100,000,000)	/	(30,000)	(7.12)	(219)	=	171.02
2 During	(89)	(100,000,000)	/	(30,000)	(7.12)	(219)	=	190.26
3 Before	(138)	(100,000,000)	/	(40,000)	(4.25)	(315)	=	257.70
3 During	(108)	(100,000,000)	/	(40,000)	(4.25)	(315)	=	201.68
4 Before	(75)	(100,000,000)	/	(87,000)	(3.87)	(113)	=	197.13
4 During	(109)	(100,000,000)	/	(87,000)	(3.87)	(113)	=	286.50
5 Before	(137)	(100,000,000)	/	(57,000)	(8.77)	(85)	=	322.42
5 During	(116)	(100,000,000)	/	(57,000)	(8.77)	(85)	=	273.00
6 Before	(116)	(100,000,000)	/	(27,300)	(6.90)	(92)	=	669.36
6 During	(136)	(100,000,000)	/	(27,300)	(6.90)	(92)	=	784.76
7 Before	(199)	(100,000,000)	/	(25,000)	(2.99)	(270)	=	986.00
7 During	(221)	(100,000,000)	/	(25,000)	(2.99)	(270)	=	1,095.01
8 Before	(19)	(100,000,000)	/	(37,700)	(1.76)	(231)	=	123.96
8 During	(36)	(100,000,000)	/	(37,700)	(1.76)	(231)	=	234.87
9 Before	(23)	(100,000,000)	/	(20,000)	(3.79)	(219)	=	138.55
9 During	(33)	(100,000,000)	/	(20,000)	(3.79)	(219)	=	198.79
10 Before	(11)	(100,000,000)	/	(9,200)	(5.56)	(227)	=	94.73
10 During	(11)	(100,000,000)	/	(9,200)	(5.56)	(227)	=	94.73
11 Before	(21)	(100,000,000)	/	(4,000)	(8.29)	(303)	=	194.25
11 During	(27)	(100,000,000)	/	(4,000)	(8.29)	(539)	=	151.06
12 Before	(18)	(100,000,000)	/	(10,000)	(4.94)	(181)	=	201.31
12 During	(15)	(100,000,000)	/	(10,000)	(4.94)	(181)	=	167.76
13 Before	(15)	(100,000,000)	/	(10,000)	(6.59)	(184)	=	123.71
13 During	(45)	(100,000,000)	/	(10,000)	(6.59)	(274)	=	249.22
14 Before	(18)	(100,000,000)	/	(6,000)	(4.28)	(153)	=	458.13
14 During	(6)	(100,000,000)	/	(6,000)	(4.28)	(153)	=	152.71
15 Before	(12)	(100,000,000)	/	(6,000)	(5.03)	(191)	=	208.18
15 During	(9)	(100,000,000)	/	(6,000)	(5.03)	(191)	=	156.13
16 Before	(18)	(100,000,000)	/	(6,000)	(5.44)	(220)	=	250.67
16 During	(19)	(100,000,000)	/	(6,000)	(5.44)	(220)	=	264.59
17 Before	(174)	(100,000,000)	/	(58,000)	(10.1)	(395)	=	74.17
17 During	(427)	(100,000,000)	/	(58,000)	(10.1)	(655)	=	109.77
18 Before	(347)	(100,000,000)	/	(29,500)	(3.07)	(394)	=	972.46
18 During	(331)	(100,000,000)	/	(29,500)	(3.07)	(610)	=	599.15
19 Before	(55)	(100,000,000)	/	(17,920)	(1.00)	(285)	=	1,076.91
19 During	(18)	(100,000,000)	/	(17,920)	(1.00)	(285)	=	352.44

NOT REPRODUCIBLE

ACCIDENT RATE CALCULATIONS (Continued)

Project Number	Number of Accidents	100 Million	/	(ADT)	Section Length	Duration	=	Accident Rate in ACC/100 MVM
20 Before	(5)	(100,000,000)	/	(3,300)	(8.60)	(100)	=	176.18
20 During	(7)	(100,000,000)	/	(3,300)	(8.60)	(100)	=	246.65
21 Before	(16)	(100,000,000)	/	(10,600)	(3.85)	(313)	=	125.26
21 During	(14)	(100,000,000)	/	(10,600)	(3.85)	(313)	=	109.60
22 Before	(24)	(100,000,000)	/	(7,000)	(4.55)	(239)	=	315.29
22 During	(42)	(100,000,000)	/	(7,000)	(4.55)	(239)	=	551.75
23 Before	(1)	(100,000,000)	/	(8,600)	(5.70)	(39)	=	52.31
23 During	(4)	(100,000,000)	/	(8,600)	(5.70)	(39)	=	209.23
24 Before	(5)	(100,000,000)	/	(11,450)	(2.90)	(54)	=	278.85
24 During	(7)	(100,000,000)	/	(11,450)	(2.90)	(54)	=	390.39
25 Before	(91)	(100,000,000)	/	(20,450)	(3.48)	(186)	=	687.47
25 During	(163)	(100,000,000)	/	(20,450)	(3.48)	(186)	=	1,231.41
26 Before	(439)	(100,000,000)	/	(80,000)	(6.18)	(271)	=	327.65
26 During	(496)	(100,000,000)	/	(80,000)	(6.18)	(271)	=	370.20
27 Before	(117)	(100,000,000)	/	(70,000)	(8.57)	(94)	=	207.48
27 During	(179)	(100,000,000)	/	(70,000)	(8.57)	(122)	=	244.58
28 Before	(21)	(100,000,000)	/	(60,000)	(3.48)	(47)	=	213.99
28 During	(19)	(100,000,000)	/	(60,000)	(3.48)	(47)	=	193.61
29 Before	(97)	(100,000,000)	/	(17,000)	(2.86)	(294)	=	678.59
29 During	(112)	(100,000,000)	/	(17,000)	(2.86)	(294)	=	783.53
30 Before	(49)	(100,000,000)	/	(25,000)	(10.10)	(215)	=	90.26
30 During	(93)	(100,000,000)	/	(25,000)	(10.10)	(215)	=	171.31
31 Before	(647)	(100,000,000)	/	(50,000)	(10.68)	(212)	=	571.51
31 During	(681)	(100,000,000)	/	(50,000)	(10.68)	(212)	=	601.55
32 Before	(172)	(100,000,000)	/	(77,500)	(5.25)	(365)	=	115.82
32 During	(238)	(100,000,000)	/	(77,500)	(5.25)	(464)	=	126.07
33 Before	(80)	(100,000,000)	/	(35,000)	(8.43)	(201)	=	134.90
33 During	(117)	(100,000,000)	/	(35,000)	(8.43)	(201)	=	197.29
34 Before	(122)	(100,000,000)	/	(60,000)	(9.06)	(209)	=	107.38
34 During	(155)	(100,000,000)	/	(60,000)	(9.06)	(209)	=	136.43
35 Before	(301)	(100,000,000)	/	(13,000)	(5.71)	(365)	=	1,110.95
35 During	(365)	(100,000,000)	/	(13,000)	(5.71)	(452)	=	1,087.86
36 Before	(27)	(100,000,000)	/	(3,395)	(15.79)	(194)	=	259.62
36 During	(24)	(100,000,000)	/	(3,395)	(15.79)	(194)	=	230.77
37 Before	(147)	(100,000,000)	/	(55,000)	(15.09)	(55)	=	322.03
37 During	(210)	(100,000,000)	/	(55,000)	(15.09)	(55)	=	460.05
38 Before	(5)	(100,000,000)	/	(26,000)	(0.59)	(121)	=	269.38
38 During	(4)	(100,000,000)	/	(26,000)	(0.59)	(121)	=	215.50

ACCIDENT RATE CALCULATIONS (Continued)

Project Number	Number of Accidents	100 Million	/	(ADT)	Section Length	Duration	=	Accident Rate in ACC/100 MVM
39 Before		(No Before Data for this project)						
39 During	(23)	(100,000,000)	/	(7,750)	(4.25)	(983)	=	71.04
40 Before	(108)	(100,000,000)	/	(117,000)	(7.61)	(67)	=	181.04
40 During	(143)	(100,000,000)	/	(46,500)	(7.61)	(67)	=	603.15
41 Before	(5)	(100,000,000)	/	(7,625)	(2.86)	(122)	=	187.93
41 During	(14)	(100,000,000)	/	(7,625)	(2.86)	(122)	=	526.21
42 Before	(39)	(100,000,000)	/	(6,300)	(3.17)	(241)	=	810.30
42 During	(50)	(100,000,000)	/	(6,300)	(3.17)	(241)	=	1,038.85
43 Before	(11)	(100,000,000)	/	(2,400)	(13.39)	(241)	=	142.03
43 During	(9)	(100,000,000)	/	(2,400)	(13.39)	(241)	=	116.21
44 Before	(40)	(100,000,000)	/	(9,000)	(9.73)	(241)	=	189.53
44 During	(50)	(100,000,000)	/	(9,000)	(9.73)	(241)	=	236.92
45 Before	(72)	(100,000,000)	/	(24,500)	(0.72)	(365)	=	1,118.26
45 During	(28)	(100,000,000)	/	(24,500)	(0.72)	(365)	=	434.88
46 Before	(69)	(100,000,000)	/	(68,000)	(6.09)	(89)	=	187.21
46 During	(103)	(100,000,000)	/	(44,000)	(6.09)	(89)	=	431.89
47 Before	(67)	(100,000,000)	/	(37,000)	(7.58)	(79)	=	302.40
47 During	(95)	(100,000,000)	/	(37,000)	(7.58)	(79)	=	428.77
48 Before	(7)	(100,000,000)	/	(29,100)	(2.04)	(267)	=	44.16
48 During	(34)	(100,000,000)	/	(29,100)	(2.04)	(267)	=	214.51
49 Before	(75)	(100,000,000)	/	(8,075)	(8.18)	(379)	=	299.59
49 During	(141)	(100,000,000)	/	(8,075)	(8.18)	(443)	=	481.86
50 Before	(2)	(100,000,000)	/	(5,750)	(0.80)	(390)	=	111.48
50 During	(13)	(100,000,000)	/	(5,750)	(0.80)	(673)	=	419.92
51 Before	(17)	(100,000,000)	/	(6,200)	(4.32)	(297)	=	213.71
51 During	(17)	(100,000,000)	/	(6,200)	(4.32)	(297)	=	213.71
52 Before	(162)	(100,000,000)	/	(10,700)	(25.06)	(192)	=	314.67
52 During	(226)	(100,000,000)	/	(10,700)	(25.06)	(192)	=	438.98
53 Before	(144)	(100,000,000)	/	(25,200)	(6.20)	(368)	=	250.45
53 During	(329)	(100,000,000)	/	(25,200)	(6.20)	(1,002)	=	210.15
54 Before	(120)	(100,000,000)	/	(53,000)	(6.19)	(304)	=	120.32
54 During	(129)	(100,000,000)	/	(53,000)	(6.19)	(304)	=	129.34
56 Before	(870)	(100,000,000)	/	(113,000)	(9.80)	(374)	=	210.06
56 During	(908)	(100,000,000)	/	(113,000)	(9.80)	(386)	=	212.42
57 Before	(40)	(100,000,000)	/	(25,000)	(10.30)	(384)	=	40.45
57 During	(102)	(100,000,000)	/	(15,200)	(10.30)	(659)	=	98.86

NOT REPRODUCIBLE

ACCIDENT RATE CALCULATIONS (Continued)

Project Number	Number of Accidents	100 Million	/	(ADT)	Section Length	Duration	=	Accident Rate in ACC/100 MVM
58 Before	(148)	(100,000,000)	/	(18,570)	(14.74)	(366)	=	147.73
58 During	(257)	(100,000,000)	/	(18,570)	(14.74)	(507)	=	185.19
59 Before	(65)	(100,000,000)	/	(19,900)	(5.90)	(273)	=	202.79
59 During	(61)	(100,000,000)	/	(19,900)	(5.90)	(273)	=	190.31
60 Before	(54)	(100,000,000)	/	(22,500)	(14.48)	(167)	=	99.25
60 During	(72)	(100,000,000)	/	(22,500)	(14.48)	(167)	=	132.33
61 Before	(65)	(100,000,000)	/	(16,000)	(9.63)	(366)	=	115.26
61 During	(81)	(100,000,000)	/	(16,000)	(9.63)	(395)	=	133.09
62 Before	(40)	(100,000,000)	/	(23,070)	(7.94)	(273)	=	79.99
62 During	(69)	(100,000,000)	/	(23,070)	(7.94)	(273)	=	137.98
63 Before	(72)	(100,000,000)	/	(22,500)	(14.48)	(198)	=	111.61
63 During	(93)	(100,000,000)	/	(22,500)	(14.48)	(250)	=	114.18
64 Before	(97)	(100,000,000)	/	(22,540)	(8.20)	(366)	=	143.39
64 During	(99)	(100,000,000)	/	(22,540)	(8.20)	(619)	=	86.53
65 Before	(115)	(100,000,000)	/	(22,600)	(10.59)	(366)	=	131.28
65 During	(63)	(100,000,000)	/	(22,600)	(10.59)	(370)	=	71.14
66 Before	(35)	(100,000,000)	/	(23,070)	(7.94)	(244)	=	78.31
66 During	(53)	(100,000,000)	/	(23,070)	(7.94)	(244)	=	118.58
67 Before	(81)	(100,000,000)	/	(23,000)	(8.91)	(285)	=	138.69
67 During	(96)	(100,000,000)	/	(23,000)	(8.91)	(285)	=	164.37
68 Before	(67)	(100,000,000)	/	(8,000)	(36.46)	(215)	=	106.84
68 During	(56)	(100,000,000)	/	(8,000)	(36.46)	(215)	=	89.30
69 Before	(84)	(100,000,000)	/	(13,630)	(16.10)	(365)	=	104.87
69 During	(110)	(100,000,000)	/	(13,630)	(16.10)	(470)	=	106.65
70 Before	(37)	(100,000,000)	/	(23,500)	(6.60)	(365)	=	65.36
70 During	(118)	(100,000,000)	/	(23,500)	(6.60)	(574)	=	132.54
71 Before	(241)	(100,000,000)	/	(21,300)	(23.18)	(365)	=	133.73
71 During	(228)	(100,000,000)	/	(21,300)	(23.18)	(514)	=	89.84
72 Before	(43)	(100,000,000)	/	(23,400)	(10.2)	(165)	=	109.19
72 During	(28)	(100,000,000)	/	(23,400)	(10.2)	(165)	=	71.10
73 Before		(No Before Data for this project)						
73 During	(61)	(100,000,000)	/	(37,400)	(1.57)	(989)	=	105.04
74 Before	(10)	(100,000,000)	/	(15,500)	(2.64)	(187)	=	130.68
74 During	(12)	(100,000,000)	/	(15,500)	(2.64)	(187)	=	156.82
75 Before	(8)	(100,000,000)	/	(14,300)	(3.45)	(356)	=	45.55
75 During	(18)	(100,000,000)	/	(14,300)	(3.45)	(356)	=	102.49

ACCIDENT RATE CALCULATIONS (Concluded)

Project Number	Number of Accidents	100 Million	/	(ADT)	Section Length	Duration	=	Accident Rate in ACC/100 MVM
76 Before	(16)	(100,000,000)	/	(17,400)	(4.20)	(105)	=	208.51
76 During	(14)	(100,000,000)	/	(17,400)	(4.20)	(105)	=	182.45
77 Before	(54)	(100,000,000)	/	(24,000)	(2.93)	(114)	=	673.61
77 During	(79)	(100,000,000)	/	(24,000)	(2.93(	(114)	=	985.47
78 Before	(5)	(100,000,000)	/	(42,100)	(1.44)	(60)	=	137.46
78 During	(5)	(100,000,000)	/	(42,100)	(1.44)	(60)	=	137.46
79 Before		(No Before Data for this project)						
79 During	(44)	(100,000,000)	/	(20,000)	(5.84)	(379)	=	99.40
80 Before		(No Before Data for this project)						
80 During	(11)	(100,000,000)	/	(14,000)	(6.03)	(134)	=	97.24

NOT REPRODUCIBLE

APPENDIX B

STATE VISITS FOR ACCIDENT STUDY DATA

Ohio

The Ohio Department of Transportation, Bureau of Traffic, was visited in March 1976 to collect data on construction zones. Data on several minor safety projects were collected from the ODOT and was used to select 11 of these projects for study. Project diary entries concerning traffic control problems plus detailed descriptions of daily work in progress were available for these projects.

On the second visit, zone and accident data were received for the 11 projects. A trip was made to the Ohio DOT District 5 Office to obtain information on some two-lane projects. However, no suitable two-lane projects were found.

Accident summaries were obtained for all before and during accidents. Hard copy reports were obtained for all "construction-related" accidents.

Georgia

Construction data on 11 projects were obtained in Georgia. The data were collected at district offices. Documentation of the traffic control was often sparse except on special projects. The information that was obtained included sections from the contract proposals on traffic control and sequence of operations, available traffic control plans, and selected pages from construction diaries. This information was supplemented by verbal descriptions of the projects from District Traffic Engineers, Resident Engineers, and Project Engineers. Two of the projects that were underway were visited and photographed.

Accident data were obtained for 10 projects from the Georgia Department of Transportation. Hard copies of all during accidents were obtained, however, before data consisted only of group summaries. Additional accident information on one of the projects was obtained from Dekalb County Police Department. Accident data from one project were not available, dropping the project from the study.

Minnesota

Ten projects were selected in Minnesota. The projects were selected at the State Highway Office in St. Paul. Data available at the central office included proposals, and construction plans. Five of the district highway departments were also visited to collect Traffic Control Orders for the chosen projects. These orders were prepared by the District Traffic

Engineers, and specify traffic control on the project. For some projects, these orders were quite extensive. Also the projects were discussed with district traffic engineers, project engineers, and construction inspectors. Four of the projects were visited and photographed. Also photologs of two projects were observed.

The second trip to the Minnesota Highway Department took place May 24-26, 1976. Traffic Control Orders not available on the first visit were collected. Data from one additional project, an interstate median reconstruction project, were collected from the St. Paul district office.

Hard copies of all accidents during construction were obtained from traffic accident system personnel. Computer listings of accidents occurring before construction were also obtained.

Colorado

Construction data from nine projects were obtained on the initial trip to the Colorado Department of Highways, April 5-9, 1976. The data were obtained from the district offices. Although the traffic control data were not as extensive as anticipated several pieces of information from each project were obtained that outline the basic traffic control used in each project. This information included: preconstruction conference notes, the contractor's letter of proposed method of traffic control, progress schedules, and inspector's reports.

The second visit to the Colorado Department of Highways took place May 4-6, 1976. Construction data from two projects were obtained. Documentation of traffic control on these projects was fair to poor. Supplemental data (plans and project diary entries) from several of the projects chosen in the initial trip were also obtained. The traffic accident system personnel at state headquarters furnished hard copies of all accidents during construction and a computer listing of all before accidents.

Michigan

Construction data from 11 projects were obtained on the trip to the Michigan Department of State Highways and Transportation, April 20-23, 1976. Information on the traffic control in construction zones is not well documented but the Construction Proposal contains a section providing for the maintenance of traffic within the zone. A copy of the section was obtained for each zone. Additionally, traffic control plans were obtained if such plans existed.

Computer printouts of before and during accidents were also obtained listing the location, time, and other characteristics of the accidents. Accident hard copies were obtained from the Michigan State Police.

Washington

Nine projects were selected from a district office in Washington. The selections were made with the assistance of district construction and traffic people. Construction zone data was then collected from six project offices. The information obtainable in the project offices varied widely, but was basically good to excellent. In general the information included vicinity maps, inspection logs, sign logs, and traffic control plans.

Accident data summaries for all projects were obtained through correspondence and telephone conversations. Hard copy reports were obtained for during accidents.

New York

Construction data on 11 projects were obtained. The data were gathered at three regional offices. Six of the projects were visited and photographed. The engineer-in-charge of each project was interviewed by phone or during the visit to the project.

On the second visit to New York, an additional project was obtained based on a recommendation by the FHwA District Engineer. Accident data on 10 of 12 projects were received from the NYDOT. The other projects were on parkways and data were received directly from parkway authorities. For the three projects in New York City data were requested from both the NYDOT and the NYC Department of Traffic. Hard copy reports for three projects were obtained from the NYDOT.

APPENDIX C

CONSTRUCTION TRAFFIC CONTROL COSTS

The tables in this Appendix give costs of various construction zone traffic control methods and devices. The Table C-1 contains data for average statewide costs. California cost data were taken from the 1974 California contracts cost data book.

Table C-2 contains data on projects in the accident study obtained during the state visits.

TABLE C-1

AVERAGE COST DATA INFORMATION

Source	Date	Item Description	Quantity	Average Price Per Unit	Total Amount
California	1974	Portable Timber Barricade (Class I)	1,237.0	62.2231	76,970.00
		Portable Timber Barricade (Class II)	6.0	15.0000	90.00
		Timber Barricade (Left in Place)	66.0	38.3333	2,530.00
		Temporary Gate	1	200.0000	200.00
		Temporary Metal Beam Guard Railing	156.0	15.0000/linear ft	2,340.00
		Temporary Railing (Type K)	1,300.0	7.1077/linear ft	9,240.00
		Temporary Metal Beam Guard Railing	7,691.0	8.1139/ linear ft	62,404.00
		Temporary Cable Anchor Assembly	71.0	165.5634	11,755.00
		Temporary Cable Anchor Assembly (Breakaway)	6.0	390.0000	2,340.00
		Temporary Railing (Type H) [Apparently all temporary railing consists of steel rail elements supported on timber or steel posts]	5,971.0	9.8589/ linear ft	58,867.40
		Temporary Railing (Type K)	88,407.0	8.7529/ linear ft	773,816.00
		Temporary Railing (Type L)	5,140.0	10,4971/ linear ft	53,955.00
		Temporary Railing (Type M)	3,808.0	15.000/linear ft	57,120.00
		Temporary Fence	280.0	2.000/linear ft	560.00
		Temporary Fence (Type BW) 'Barbed Wire'	11,300.0	3.0000/ linear ft	33,900.00
		Temporary Fence (Type WM) 'Wire Mesh'	3,500.0	3.0000/ linear ft	10,500.00
		Temporary Chain Link Fence (Type CL-6) 'chain link with 6 ft. fabric width'	2,395.0	2.0000/ linear ft	4,790.00
		Temporary Headlight Glare Screen	3,600.0	1.5000	5,400.00
		Temporary Single Metal Beam Barrier	320.0	3.0000/ linear ft	960.00
		Temporary Double Metal Beam Barrier	3,630.0	7.8237/ linear ft	28,400.00
		Traffic Delineator	275.0	15.6545	4,305.00
		Self Erecting Delineator	148.0	11.4189	1,690.00
		Portable Delineator	12.0	10.0000	120.00
		Flashing Beacon (Portable)	44.0	553.0000	24,332.00
		Temporary Pavement Marker	17,582.0	3.0403	53,454.00
		Temporary Pavement Marker (nonreflective)	5,100.0	2.0000	10,200.00
		Temporary Pavement Marker (reflective)	2,700.0	4.0000	10,800.00
		Temporary Type A Pavement Marker (nonreflective white markers)	25,800.0	1.4349	37,020.00
		Temporary Type C Pavement Marker (Red-clear reflective markers)	5,140.0	3.5058	18,020.00
		Temporary Type D Pavement Marker (2-way yellow reflective markers)	2,700.0	2.0000	5,400.00
		Temporary Type G Pavement Marker (one-way clear reflective markers)	400.0	2.0000	800.00
		Temporary Type H Pavement Marker (one-way yellow reflective markers)	8,240.0	2.5413	20,940.00
		Temporary Type AY Pavement Marker (nonreflective yellow markers)	11,200.0	0.7000	7,840.00
		Temporary Guide Marker	408.0	11.1275	4,540.00
		Temporary Detour Culvert	534.0	16.0000/ linear ft	8,544.00
		12 in. Temporary Detour Culvert	3,270.0	5.5642	18,195.00
		24 in. Temporary Detour Culvert	734.0	12.0163	8,820.00
		36 in. Temporary Detour Culvert	1,134.0	18.9083	21,442.00
		84 in. Temporary Detour Culvert	450.0	51.0000	22,950.00
		Install Temporary Railing	166.0	10.0000/ linear ft	1,660.00
		Install Temporary Sign	211.0	42.2275	8,910.00
Colorado	1975	Flagging (hr)	236,430	7.2465/hr	1,713,282.70
		Pilot Car Operation (hr)	300	5.0000/hr	1,500.00
		Traffic Control Supervision (day)	2,580	120.2716/day	310,300.80
Minnesota	March 1976	Engineer's estimate 15% of total project costs to provide for traffic control.			
Minnesota	1976	2-way raised yellow pavement markers		2.07/each	

NOT REPRODUCIBLE

TABLE C-2

PROJECT COST DATA

Project	Total Project Cost	Date	Item Description	Quantity	Cost Per Unit ($)	Total Cost	% of Total Project Cost
Colorado 1	2,198,502.37	4/75	Flagging	3,000 hr	$7.50/hr	$22,500	1.023
Colorado 2	5,582,437.69	4/75	Flagging	4,000 hr	8.00/hr	32,000	0.573
			Traffic Control Supervision	200 days	100/day	20,000	0.358
Colorado 3	2,451,766.57	5/74	Flagging	4,000 hr	8.50/hr	34,000	1.387
			Flagging	1,000 hr	7.00/hr	7,000	0.286
			Construction Traffic Signing			5,000	0.204
Colorado 4	294,762.35	1/75	Flagging	1,500 hr	8.00/hr	12,000	4.071
			Traffic Control Supervision	90 days	90/day	8,100	2.748
Colorado 5	724,242.62	10/74	Flagging	1,000 hr	7.50/hr	7,500	1.036
			Traffic Control Supervision	90 days	95/day	8,550	1.181
			Construction Traffic Signing			500	0.069
Colorado 6	388,019.76	4/75	Flagging	1,500 hr	3/hr	4,500	1.160
			Traffic Control Supervision	80 days	100/day	8,000	2.062
			Construction Signing and Striping			3,000	0.773
Colorado 7	3,580,014.08	5/75	Flagging	5,000 hr	9/hr	45,000	1.257
			Traffic Control Supervision	180 days	100/day	18,000	0.503
Colorado 8	3,271,498.69	4/75	Flagging	3,000 hr	7.50/hr	22,500	0.688
			Signing			200	0.006
Colorado 9	6,671,084.30	12/73	Flagging	3,500 hr	7.25/hr	25,375	0.380
			Flagging	3,000 hr	7/hr	21,000	0.315
			Signing			2,000	0.030
*Colorado 10	663,360.48	2/75	Flagging	4,000 hr	7.50/hr	30,000	4.522
Colorado 11	2,634,172.60	4/74					
Georgia 4		3/75	Precast portable concrete barriers (installed)		40/linear ft		
Georgia 9	1,800,000.00	9/75					
Michigan 1	1,559,524	7/74	Traffic Control			50,000	3.206
Michigan 2	846,478.65	9/74	Traffic Control			20,000	2.363
**Michigan 3	1,345,831.56	1/75					
**Michigan 4	13,854,131.46	12/74					
Michigan 5	1,374,060.80	3/75	Traffic Control			20,420	1.486
Michigan 6	2,867,990	7/74	Traffic Control			90,000	3.138
**Michigan 7	588,849.37	4/75					
Michigan 8	2,316,792	4/75	Traffic Control			65,000	2.806
**Michigan 9	991,357.65	4/75					
**Michigan 10	2,812,215.76	8/74					
New York 12	3,117,931.64	2/74	Basic Maintenance and Protection of Traffic			128,355	4.117
			Construction Signs			13,500	0.433
			Delineation and Guiding Devices for Construction			19,133	0.614
			Construction Barricades			37,916.80	1.216
			Watchman Service			57,801.25	1.854

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* Figures represent only one of three separate projects combined to form Colorado 10.

** Figures obtained from Report of Awards.

NOT REPRODUCIBLE

APPENDIX D

USER COSTS DUE TO CONSTRUCTION

This Appendix discusses the development of user costs associated with construction activities. The user cost factors that are given directly are travel time delay in vehicle-hours of delay per day and excess fuel consumed in gallons of fuel per day. Costs are determined from these factors by specifying the unit value of vehicle delays and the costs of fuel.

This Appendix first summarizes the various formulas and values used for the determination of delays and fuel consumption, and then presents the reasoning, assumptions and data used in developing the formulas.

1. Summary: Five typical construction zone configurations are specified, based on the roadway type before construction and the number of lanes open during construction. The zone configurations considered are as follows:

1. Two-way, two-lane roadway reduced to one lane with alternating directions of traffic.
2. Two unidirectional lanes reduced to one lane.
3. Two-way, four-lane, divided highway reduced to two-way, two-lane.
4. Three unidirectional lanes reduced to two lanes.
5. Three unidirectional lanes reduced to one lane.

Formulas for vehicle-hours of delay and excess fuel consumed were developed from curve fits for configurations 1 and 2 only. Data are presented that could be used to develop formulas for the delay and fuel consumed for the other three configurations.

Five area type-closure schedule combinations are considered for each zone configuration. These are shown in Table D-1. The information necessary to develop formulas for other scheduling alternatives can be found in the following sections.

a. Two-lane, two-way highway reduced to one lane (Configuration 1): On a two-lane, two-way highway reduced to one lane with alternating directions of traffic the formulas for delay and excess fuel consumed are as follows:

Vehicle Hours of Delay

$$D = [(C_1A + C_2A^2 + C_3A^3)/(d_o + d_1A)]\ell$$

where

D = Vehicle-hours of delay per day,

A = ADT/1,000 (both directions summed), and

ℓ = Length of one-lane section (miles).

Table D-2 provides the coefficient values.

TABLE D-1

AREA TYPE - CLOSURE SCHEDULE COMBINATIONS

Code	Area Type	Lane Closure Schedule
U-1	Urban	Lanes closed 24 hr a day
U-2	Urban	Lanes closed at all times except 6 to 8 AM and 3 to 6 PM
U-3	Urban	Lanes closed 8 AM to 3 PM
R-1	Rural	Lanes closed 24 hr a day
R-2	Rural	Lanes closed 8 AM to 4 PM

TABLE D-2

COEFFICIENTS FOR DELAY EQUATION (Configuration 1)

Area Closure Schedule Code	Schedule	C_1	C_2	C_3	d_o	d_1
U-1	All 24 hr	1055.23	-24.0705	-0.527063	23.0	-1.0
U-2	6 to 8 AM and 3 to 6 PM	30.708	0.007222	0.038444	1.0	0.0
U-3	8 AM to 3 PM	17.0173	-0.004555	0.026622	1.0	0.0
R-1	All 24 hr	1055.23	-24.0705	-0.527063	23.0	-1.0
R-2	8 AM to 4 PM	24.650	0.508656	0.074933	1.0	0.0

Excess Fuel Consumed

$$G = C_1A + C_2A^2 + C_3A^3 + C_ID$$

where G = Excess gallons of fuel consumed per day,

A = ADT/1,000 (both directions summed),

C_I = Average consumption at idle, gal/vehicle-hour, and

D = Vehicle-hours of delay per day.

Table D-3 gives the coefficient values.

TABLE D-3

COEFFICIENTS FOR EXCESS FUEL CONSUMPTION EQUATION (Configuration 1)

Area Closure Schedule Code	Closure	C_1	C_2	C_3
U-1	All 24 hr	$22.35-8.5767\ell$ [a]	$-0.325+0.48907\ell$ [a]	-0.007787ℓ [a]
U-2	6 to 8 AM and 3 to 6 PM Excluded	$14.15-4.8047\ell$	$-0.165+0.16417\ell$	-0.000395ℓ
U-3	8 AM to 3 PM	$7.70-2.9876\ell$	$-0.100+0.15609\ell$	-0.002112ℓ
R-1	All 24 hr	$22.35-8.5767\ell$	$-0.325+0.4897\ell$	-0.007787ℓ
R-2	8 AM to 4 PM	$7.70-2.9876\ell$	$-0.100+0.15609\ell$	-0.002112ℓ

---

[a] The multiplier, ℓ, is the length of the one-lane section (miles).

The average fuel consumption at idle, C_I, is 0.376 gal/vehicle-hour for the traffic composition including 10% trucks.

b. Two unidirectional lanes reduced to one unidirectional lane (Configuration 2): On a highway with two unidirectional lanes reduced to one unidirectional lane, the formulas for delay and excess fuel consumed are as follows:

Vehicle Hours of Delay

$$D = C_o + C_1A + C_2A^2 + C_3A^3$$

where D = Vehicle-hours of delay per day

A = ADT/1,000 (ADT in the direction affected)

Table D-4 presents the coefficient values.

Excess Fuel Consumed

$$G = C_o + C_1A + C_2A^2 + C_3A^3$$

where G = Excess fuel consumed (gallons/day)

A = ADT/1,000 (ADT in direction affected)

Table D-5 provides the coefficient values.

2. Development of delay formulas for two-way two-lane highway reduced to one-lane with alternating traffic (Configuration 1): In this configuration one direction of traffic is stopped while vehicles traveling in the opposite direction travel through the one-lane portion of the roadway. Figure D-1 is a diagram of a typical work site of this configuration. Traffic control is normally accomplished by flagmen or signals at each of the stop lines.

The operation of this type of zone, of course, is cyclic. A cycle of length T hours consists of four elements:

$$T = t_{c1} + t_t + t_{c2} + t_t$$

where t_{c1} = Time for released vehicles to clear stop line (hours), direction 1

t_{c2} = Time for released vehicles to clear stop line (hours), direction 2

t_t = Time for last of released vehicles to travel the one-way section (hours).

The types of delays that a vehicle may experience in this zone configuration are:

1. Stopped delays

2. Delays due to reduced speeds

TABLE D-4

COEFFICIENTS FOR THE DELAY EQUATION (Configuration 2)

Area Closure Schedule		Range				
Code	Closure	of A	Co	C1	C2	C3
U-1	All 24 hr	0 to 23	0	-0.39276ℓ a/	0.23930ℓ a/	0.003488ℓ a/
		23 to 30 b/	39,675	-3450.0-0.39276ℓ	75.0+0.23930ℓ	0.003488ℓ
U-2	6 to 8 AM and 3 to 6 PM Excluded	0 to 35	0	0.147755ℓ	0.073776ℓ	0.002554ℓ
		35 to 38	28,175	-1610.0+0.14775ℓ	23.0+0.073776ℓ	0.002554ℓ
U-3	8 AM to 3 PM	0 to 35	0	0.13767ℓ	0.038042ℓ	0.001949ℓ
		35 to 38	52,307	-2989+0.13767ℓ	42.7+0.038042ℓ	0.001949ℓ
R-1	All 24 hr	0 to 23	0	-0.39276ℓ	0.23930ℓ	0.003488ℓ
		23 to 30 b/	39,675	-3450.0-0.39276ℓ	75.0+0.23930ℓ	0.003488ℓ
R-2	8 AM to 4 PM	0 to 35	0	0.13767ℓ	0.038042ℓ	0.001949ℓ
		35 to 38	52,307	-2989+0.13767ℓ	42.7+0.038042ℓ	0.001949ℓ

---

a/ The multiplier, ℓ, is the length of the one-lane section plus 0.20 (miles).

b/ The 24-hr closure is very undesirable at A >30 because of long queues and long delays per vehicle.

TABLE D-5

COEFFICIENTS FOR EXCESS FUEL CONSUMPTION EQUATION (Configuration 2)

Area Closure Schedule Code	Closure	Range of A	C_o	C_1	C_2	C_3
U-1	All 24 hr	0 to 23	0	$1.99482+1.18790\ell$ [a]	$0.40671-0.78473\ell$ [a]	$0.003178+0.014194\ell$ [a]
		23 to 30 [b]	$39675\ C_I$ [c]	$1.99482+1.18790\ell\ -3450\ C_I$ [c]	$0.40671-0.78473\ell\ +75.0\ C_I$ [c]	$0.003178+0.014194\ell$
U-2	6 to 8 AM and 3 to 6 PM Excluded	0 to 35	0	$-0.032732+1.21555\ell$	$0.34387-0.45329\ell$	$-0.002561+0.006874\ell$
		35 to 38	$28175\ C_I$	$-0.032732+1.21555\ell-1610\ C_I$	$0.34387-0.45329\ell+23.0\ C_I$	$-0.002561+0.006874\ell$
U-3	8 AM to 3 PM	0 to 35	0	$0.24635+0.87530\ell$	$0.18055-0.29866\ell$	$-0.000919+0.004813\ell$
		35 to 38	$52307\ C_I$	$0.24635+0.87530\ell-2989\ C_I$	$0.18055-0.29866\ell+42.7\ C_I$	$-0.000919+0.004813\ell$
R-1	All 24 hr	0 to 23	0	$1.99482+1.18790\ell$	$0.40671-0.78473\ell$	$0.003178+0.014194\ell$
		23 to 30 [b]	$39675\ C_I$	$1.99482+1.18790\ell - 3450\ C_I$	$0.40671-0.78473\ell\ +75.0\ C_I$	$0.003178+0.014194\ell$
R-2	8 AM to 4 PM	0 to 35	0	$0.24635+0.87530\ell$	$0.18055-0.29866\ell$	$-0.000919+0.004813\ell$
		35 to 38	$52307\ C_I$	$0.24635+0.87530\ell-2989\ C_I$	$0.18055-0.29866\ell+42.7\ C_I$	$-0.000919+0.004813\ell$

---

a/ The multiplier, ℓ, is the construction zone length plus 0.2 (miles).

b/ The 24-hr closures (U-1 and R-1) are undesirable for ADT$>$30,000 because queues lengths and delays will be excessive.

c/ The multiplier, C_I, is the average fuel consumption at idle (gal/vehicle hr). C_I is 0.376 gal/vehicle-hr for the traffic composition including 10% trucks.

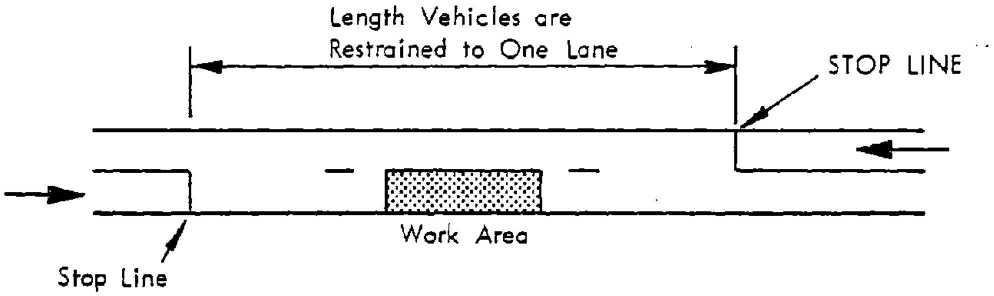


Figure D-1 - Two-Way, Two-Lane Highway Reduced to One Lane (Configuration 1)

The computation of the delays is dependent on the mode of operation of the zone. The two modes of operation are saturated and unsaturated. The distinction between these two modes is addressed next.

In general, the numbers of vehicles served during one cycle at saturation conditions are:

$$n_1 = t_{c1}{*}R, \text{ and}$$

$$n_2 = t_{c2}{*}R$$

where

n_1 = Number of direction 1 vehicles served in one cycle

n_2 = Number of direction 2 vehicles served in one cycle

R = Approach flow rate (vph) at intersection capacity

The total number of vehicles served per cycle is:

$$n_1 + n_2 = R(t_{c1} + t_{c2}).$$

But $(t_{c1} + t_{c2}) = T - 2t_t.$

Therefore $n_1 + n_2 = R(T - 2t_t).$

And, since there are $\frac{1}{T}$ cycles per hour, the volume served (vph) during saturated conditions is:

$$V_1 + V_2 = R\ (1 - 2t_t/T) \text{ vehicles/hour}$$

Clearly, the volume served is maximized by taking long cycles (large T). However, an upper limit on acceptable cycle length for drivers is about 5 min or 1/12 hr. This value is taken as the condition separating two modes of operation. This should reduce delay under those conditions. For demand volumes, $V_1 + V_2$, above $R\,[1 - 2t_t/(1/12)]$, the facility is saturated or oversaturated, and the cycle time T, of 1/12 hr will result in queues that will grow at each of the two approaches. For demand volumes less than that value the cycle period will be set by the demand.

When the cycle period, T, is set by the demand, the period t_c is sufficient to exhaust the queue in each direction.

Thus,

$$t_{c1} = V_1T/R, \text{ and}$$

$$t_{c2} = V_2T/R.$$

This simply states that the time required for the i^{th} direction vehicles to clear the stop line is sufficient to clear all vehicles that arrive in one cycle. Then, since

$$T = t_{c1} + t_{c2} + 2t_t = (V_1 + V_2)\ T/(R) + 2t_t,$$

$$T = \frac{2t_t}{1 - \frac{V_1 + V_2}{R}} .$$

This equation gives the desired cycle period under unsaturated conditions.

a. Delays due to stopping: We first consider the unsaturated case. For direction 1 the stopped delays during a cycle start when the period t_{c1} ends. We count time from that origin in the following development. Vehicles arrive at the rate V_1 per hour and are stopped. The first vehicle to arrive and be stopped is released after time $(t_{c2} + 2\ t_t)$. The last vehicle stopped in direction 1 crosses the stop line at time $(t_{c2} + 2t_t) + (t_{c2} + 2t_t)\cdot V_1R$, where the second term accounts for clearing time required for vehicles in the stopped queue after the first vehicle in the queue has been released. Note that some of the vehicles will not be forced to stop. The number of direction 1 vehicles per cycle that do not need to stop is

$$V_1[t_{c1} - (t_{c2} + 2t_t)V_1/R] .$$

Assuming constant arrival rates, the stopped delay per cycle in direction 1 is approximated as

$$1/2 \left\{(t_{c2} + 2t_t)(1 + \frac{V_1}{R})\right\}^2 V_1$$

The stopped delay time per cycle in direction 2 is obtained by substituting subscript 2 for 1 and vice versa. Then, the sum of the stopped delays in both directions is

$$\text{Stopped delay per cycle} = 1/2 \left\{(t_{c2} + 2t_t)(1 + \frac{V_1}{R})\right\}^2 V_1$$
$$+ 1/2 \left\{(t_{c1} + 2t_t)(1 + \frac{V_2}{R})\right\}^2 V_2$$

Eliminating t_{c1}, t_{c2} , and t_t using the previously developed expressions gives

$$\text{Stopped delay per cycle} = 1/2\ T^2 \left\{ V_1 \left[(1-\frac{V_1}{R})(1+\frac{V_1}{R}) \right]^2 + V_2 \left[(1-\frac{V_2}{R})(1+\frac{V_2}{R}) \right]^2 \right\}$$

Dividing this expression by T , the time per cycle, gives the delay expressed as vehicle-hours per hour. (This expression is applicable only for unsaturated flows.)

The value of R , the intersection capacity, was taken as $(1300)(1.30) \approx 1700$ vph, where 1300 is an approximation for several geometrics applicable to construction zones and the factor, 1.3, adjusts for no turns. Moreover, t_t can be expressed as the quotient of the length of the one-way section (miles) and the speed of vehicles on a one-way section (mph). This speed is always assumed to be 30 mph.

The above expression can be further simplified. Let $V = V_1 + V_2$, the total of the two approach volumes. For the special case where $V_1 = V_2$,

$$\text{Stopped delay} = \frac{T}{2} \left\{ V \left[(1-\frac{V}{2R})(1+\frac{V}{2R}) \right]^2 \right\} \text{ vehicle-hours/hour}$$

This represents a "worst case" as can be verified by examination of situations where $V_1 \neq V_2$. This is the case used in subsequent developments for <u>unsaturated flows</u>.

When vehicles arrive at a greater rate than can be served during the cycle, a queue forms. Under these conditions we treat the total queue in two parts. One is the queue to be served during the cycle, the served queue. The second is the wait queue--vehicles that must wait through one or more cycles.

The number of vehicles in the wait queue is the excess of arrivals over the number served at the saturation rate since oversaturation began. The number of such vehicles at any time, t , is

$$N_w(t) = \int_{t_0}^{t} [V(\tau) - V_s] d\tau$$

where $V(\tau)$ = Demand volume as function of time,

V_s = Saturation flow rate, and

t_o = Time when oversaturation began.

The stopped (or creeping) delay in the wait queue is

$$D_w(t) = \int_{t_o}^{t} N_w(t)dt \text{ vehicle-hours,}$$

where the integral is evaluated over all times when $N_w(t) \geq 0$. The total stopped delay accumulated during oversaturation is

$$D(t) = \int_{t_o}^{t} [D_{rs} + N_w(t)]dt$$

where D_{rs} = Rate (vehicle-hours/hour) that stopped delay is incurred in the served queue with saturated flows (T = 0.0833 hr), (Note that $D_{rs} = R(1-24t_t)$.)

b. Delay due to reduced speed: The reduced speed is 30 mph; otherwise the speed in rural areas would be $U = (50 - \frac{20}{2000} V)$ mph, where V = total of the two-way demands (vph).

This delay per vehicle is $\ell\left(\frac{1}{30} - \frac{1}{u}\right)$

where ℓ = length of one-way section (miles).

The total delay per hour due to reduced speed = $V\ell\left(\frac{1}{30} - \frac{1}{u}\right)$

Table D-6 gives reduced speed delay factors for given demands.

TABLE D-6

REDUCED SPEED DELAY FACTORS

Volume V (vph)	Normal Speed U (mph)	Delay/Mile $V\left(\frac{1}{30} - \frac{1}{U}\right)$ $\left(\frac{\text{Vehicle-Hours}}{\text{Hour Mile}}\right)$
0	50	0
200	48	2.5
400	46	4.636
800	42	7.616
1200	38	8.424
1600	34	6.272
1800	32	3.749
1900	31	2.043
2000	30	0

c. Total delay data: Using the delay equation developed for unsaturated conditions the two-direction sum of stopped delays was computed. This equation was used to compute delays at all volumes, since the definition of saturated conditions depends on travel time, t_t , and thus the length of the work site. If the volumes shown represent saturated or oversaturated conditions, the delays will of course be underestimated.

The computed values are plotted in Figures D-2 and D-3. In Figure D-2 the values of delay due to reduced speeds were also added and the total is shown as a dashed curve. This latter delay was found to be important at volumes up to 1400 vehicles per hour, and is not included in Figure D-3, which covers volumes of 1400 to 1700. The bottom curve is used for volumes of 1400 to 1620 and the top curve for volumes from 1630 to 1700.

The Highway Capacity Manual gives a breakdown of the average fraction of the ADT that can be expected during each hour of the day (Figure 3.6, p. 32). With this breakdown and the information from Figures D-2 and D-3 we can determine the daily delay for rural or urban conditions under a number of construction schedules.

Figure D-4 gives the computed delay versus ADT for schedule R-1 (lane closed 24 hr per day) or R-2 (lane closed 8 AM to 4 PM). Also shown are equations developed by curve fitting.

Figure D-5 gives the delay versus ADT under schedules U-1 (lane closed 24 hr per day), U-2 (lane closed all hours except 6 to 8 AM and 3 to 6 PM), and U-3 (lane closed 8 AM to 3 PM). Again, equations developed by curve fitting are given.

3. Development of delay formulas for multilane highways: Several construction zone configurations are commonly used on multilane highways. Four configurations considered here are shown in Figure D-6.

The vehicle-hours of delay in multilane construction zones arise from reduced speed and queuing. When queuing occurs, delays result from the stopped delay of vehicles and the reduced speed that the vehicles travel when going through the zone.

a. Reduced speeds: When capacity is not exceeded the delays are due entirely to reduced speeds. Let E be the delay vehicle-hours/hour) due to reduced speeds.

$$E = \ell\left(\frac{1}{u_r} - \frac{1}{u_n}\right)$$

where ℓ = Construction zone length (miles) + 0.20

u_r = Reduced speed in zone, and

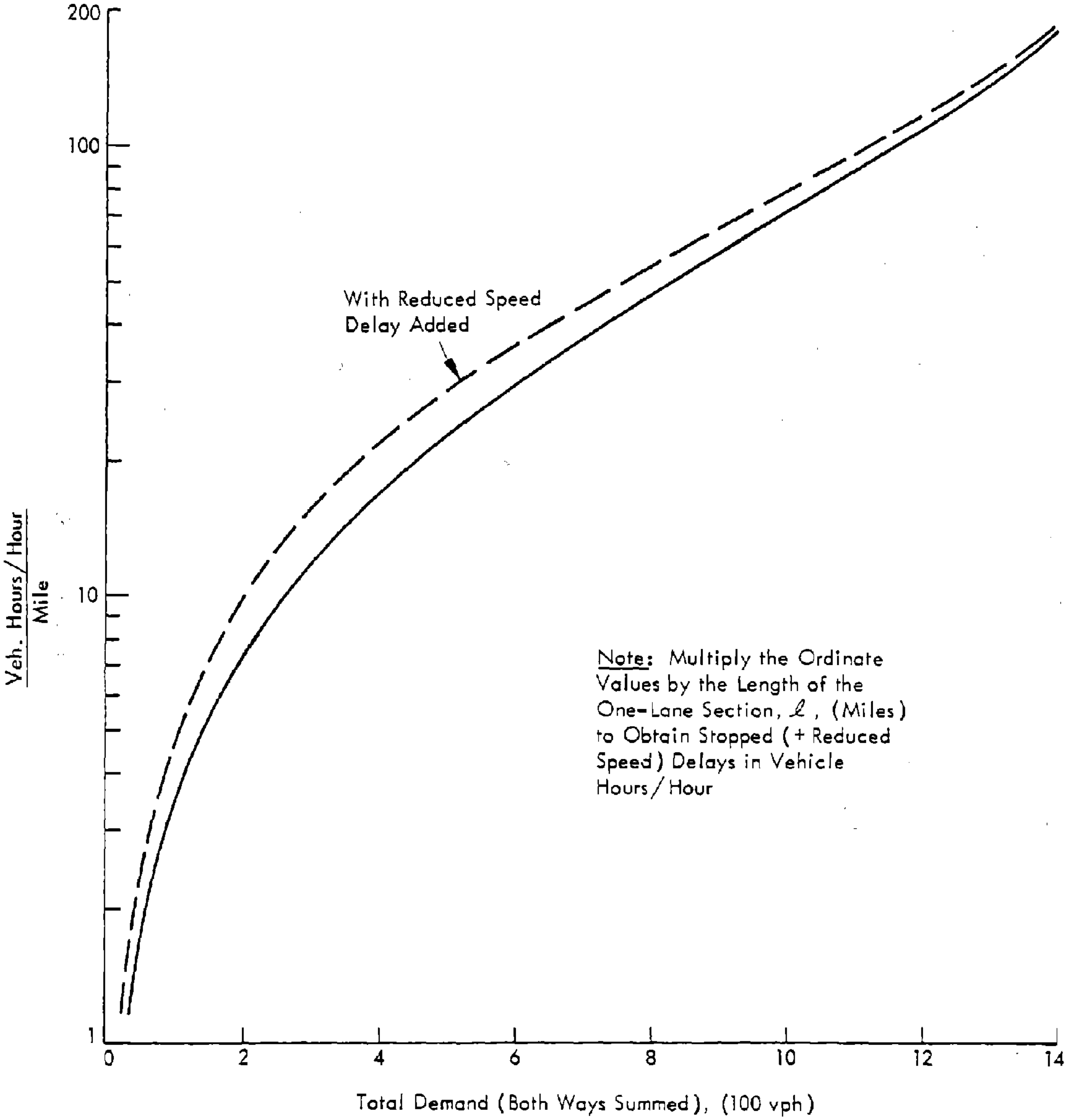


Figure D-2 - Stopped Delays, Configuration 1 for Volumes up to 1,400 vph

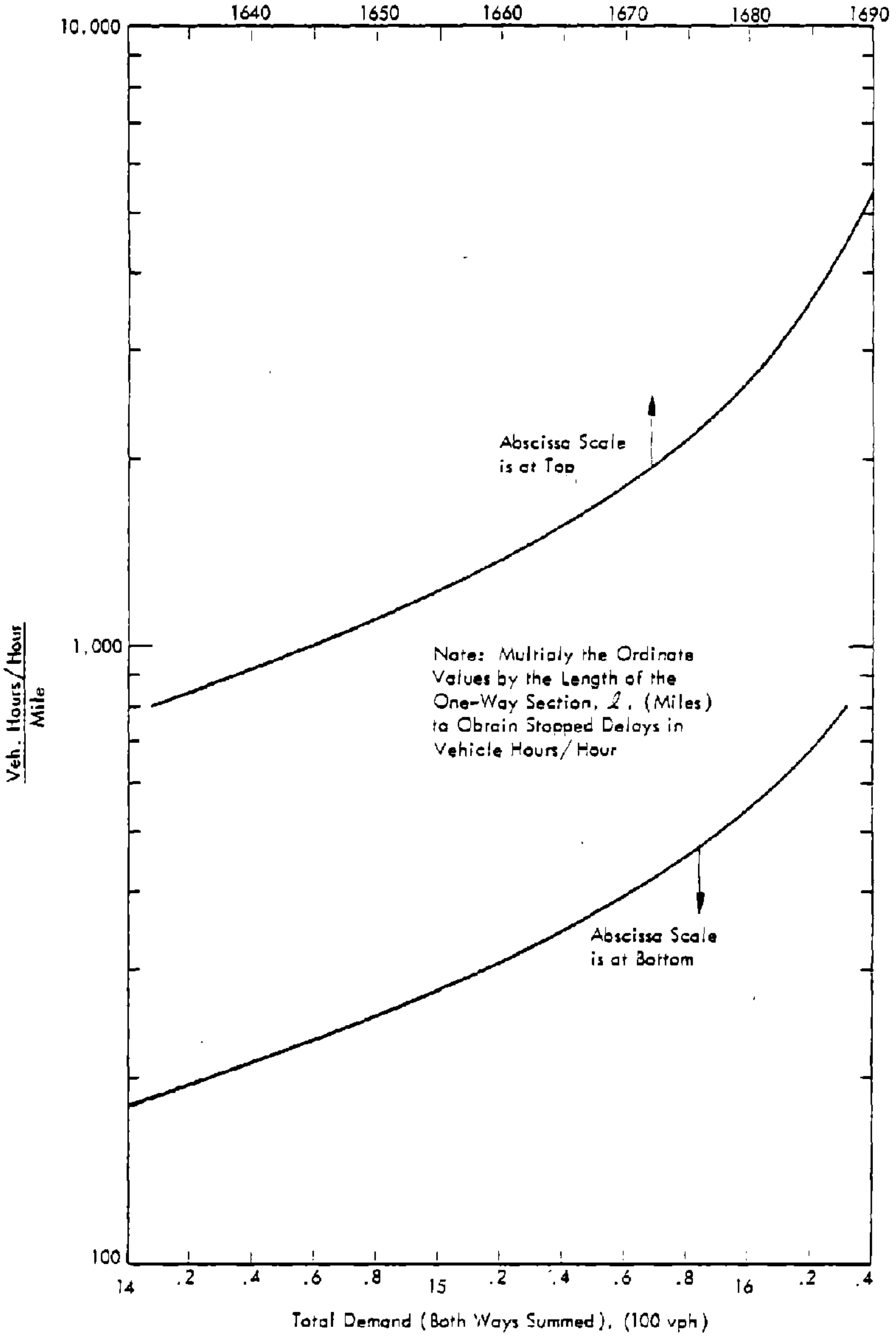


Figure D-3 - Stopped Delays, Configuration 1 for Volumes of 1,400 to 1,700 vph

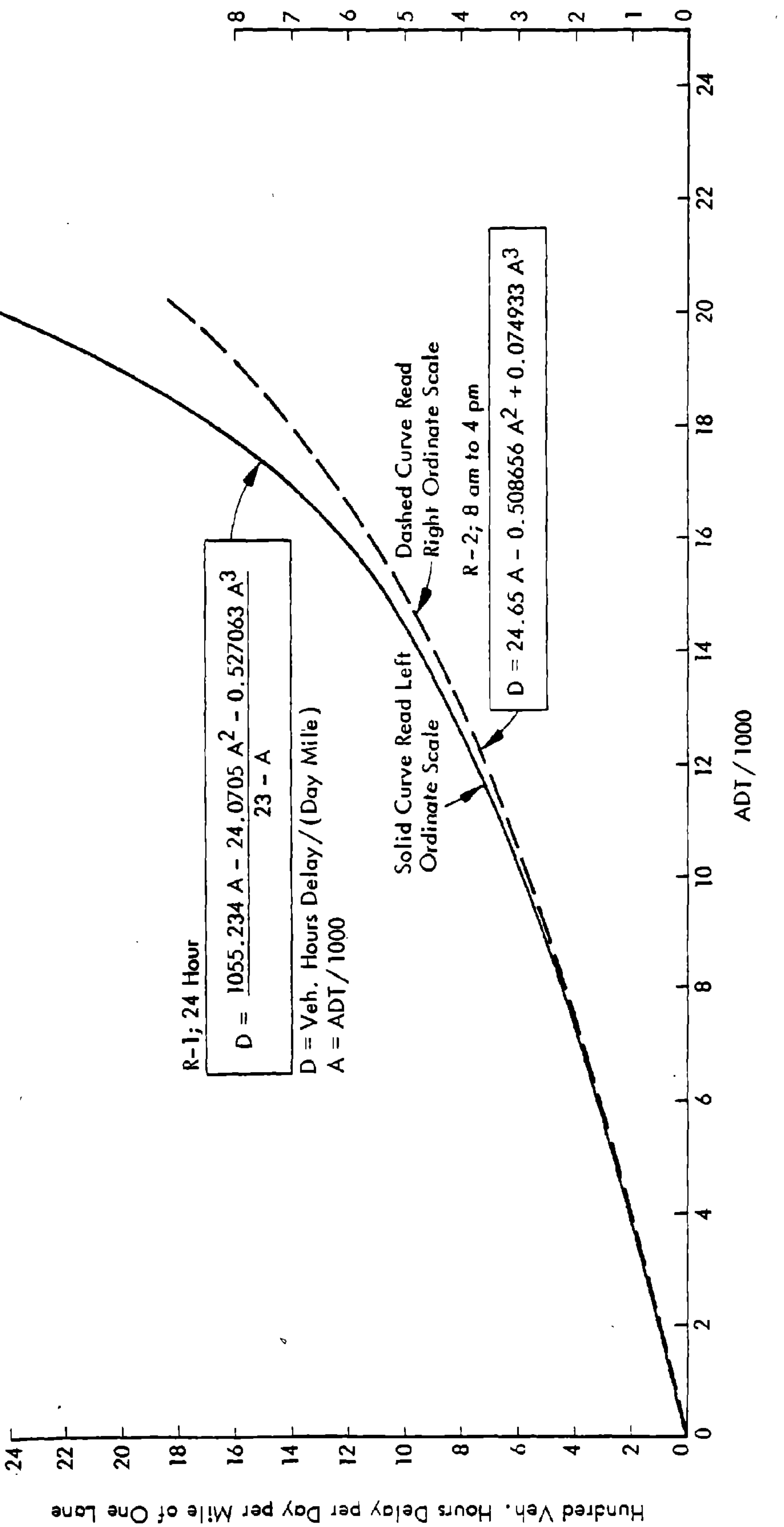


Figure D-4 - Stopped Delays, Configuration 1, Rural

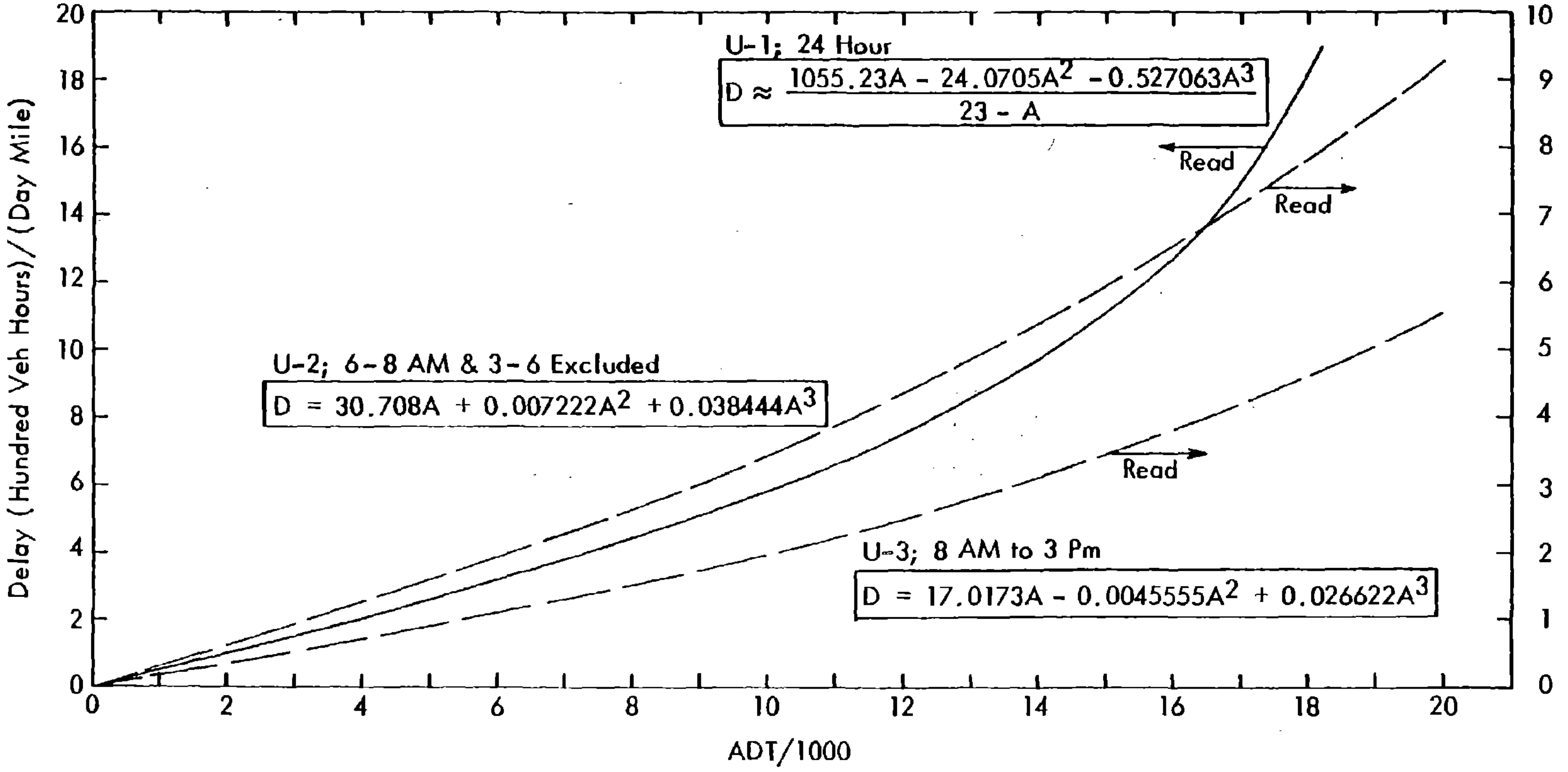
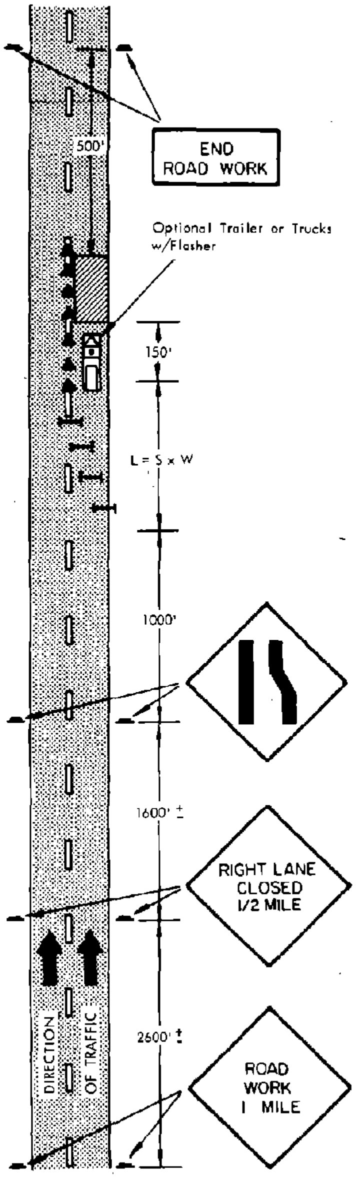
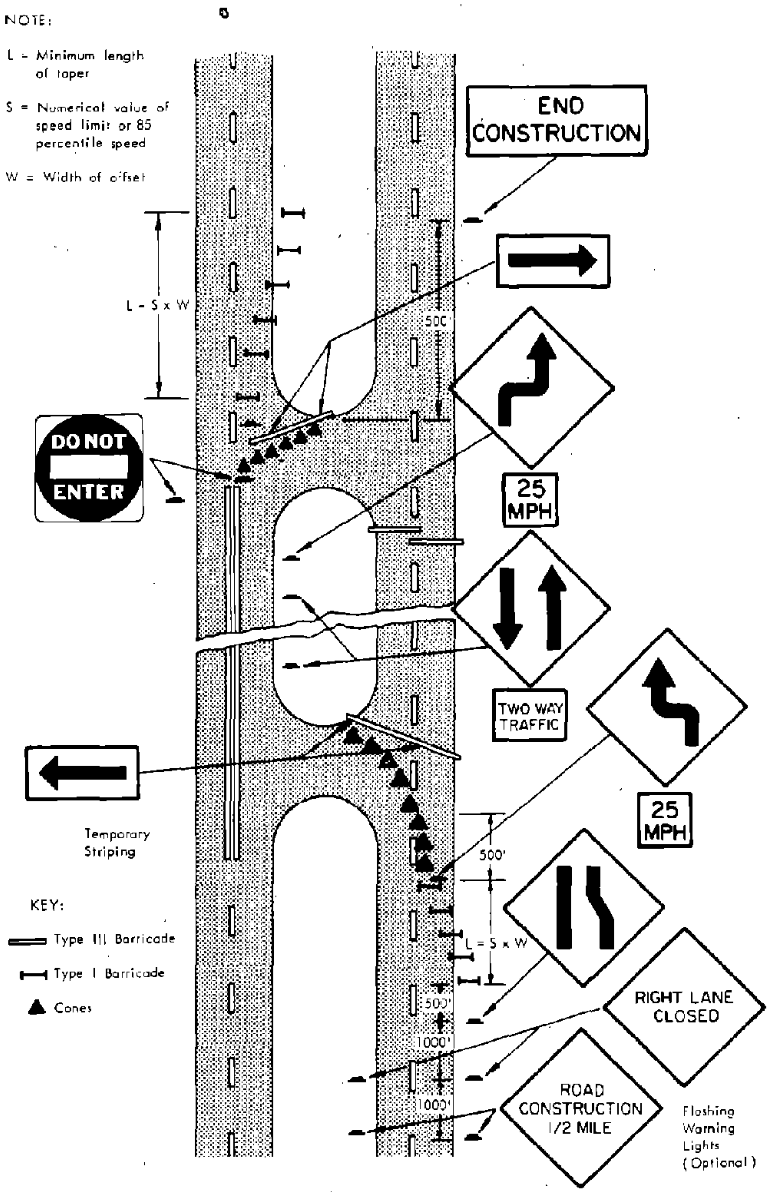


Figure D-5 - Stopped Delays, Configuration 1, Urban

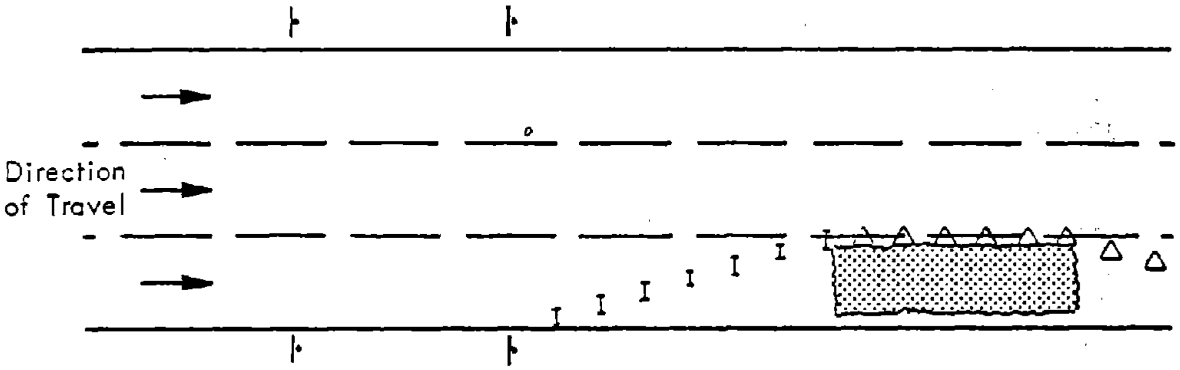


Two Unidirectional Lanes
Reduced to One Lane
(Configuration 2)

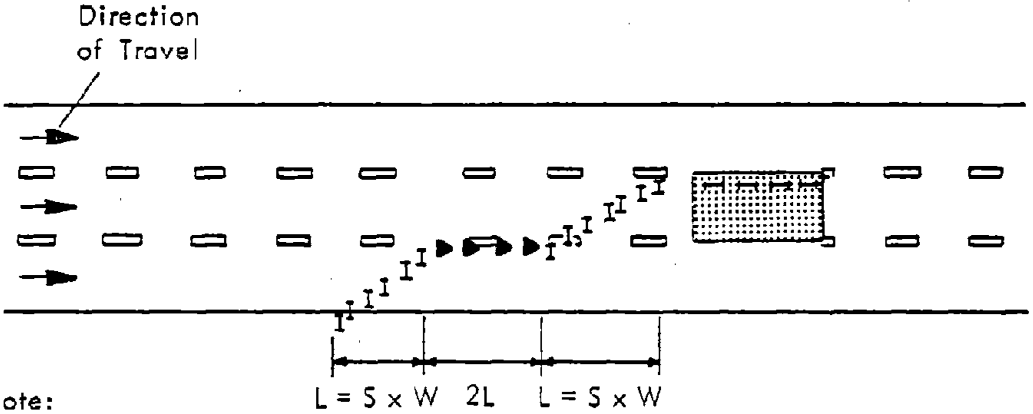


Two-way Four Lane Divided Highway
Reduced to Two-way Two Lane
(Configuration 3)

Figure D-6 - Multilane Construction Zone Configurations



Three Unidirectional Lanes Reduced to Two Lane
(Configuration 4)



Note:
L = Minimum length of taper
S = Numerical value of the speed limit or 85 percentile speed
W = Width of offset

Key:
⊢⊣ Type I Barricade
▲ Cone

Three Unidirectional Lanes Reduced to One Lane
(Configuration 5)

Figure D-6 (concluded)

u_n = Normal speed in zone.

The value, 0.20, is used as the average length of the taper, and u_r and u_n depend on the volume, V , which is less than capacity.

Figure D-7 shows the speeds of vehicles in the various configurations and during normal roadway operation. During the time queues are present u_n will depend on demand volume but u_r will be 30 mph for capacity flow conditions in the construction zone. Thus, the delay from reduced speeds when a queue is present is $E = \ell(1/30 - 1/u_n)$.

Using the above formula and the general data on hourly volumes and vehicle population given earlier, a representation of the delay in two unidirectional lanes reduced to one lane (configuration 2) was developed. The process used may be explained easily by an example. Referring to curve 1 in Figure D-7, the normal average speed u_n in a zone at one-eighth of capacity (0.125) would be 55 mph. Using curve 3 in Figure D-7, the reduced average speed u_r would be 50. The last two columns of Table D-7 gives the results of calculations of delays, with and without queue dissipation, for various volumes. A plot of the information in Table D-7 is shown in Figure D-8.

Figure D-8 and the traffic demands in 1-hr periods of a day (from the Highway Capacity Manual) were then used to develop the hourly vehicle delays experienced in each mile of a construction zone due to reduced speeds. Figure D-9 is a plot of this information for schedules U-1, U-2 and U-3 (see Table D-1).

In Figure D-9 the coefficients are given for the best fit for each of the curves. These three curves represent the total delay for all times except when there are queues present. For example, on the U-1 curve the ADT where queues could be expected during some hours of the day ($V > 2,000$) is 23,000. This means that, for the U-1 schedule, stopped delay must be added for ADT's greater than 23,000. Thus, the U-1 coefficients shown can be used for ADT's ≤ 23,000. For the U-2 and U-3 curves, queues can be expected for ADT's of 35,000 and above.

b. Stopped delays: When queues are present, delays from stoppage in queues must be added to reduced speeds during queue dissipation. The computed values for these additional delays are shown in Table D-8. The value for stopped delays (ΔD_{wi}) was computed for each hour that queues are present from the formula:

$$\Delta D_{wi} = N_{io}\ (\Delta t) + (V_i - V_s)\frac{(\Delta t)^2}{2}\ ,$$

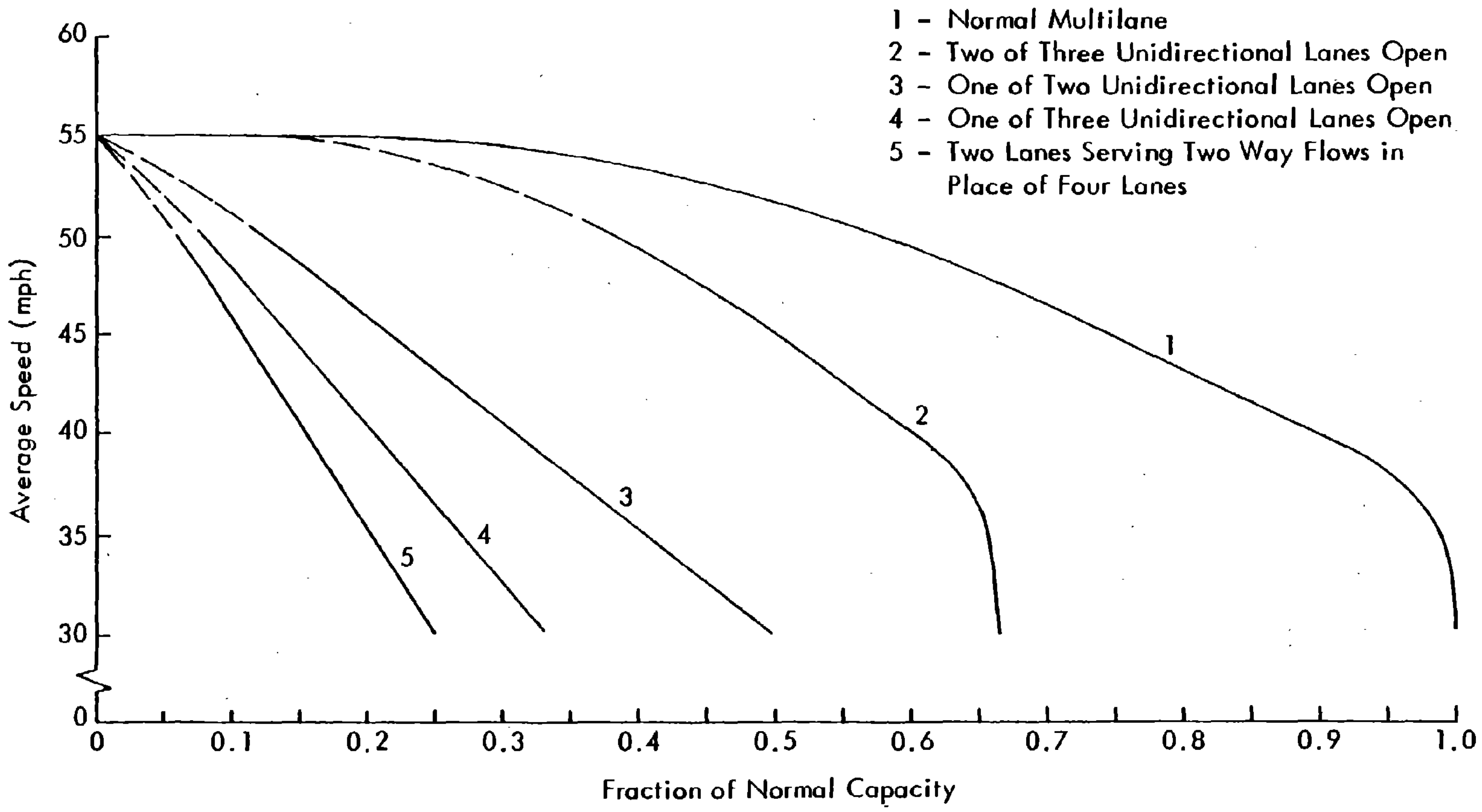


Figure D-7 - Speed Capacity Relationships, Multilane Facilities

TABLE D-7

DELAYS FROM REDUCED SPEEDS (CONFIGURATION 2)

Fraction of Normal Capacity	Volume V (vph)	Reduced Speed U_r (mph)	Normal Speed U_n (mph)	Delay $\left(\frac{1}{U_r} - \frac{1}{U_n}\right) V$ $\left(\frac{\text{Vehicle-Hours}}{\text{Hour Mile}}\right)$	Delay During Queue Dissipation $\left(\frac{1}{U_r} - \frac{1}{U_n}\right) V$ With $U_n = 30$
0	0	50	55	0	0
0.125	500	50	55	0.9091	7.576
0.200	800	46	55	2.8458	12.121
0.300	1200	40.6	54.4	7.4978	17.941
0.400	1600	35.3	53.3	15.3070	23.315
0.500	2000	30.0	51.6	27.9070	Queue is not dissipating for these volumes.
0.600	2400	30.0	49.3	31.3186	
0.700	2800	30.0	46.4	32.9885	
0.800	3200	30.0	43.3	32.7635	
0.900	3600	30.0	39.9	29.7745	
0.950	3800	30.0	38.0	26.6665	
0.980	3920	30.0	36.0	21.7780	
0.990	3960	30.0	34.8	18.2069	
1.000	4000	30.0	30.0	0	

Notes: Capacity flow, V_s, taken as 2000 vph.
For $V > 2000$ vph, queue will increase.
After queue is normal but $V < 2000$ vph, U_n will remain at 30 mph until queue dissipates.

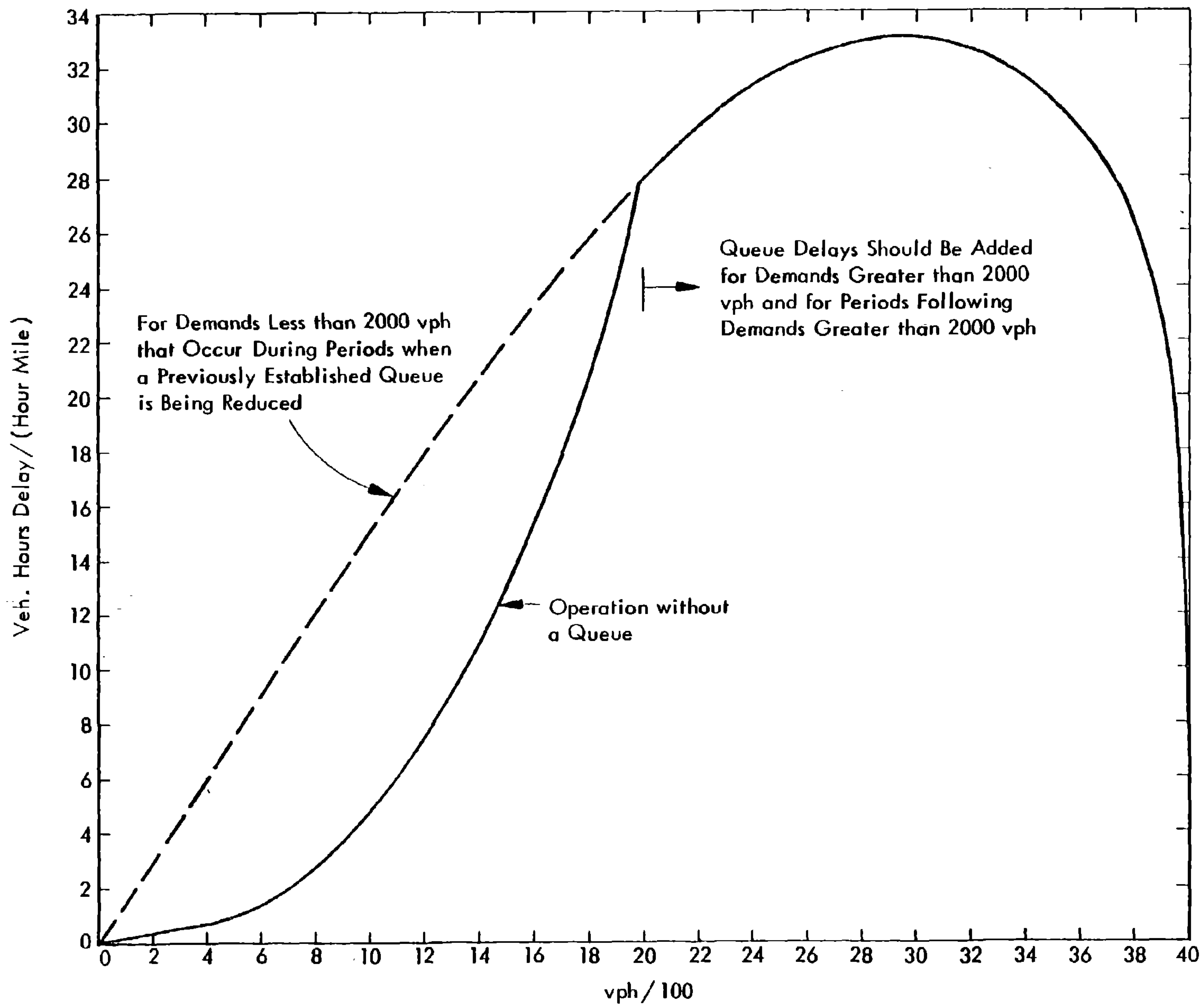
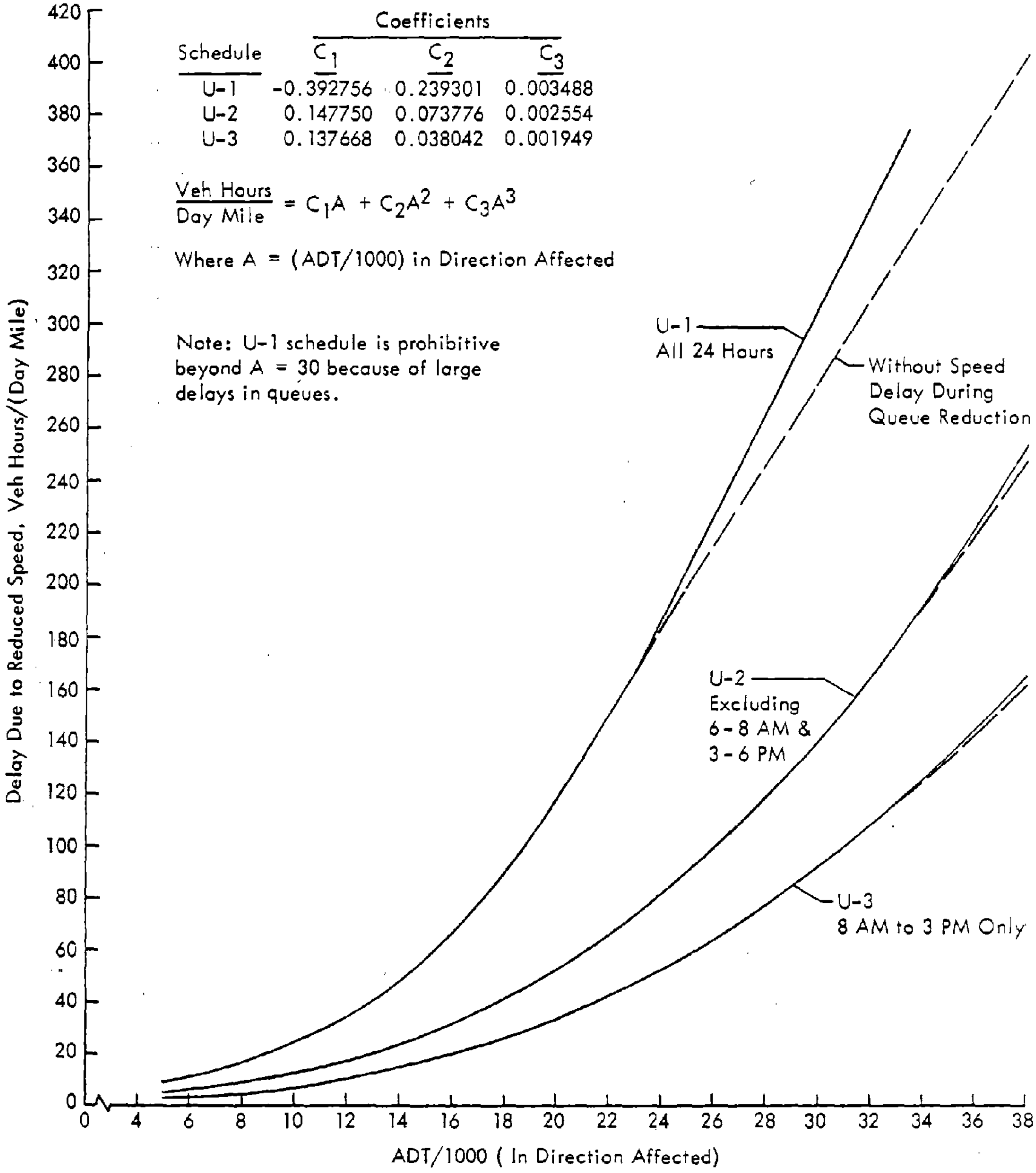


Figure D-8 - Vehicle-Hours of Delay Due to Reduced Speeds
(Configuration 2)



Schedule	Coefficients C_1	C_2	C_3
U-1	-0.392756	0.239301	0.003488
U-2	0.147750	0.073776	0.002554
U-3	0.137668	0.038042	0.001949

$$\frac{\text{Veh Hours}}{\text{Day Mile}} = C_1A + C_2A^2 + C_3A^3$$

Where A = (ADT/1000) in Direction Affected

Note: U-1 schedule is prohibitive beyond A = 30 because of large delays in queues.

Figure D-9 - Delays Due to Reduced Speeds, Configuration 2, Urban

TABLE D-8

DELAYS DUE TO STOPPAGE IN QUEUES AND REDUCED SPEEDS DURING QUEUE DISSIPATION FOR CONFIGURATION 2

Hour	Demand Hour Volume (vehicle/hour)	Stopped Delay in Queues ΔD_W (vehicle-hour)	Delay Due to Reduced Speeds During Queue Dissipation (vehicle-hour/mile)
ADT = 28,000 (U-1) (Note, effect on U-1 starts at 23,000 ADT.)			
7-8	2,128	64.0	
8-9	1,568	18.96	2.52
15-16	2,156	78.0	
16-17	2,436	374.0	
17-18	2,156	670.0	
18-19	1,484	490.0	9.30
19-20	1,344	41.02	3.54
		1,735.98	15.36
ADT = 33,000 (U-1)			
7-8	2,508	254.0	
8-9	1,848	432.0	3.95
9-10	1,485	123.04	6.36
15-16	2,541	270.5	
16-17	2,871	976.5	
17-18	2,541	1,669.0	
18-19	1,749	1,827.5	5.90
19-20	1,584	1,494.0	8.30
20-21	1,287	929.5	10.20
21-22	1,221	210.74	7.69
		8,186.78	42.40
ADT = 38,000 (U-3) (Note, effect on U-2 and U-3 starts at 35,090 ADT)			
8-9	2,128	64	
9-10	1,710	28.25	2.93
14-15	2,166	83.0	
15-16	2,926	12.83	1.95
		188.08	4.88
ADT = 38,000 (U-2 = U-3 from above, plus.)			
18-19	2,014	7.00	
19-20	1,824	0.56	0.37
		195.64	5.25

where N_{io} = Number of queued vehicles at the beginning of the i^{th} time intervals,

Δt = Duration of time interval (hours),

V_i = Demand (vph) during i^{th} time interval, and

V_s = Saturation (or capacity) flow (vph).

Moreover, $N_{io} = N_{(i-1)o} + (V_{i-1} - V_s)(\Delta t)$, and

$$N_{(i+1)o} = N_{io} + (V_i - V_s)(\Delta t)$$

During the interval that the queue dissipates,

$$\Delta t = \frac{N_{io}}{V_s - V_i}$$

and the stopped delay during that interval is:

$$N_{io}\ (\Delta t) + (V_i - V_s)\ \frac{(\Delta t)^2}{2} = \frac{(N_{io})^2}{2(V_s - V_i)}$$

The reduced speeds during the queue dissipation ($\Delta E_{i/\ell}$) are computed exactly as the delays due to reduced speeds except that u_r is always equal to 30 mph.

Approximating the values of ΔD_{wi} with a quadratic leads to the following forms:

U-1: $\Delta D_{wi} = 39675 - 3450A + 75A^2$; $A > 23$,

U-2: $\Delta D_{wi} = 28175 - 1610A + 23A^2$; $A > 35$, and

U-3: $\Delta D_{wi} = 52307 - 2989A + 42.7A^2$; $A > 35$

where

$$A = ADT/1000$$

Formulas for the R-1 and R-2 schedules can be approximated by using the U-1 coefficients for R-1 schedule and the U-3 coefficients for the R-2 schedule.

The addition of the formulas for stopped delay and the formulas for delay due to reduced speed result in the following form that approximates the total delay D:

where

$$D = C_o + C_1A + C_2A^2 + C_3A^3$$

D = Vehicle-hours of delay per day, and

A = ADT/1000 (ADT in the direction affected).

These are the coefficients given in Table D-4.

4. Development of formulas for excess fuel consumption: Fuel costs are the major component of increased operating expense and are the only costs treated here. Fuel costs can be affected by up to three factors. The first is a speed change cycle from the normal speed to a stop and back to normal speed. (This is applied for each vehicle although some will not need to stop.) The second is fuel consumed during idling while in the stopped delay. The third is the fuel consumed in traversing the construction zone minus the fuel that would have been used at normal speed. Note that the contributions of the individual factors may be negative.

In order to compute the excess amount of fuel consumed for various conditions, it was necessary to specify the percentage of passenger cars and trucks in the vehicle population. The specified vehicle population is 90% - passenger cars, 1% - 5,000 lb delivery trucks, 2% - 12,000 lb single unit trucks, and 7% - 40,000 lb gasoline-powered semitrailers or 50,000 lb diesel-powered semitrailers.

a. Excess fuel consumption formula for two-lane, two-way highway reduced to one-lane of alternating traffic: Table D-9 presents data needed to compute the excess fuel consumption due to speed change cycles and due to reduced speeds. Information in this table and the hourly volume data referenced earlier were used to compute the excess fuel consumed, plotted in Figure D-10.

The fuel consumption due to stopped delay is 0.376 gal. for every vehicle hour of stopped delay.

By combining equations that approximate the curves for excess fuel consumption due to speed change cycles and reduced speed plus the relationship for fuel consumption due to stopped delay we can determine the following formula for excess fuel consumed:

$$G = C_1A + C_2A^2 + C_3A^3 + C_ID$$

where

G = Excess gallons of fuel consumed per day,

A = ADT/1,000 (both directions summed),

C_I = Average consumption at idle, gallons/vehicle hour, and

D = Vehicle hours of delay per day.

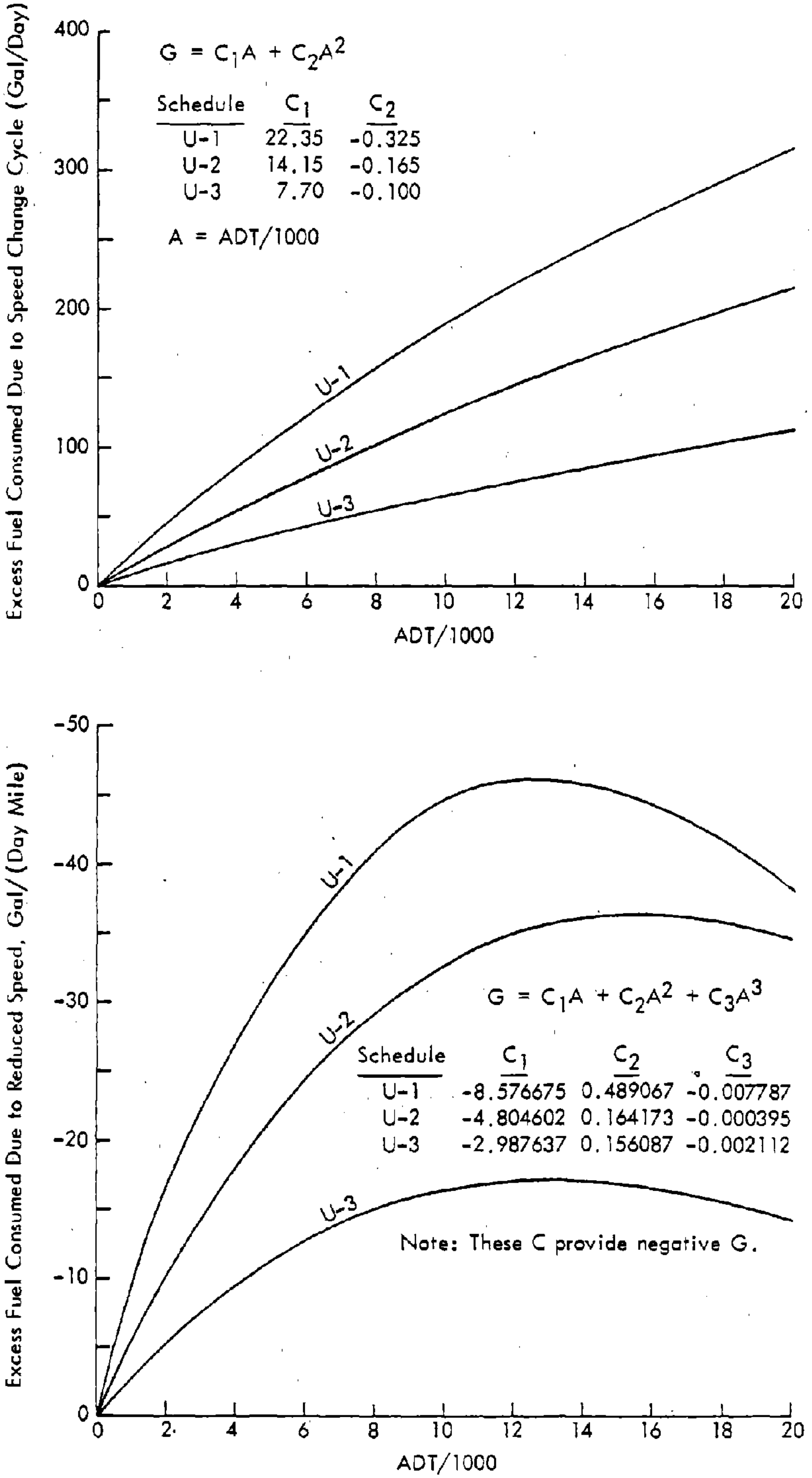


TABLE D-9

EXCESS FUEL CONSUMPTION, CONFIGURATION 1

Volume V (vph)	Normal Speed U_n (mph)	Excess Consumption Due to Speed Change Cycles (gal/hr)	Excess Consumption Due to Reduced Speed (gal/hr-mile)
0	50	0.	0
200	48	4.26	-1.38
400	46	8.00	-2.16
800	42	14.08	-2.40
1,200	38	18.36	-1.56
1,600	34	21.12	-0.32
1,800	32	21.78	0
2,000	30	22.20	0

Table D-3 gives the coefficient values.

b. Excess fuel consumption formula for two unidirectional lanes reduced to one unidirectional lane (Configuration 2): On multilane highways during periods when there is no queuing added fuel consumption arises from only two sources, a speed change cycle between the normal and reduced speed, and traversing the zone at a reduced speed. When queues are formed or are dissipating, all three factors are involved: a speed cycle from normal speed to stop and then back to normal; a lower than normal speed in the zone of 30 mph; and the fuel consumed during idling for the vehicle hours in queue. (Actually, the time in queues is spent at intermittant speeds less than 30 mph. This is a much higher fuel consumption condition than would occur during normal travel through the queue length. We approximate the difference by the idle consumption during time in the queue.)

Figure D-11 gives the excess fuel consumption due to speed change cycles. The dashed line includes the excess fuel consumed when queues formed in previous hours are being dissipated. Figure D-12 gives the excess fuel consumption due to reduced speeds. During queue dissipation the reduced speed, u_r , is always equal to 30 mph. This effect is accounted for in the dashed line in Figure D-12.

The information shown in Figures D-11 and D-12 was used along with the hourly volume breakdown in the Highway Capacity Manual to compute the data shown in Figure D-13. Equations were determined that approximate each of the curves shown. (The equations are given in Figure D-13.)

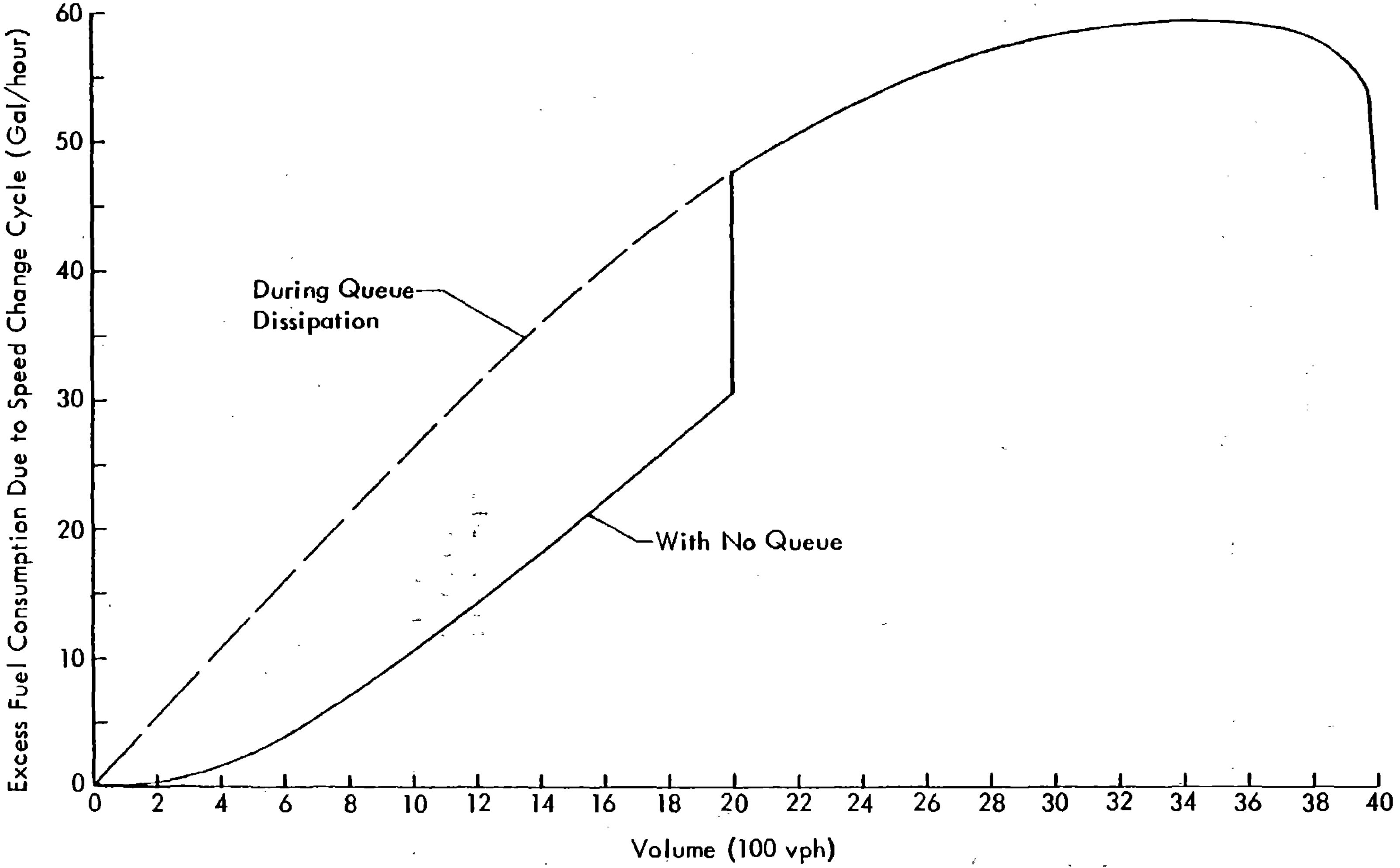


Figure D-11 - Excess Fuel Consumption Due to Speed Change Cycles, Configuration 2

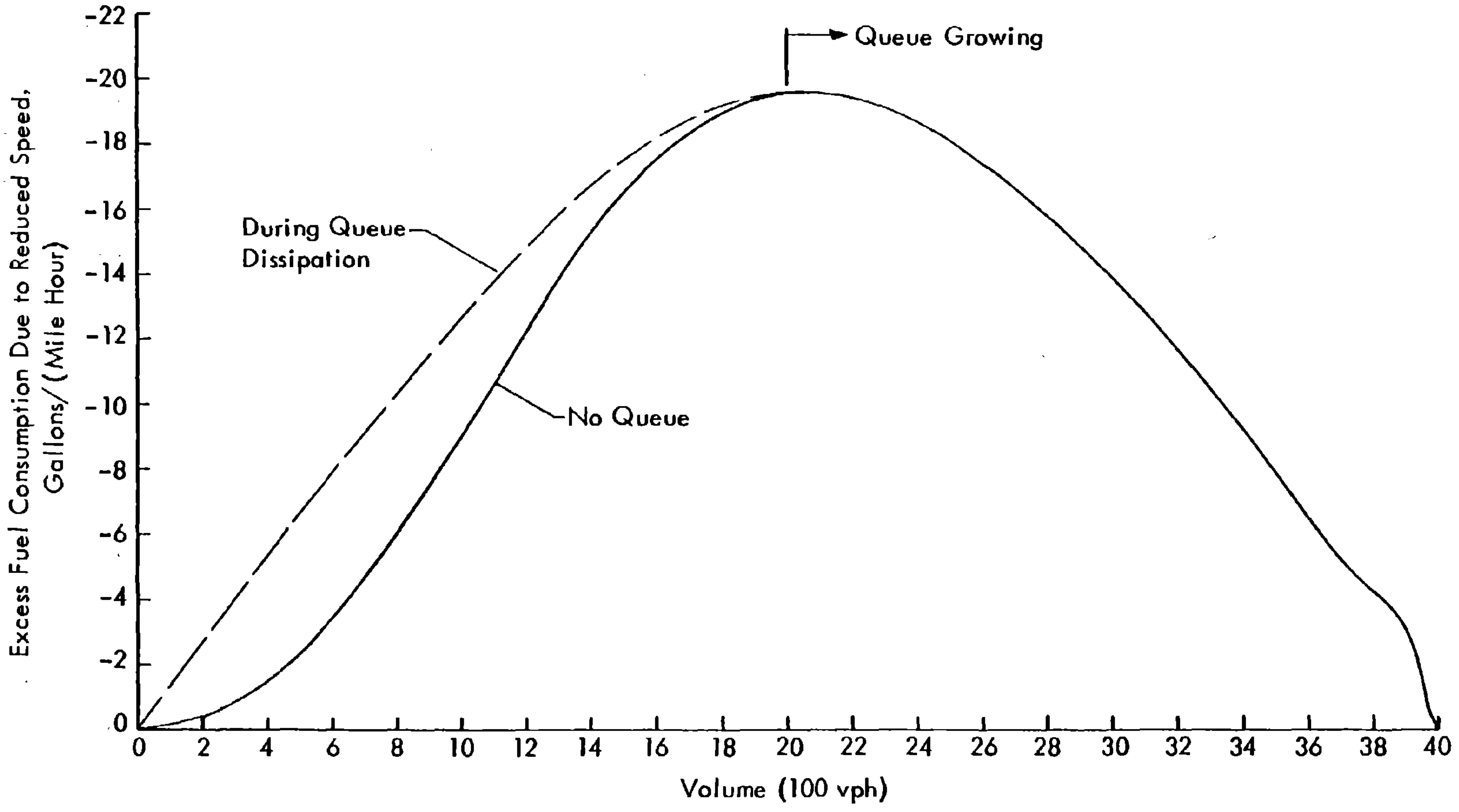
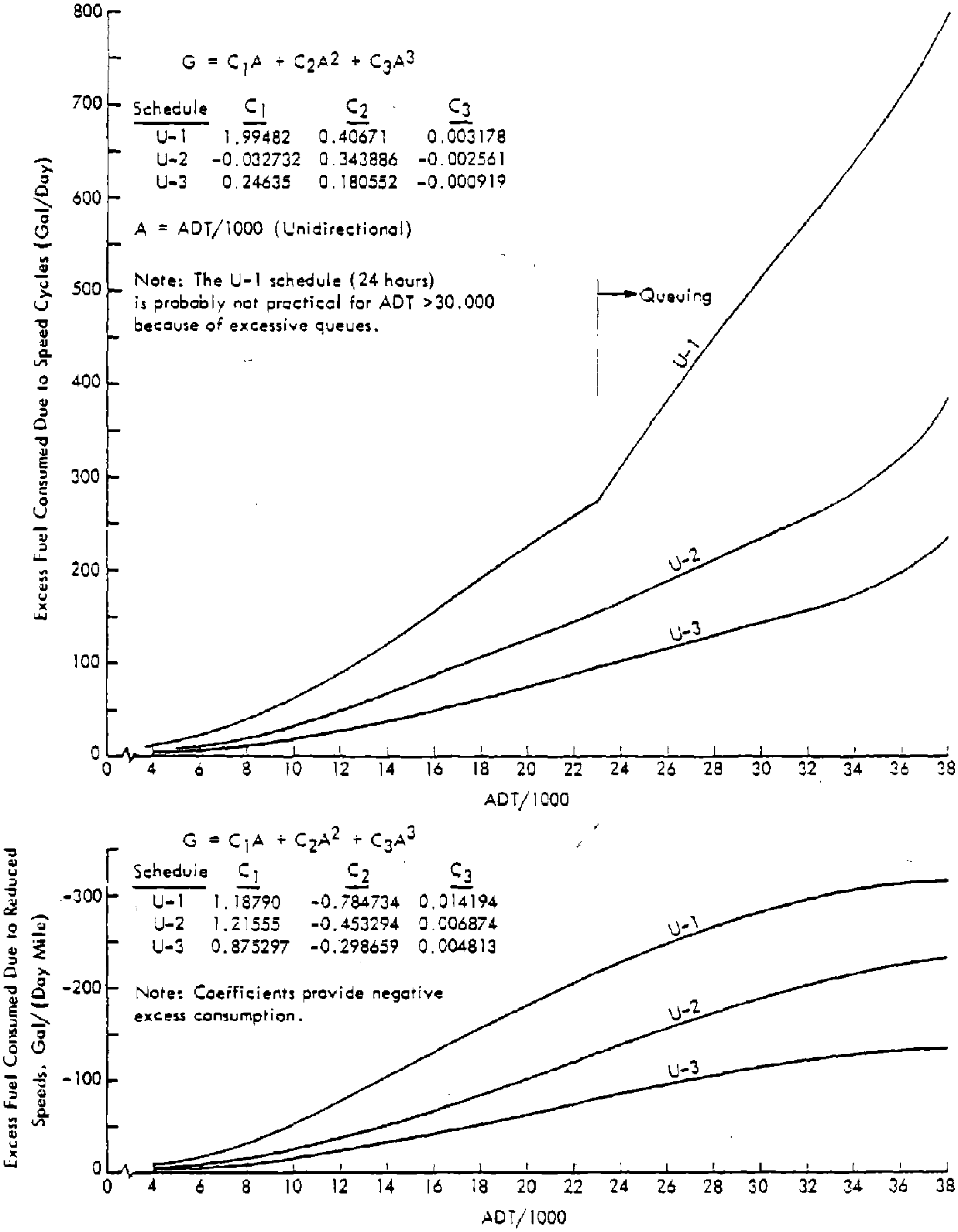


Figure D-12 - Excess Fuel Consumption Due to Reduced Speed, Configuration 2



$$G = C_1A + C_2A^2 + C_3A^3$$

Schedule	C_1	C_2	C_3
U-1	1.99482	0.40671	0.003178
U-2	-0.032732	0.343886	-0.002561
U-3	0.24635	0.180552	-0.000919

A = ADT/1000 (Unidirectional)

Note: The U-1 schedule (24 hours) is probably not practical for ADT >30,000 because of excessive queues.

$$G = C_1A + C_2A^2 + C_3A^3$$

Schedule	C_1	C_2	C_3
U-1	1.18790	-0.784734	0.014194
U-2	1.21555	-0.453294	0.006874
U-3	0.875297	-0.298659	0.004813

Note: Coefficients provide negative excess consumption.

Figure D-13 - Excess Fuel Consumed, Configuration 2

NOT REPRODUCIBLE

To obtain the total excess fuel consumed, the two equations for each schedule that are given in Figure D-13 are combined. Also, when queues are present the fuel consumed idling for the vehicle-hours in queue must also be added. The vehicle-hours in queue were determined as part of the delay computation for this configuration (Section D.3.b). This figure was combined with the two previous equations for each schedule to give the excess fuel consumed for two unidirectional lanes reduced to one lane. The equation is:

$$G = C_o + C_1A + C_2A^2 + C_3A^3$$

where

G = Excess fuel consumed (gallons/day), and

A = ADT/1,000 (ADT in direction affected)

Table D-5 provides the coefficient values.

APPENDIX E

STATE CONSTRUCTION ZONE ACCIDENT TOTALS

TABLE E-1

STATE 1 CONSTRUCTION ZONE ACCIDENTS

	Before	During	Change
TOTAL ACCIDENTS	979	1,076	+10%
NIGHT ACCIDENTS	271	353	+30%
SEVERITY			
Property-Damage-Only	779	869	+12%
Injury	194	204	+5%
Fatal	6	3	-50%
	979	1,076	
ACCIDENT TYPE			
Right Angle	41	45	+10%
Rear End	370	436	+18%
Side Swipe	103	133	+29%
Head On	9	7	-22%
Right Turn	33	29	-12%
Left Turn	38	33	-13%
Ran-Off-Road	86	103	+20%
Roll	90	82	-9%
Animal	10	14	+40%
Fixed Object	76	85	+12%
Fixed Object (Construction Zone)	0	16	N/A
Other	123	93	-24%
	979	1,076	
SURFACE			
Dry	404	492	+22%
Wet	37	48	+30%
Ice/Snow	50	62	+24%
Unknown	488	474	-3%
	979	1,076	
AREA			
Urban	835	886	+6%
Rural	144	190	+32%
	979	1,076	

TABLE E-2

STATE 2 CONSTRUCTION ZONE ACCIDENTS

	Before	During	Change
TOTAL ACCIDENTS	1,023	1,013	-1%
NIGHT ACCIDENTS	--	280	N/A
SEVERITY			
Property-Damage-Only	--	847	N/A
Injury	--	158	N/A
Fatal	--	8	N/A
		1,013	
ACCIDENT TYPE			
Right Angle	194	92	-53%
Rear End	442	444	0
Side Swipe	112	136	+22%
Head On	24	18	-20%
Turning	119	115	-3%
Ran-Off-Road	30	23	-23%
Roll	41	22	-46%
Animal	--	--	N/A
Fixed Object	49	72	+47%
Fixed Object (Construction Equipment)	0	46	N/A
Other	12	45	+275%
	1,023	1,013	
SURFACE			
Dry	--	756	N/A
Wet	--	249	N/A
Ice/Snow	--	8	N/A
Unknown	--	--	N/A
		1,013	
AREA			
Urban	683	512	-25%
Rural	340	501	+47%
	1,023	1,013	

TABLE E-3

STATE 3 CONSTRUCTION ZONE ACCIDENTS

	Before	During	Change
TOTAL ACCIDENTS	2,199	2,455	+12%
NIGHT ACCIDENTS	659	729	+11%
SEVERITY			
Property-Damage-Only	1,459	1,615	+11%
Injury	729	829	+14%
Fatal	11	11	0
	2,199	2,455	
ACCIDENT TYPE			
Right Angle	297	311	+5%
Rear End	863	979	+13%
Side Swipe	171	180	+5%
Head On	29	49	+69%
Right Turn	23	36	+57%
Left Turn	156	152	-3%
Ran-Off-Road	--	--	N/A
Roll	65	69	+6%
Animal	--	--	N/A
Fixed Object	332	405	+22%
Fixed Object (Construction Equipment)	0	0	N/A
Other	263	274	+4%
	2,199	2,455	
SURFACE			
Dry	1,458	1,682	+15%
Wet	546	571	+5%
Ice/Snow	180	190	+6%
Unknown	15	12	-20%
	2,199	2,455	
AREA			
Urban	1,776	1,997	+12%
Rural	423	458	+8%
	2.199	2,455	

TABLE E-4

STATE 4 CONSTRUCTION ZONE ACCIDENTS

	Before	During	Change
TOTAL ACCIDENTS	523	635	+21%
NIGHT ACCIDENTS	183	196	+7%
SEVERITY			
Property-Damage-Only	386	496	+28%
Injury	134	138	+3%
Fatal	3	1	-67%
	523	635	
ACCIDENT TYPE			
Right Angle	47	50	+6%
Rear End	156	258	+65%
Side Swipe	35	28	-20%
Head On	0	7	N/A
Right Turn	2	7	+250%
Left Turn	21	10	-52%
Ran-Off-Road	34	29	-15%
Roll	1	0	N/A
Animal	0	0	N/A
Fixed Object	74	50	-32%
Fixed Object (Construction Equipment)	0	21	N/A
Other	153	175	+14%
	523	635	
SURFACE			
Dry	232	372	+60%
Wet	107	77	-28%
Ice/Snow	31	35	+13%
Unknown	153	151	-1%
	523	635	
AREA			
Urban	440	538	+22%
Rural	83	97	+17%
	523	635	

TABLE E-5

STATE 5 CONSTRUCTION ZONE ACCIDENTS

	Before	During	Change
TOTAL ACCIDENTS	1,819	1,994	+13%
NIGHT ACCIDENTS	744	778	+9%
SEVERITY			
Property-Damage-Only	978	1,156	+17%
Injury	819	813	+9%
Fatal	22	25	+8%
	1,819	1,994	
ACCIDENT TYPE			
Right Angle	88	54	-41%
Rear End	650	667	+11%
Side Swipe	207	210	+7%
Head On	26	17	-35%
Right Turn	15	23	+60%
Left Turn	52	69	+30%
Ran-Off-Road	122	98	-22%
Roll	--	--	N/A
Animal	--	--	N/A
Fixed Object	249	298	+23%
Fixed Object (Construction Equipment)	0	36	N/A
Other	410	522	+27.3%
	1,819	1,994	
SURFACE			
Dry	1,280	1,296	+4%
Wet	413	446	+17%
Ice/Snow	108	96	-15%
Unknown	18	156	+632%
	1,819	1,994	
AREA			
Urban	1,080	1,132	+5%
Rural	739	862	+17%
	1,819	1,994	

TABLE E-6

STATE 6 CONSTRUCTION ZONE ACCIDENTS

	Before	During	Change
TOTAL ACCIDENTS	1,536	1,484	-3%
NIGHT ACCIDENTS	565	592	+5%
SEVERITY			
Property-Damage-Only	1,050	1,000	-5%
Injury	466	466	0
Fatal	20	18	-10%
	1,536	1,484	
ACCIDENT TYPE			
Right Angle	47	22	-53%
Rear End	94	199	+112%
Side Swipe	297	145	-51%
Head On	9	15	+67%
Right Turn	18	70	+289%
Left Turn	0	0	N/A
Ran-Off-Road	433	263	-39%
Roll	3	50	+1,567%
Animal	69	88	+28%
Fixed Object	153	388	+154%
Fixed Object (Construction Equipment)	0	0	N/A
Other	413	244	-41%
	1,536	1,484	
SURFACE			
Dry	751	937	+25%
Wet	337	266	-21%
Ice/Snow	336	239	-29%
Unknown	112	42	-63%
	1,536	1,484	
AREA			
Urban	--	--	--
Rural	1,536	1,484	-3%
	1,536	1,484	

TABLE E-7

STATE 7 CONSTRUCTION ZONE ACCIDENTS

	Before	During	Change
TOTAL ACCIDENTS	93	128	+38%
NIGHT ACCIDENTS	32	37	+16%
SEVERITY			
Property-Damage-Only	66	90	+36%
Injury	27	38	+41%
Fatal	0	0	N/A
	93	128	
ACCIDENT TYPE			
Right Angle	6	11	+83%
Rear End	39	65	+67%
Side Swipe	14	18	+29%
Head On	2	1	-50%
Right Turn	0	5	N/A
Left Turn	3	3	0
Ran-Off-Road	1	4	+300%
Roll	4	2	-50%
Animal	5	0	N/A
Fixed Object	8	9	+13%
Fixed Object (Construction Equipment)	0	1	N/A
Other	11	9	-18%
	93	128	
SURFACE			
Dry	65	91	+40%
Wet	27	35	+30%
Ice/Snow	1	2	+100%
Unknown	--	--	N/A
	93	128	
AREA			
Urban	59	84	+42%
Rural	34	44	+29%
	93	128	

APPENDIX F

CONSTRUCTION ZONE ACCIDENTS

(Case Study 1)

Roadway

The roadway is a six-lane interstate roadway in a rural area. The total length of the project was 10.3 miles. A scaled drawing of the project is shown in Figure F-1. The ADT is highest at the south end of the project. From the south end of the project to the Route 481 interchange, the ADT is 30,500 (73). Beyond this interchange the ADT drops to 20,200 (73) and near the north end of the project the ADT is near 15,000 (74). ADT's for each section are shown in Figure F-1.

Description of Work

The work involved shoulder construction, removal and installation of guardrail, sign replacement, bridge work on 11 bridges including those in the Onedia Lake area and rehabilitation of both the northbound and southbound bridges over Church Street.

Project Duration

The project began on February 20, 1974 and was completed on December 10, 1975, a period of 21.67 months. During the winter months, from the end of October to near the end of April, construction was suspended.

Construction Sequence

A general description of the traffic control sequence is:

1. Construct temporary crossovers A, B, C, D, W, X, Y, Z.

2. Detour northbound traffic onto the southbound lanes at Church Street and Onedia Lake Bridge areas while completing work on northbound bridges.

3. When the northbound bridge work was completed, detour southbound traffic to the northbound lanes and work on the southbound bridges.

Actually, there were basically two stages of construction at each of the bridge areas. On April 19, 1974 the northbound lanes were closed at the Church Street Bridge and all traffic was carried on the southbound lanes. The northbound lanes were closed in the Onedia Lake Bridge area on June 24, 1974, and again all traffic was carried on the southbound lanes of the roadway.

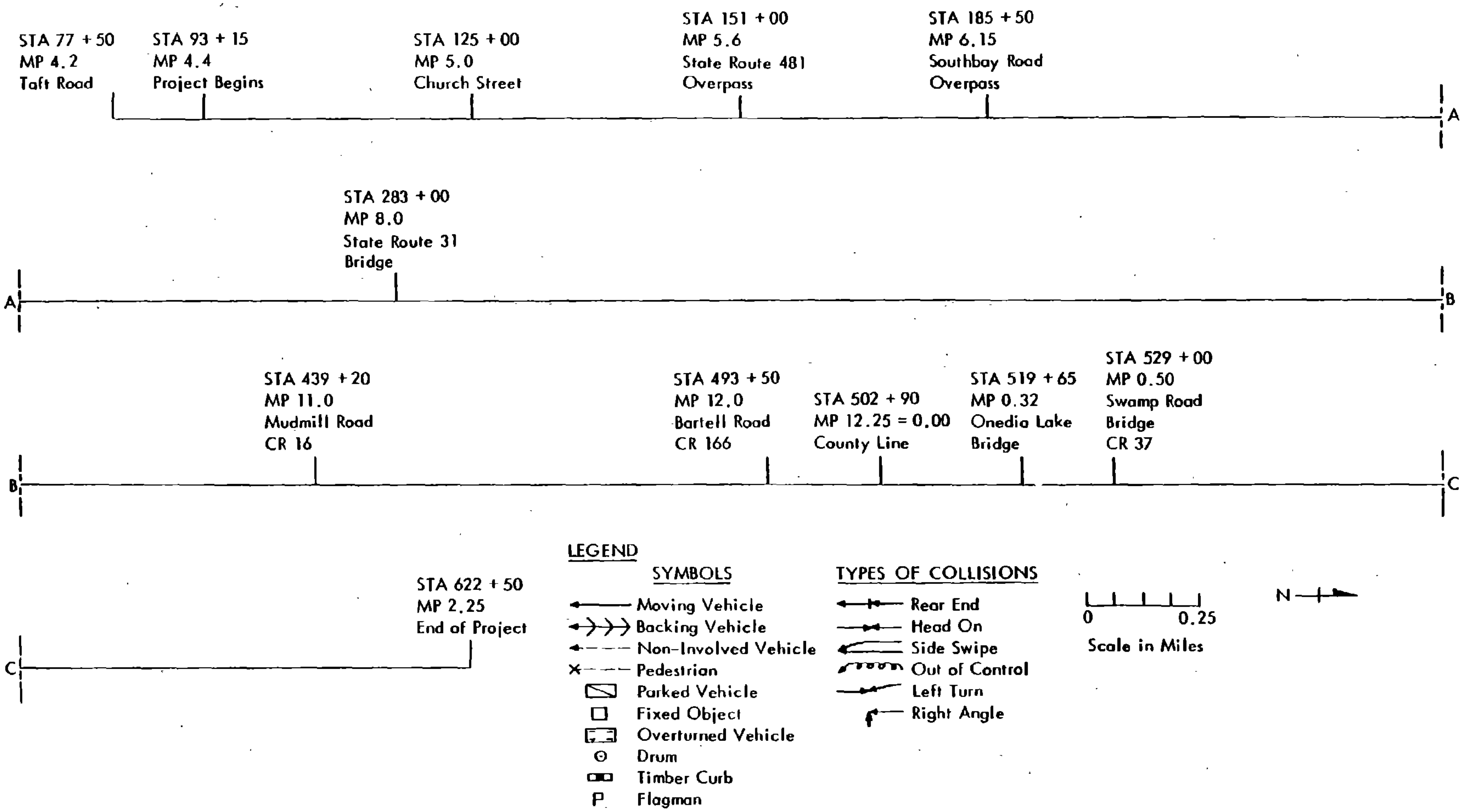


Figure F-1 - Project Diagram and ADT Map

On August 20, 1974 the northbound lanes were opened in the Onedia Lake Bridge area and the southbound lanes were closed. During this period, all traffic was carried on the northbound lanes. The northbound lanes in the Church Street Bridge area were reopened on October 16, 1974 and the southbound lanes in the Onedia Lake Bridge area on October 25, 1974. At this point the first stage of bridge work was completed at Church Street and both stages at Onedia Lake.

During the 1974-75 winter months (November through April), construction was suspended, and all lanes were open to traffic.

On April 30, 1975 the southbound lanes in the Church Street Bridge area were closed and all traffic was carried on the northbound lanes of the roadway. The southbound lanes were reopened on August 1, 1975.

Traffic Control

The primary zone types used on the project were lane closures and crossovers. The two areas of bridge work used crossovers to completely remove traffic from the lanes of the one-way bridge being worked on. In the crossover areas, the direction of traffic being diverted to the opposite roadway was guided into a single lane then crossed over the median and continued in a single 12-foot lane until crossed back over. The other direction of traffic was reduced from three to two 12-foot lanes. The two directions of traffic were separated by 12 x 12 inch timbers. These timbers started before the crossovers and continued throughout the length of the two-way roadway section.

The speed limit in the crossovers was posted at 40 mph. The project diary notes that in May of 1975 a great deal of speeding was observed in the Church Street crossover area. In June, the diary notes that radar enforcement was set up in the Church Street crossover area.

The contractor was required to have watchmen on the job during nonworking hours. The watchmen's duties were to make sure all signs, barricades, delineators, and markers were erected and in good condition and that the traveled way was in a safe and reasonable condition.

Before-During Accident Experience

Forty accidents occurred on the project in the year before construction began. During the construction period, 102 accidents occurred. If equal time periods are compared by expanding the before period to a period compared to the 1.81 years of construction, the expected number of accidents for the construction period would be 72. The actual number of accidents was 42% higher than the expected number.

If the months of May-October, when most construction was underway in this area, are compared before and during construction, 22 accidents occurred in May-October of 1974 (the before year), 32 accidents occurred in May-October of 1973, and 40 accidents occurred in May-October of 1975. Thus, the number of accidents during construction in 1974 and 1975 are 45% and 82% higher than the number of accidents before construction in 1973.

If we compare the types of accidents in the before and during period, the night accidents proportion of the total accidents was 50% in the before period and 44% in the during period. The percentage of rear-end accidents decreased from 40% of the total accidents in the before period to 21% of the during accidents. Fixed object accidents increased from 15% of the before accidents to 38% of the during accidents. There were no head-on accidents in the before period, two occurred during construction.

The severity breakdown in the before period was 38% PDO, 60% injury and 2% fatal, in the during period there were 57% PDO, 40% injury and 3% fatal.

The average ADT of the zone is 19,650. Available ADT data indicate that there was not a great diversion of traffic from the road during construction. If the 19,650 ADT is used to compile before and during rates in the zone the before period rate is 54.15 accidents/100 million vehicle miles and the during rate is 76.36 accidents/100 million vehicle miles. The fatality rates would be 1.35 accidents/100 million vehicle miles before and 2.25 accidents/100 million vehicle miles after.

Accident Report Analysis

Accident reports for the construction period were examined and divided into the following categories:

1. Precipitating cause of the accident highly related to construction activity or roadway. Example: Vehicle overturned while negotiating sharp curve on construction zone crossover.

2. Accident occurrence or severity affected by construction. Example: Vehicle leaves roadway and loses control because of low shoulder.

3. Accident did not appear to have been precipitated or affected by construction.

Full reports were available for 98 of the 102 during accidents. Thirteen accidents were judged to be in category 1, 23 in category 2, and 57 in category 3 (5 accidents occurred at ramp intersections with local streets).

Table F-1 contains a list of all the accidents that were judged to have been precipitated or affected by the construction. Figures F-2, F-3, and F-4 are collision diagrams for the category 1 and 2 accidents. Each of the diagrams covers one stage of the bridge construction work. Two of the accidents occurred after the bridge work was completed and are not shown on the diagrams. The collision diagrams show that nearly all of the category 1 and 2 accidents occurred in the areas where traffic was diverted to the opposite roadway. Also, the most common contributing factor to these accidents were the 12 inch x 12 inch timber curbs that were used to separate the two directions of traffic. The severity of these accidents is nearly identical to the overall accident severity breakdown.

Case Study Summary

Analysis of this project and its accident experience indicates a definite increase in accidents during the construction period. However, accident severity in the during period was reduced with about 60% of the during accidents being PDO accidents, compared to 38% PDO in the before period. And there were actually fewer injury accidents in the during period than would have been expected based on the before accidents. An exception to the general drop in severity was the occurrence of two fatal head-on accidents that occurred during construction. (One of the accidents resulted from a drunk driver going south in the northbound lanes, and was not related to the construction.)

The collision diagrams show that, with only two or three exceptions, the accidents occurred in the areas where traffic was being operated two-way on one side of the interstate while bridge work was completed on the opposite roadway. Also, 25 of the 36 construction related accidents involved the timber curbing used to guide and separate the traffic flows.

The accidents involving the timber curbing were of three basic types. The first type involved a vehicle being damaged by hitting the in-place curbing. Nine of the 25 curbing accidents were of this type. These accidents probably

TABLE F-1

CASE STUDY 1 ACCIDENT LISTING

	Accident Related to Construction					Accident Precipitated by Construction			
	Date	Time	Type	Contributing Factors		Date	Time	Type	Contributing Factors
1.	5/7/74	11:05 p.m.	I-ROR	Driver lost control after front-end hit something in roadway.					
					2.	5/9/74	3:30 a.m.	PDO-FO	Vehicle hit misplaced timber curb.
					3.	5/12/74	3:00 p.m.	PDO-FO	Vehicle hit timber curb during rainstorm.
					4.	7/4/74	3:45 a.m.	PDO-FO	Vehicle hit timber curb in roadway.
5.	7/4/74	4:00 a.m.	I-FO	Vehicle hit timber curb.					
6.	7/20/74	12:37 a.m.	PDO-FO	Vehicle hit timber curb and barrels.					
7.	7/25/74	3:15 p.m.	I-FO	Vehicle drove through timber curb.					
8.	8/9/74	4:55 p.m.	F-HO	Vehicle drove through timber curb and collided head-on with vehicle traveling in opposite direction.					
9.	8/25/74	4:00 a.m.	PDO-FO	Vehicle struck timber curb, barrels and amber lights					
10.	8/27/74	12:15 a.m.	PDO-FO	Driver fell asleep; vehicle hit timber curb and barrels.					
11.	8/30/74	4:25 p.m.	PDO-SS	Vehicles sideswiped, one vehicle hit curb, pushing curb into third vehicle traveling in the opposite direction.					
					12.	8/30/74	9:30 p.m.	PDO-FO	Vehicle hit timber curb in roadway.
13.	9/23/74	4:35 p.m.	I-FO	Vehicle hit timber curb.					
14.	9/30/74	1:30 a.m.	PDO-FO	Vehicle hit timber curb.					
					15.	10/5/74	1:10 p.m.	I-RE	Flagman stopping vehicles.
16.	10/10/74	8:30 p.m.	PDO-FO	Vehicle hit timber curb.					
17.	10/23/74	8:05 p.m.	I-FO	Vehicle hit dirt piled on the side of the road.					
18.	5/7/75	3:30 a.m.	PDO-FO	Vehicle hit timber curb.					
19.	5/13/75	6:30 p.m.	I-FO,HO	Vehicle 1 hit timber curb, timber curb hit vehicle 2, vehicle 1 became airborne, hit vehicle 3 and overturned.					
					20.	5/17/75	4:30 p.m.	PDO-RE	Collision at lane closure.
					21.	5/25/75	7:15 a.m.	I-FO	Vehicle hit timber curb and overturned.

TABLE F-1 (concluded)

Accident Related to Construction

	Date	Time	Type	Contributing Factors
22.	5/30/75	8:40 a.m.	I-FO	Vehicle passing other vehicle hit barrels, then ran off road and overturned.
26.	6/18/75	10:15 p.m.	PDO-RE	Vehicles were stopping at stop sign for the construction zone.
27.	6/21/75	10:10 a.m.	I-FO	Vehicle 1 hit timber curb knocking it into opposing lane, vehicles 2 and 3 hit curb.
28.	6/21/75	4:00 p.m.	PDO-FO	Driver lost control, hit timber curb.
29.	6/28/75	9:21 p.m.	I-FO	Vehicle forced into timber curb by unknown vehicle.
32.	7/1/75	11:22 p.m.	PDO-FO	Vehicle hit timber curbing.
34.	8/1/75	7:20 a.m.	PDO-FO	Vehicle hit timber curbing.
35.	9/12/75	9:30 a.m.	PDO-PK	Vehicle passed flagman, hit parked vehicle.
36.	11/26/75	2:15 p.m.	I-PK	Vehicle hit state truck parked on shoulder.

Accident Precipitated by Construction

	Date	Time	Type	Contributing Factors
23.	6/11/75	12:03 a.m.	PDO-FO	Vehicle hit "object of construction," lost control and ran over curb and sign.
24.	6/18/75	9:45 p.m.	PDO-FO	Vehicle hit timber curb in roadway.
25.	6/18/75	9:45 p.m.	PDO-FO	Vehicle hit timber curb in roadway.
30.	6/29/75	4:00 p.m.	PDO-FO	Vehicle hit timber curb displaced in earlier accident.
31.	6/30/75	12:20 a.m.	PDO-FO	Vehicle at lane closure forced into barrel taper.
33.	7/9/75	11:45 a.m.	I-FO	At lane closure truck's brakes locked up.

Legend:

PDO - Property damage only accident
I - Injury accident
F - Fatal accident
ROR - Ran off road
HO - Head-On

FO - Fixed object
SS - Sideswipe
RE - Rear end
PK - Collision with parked car

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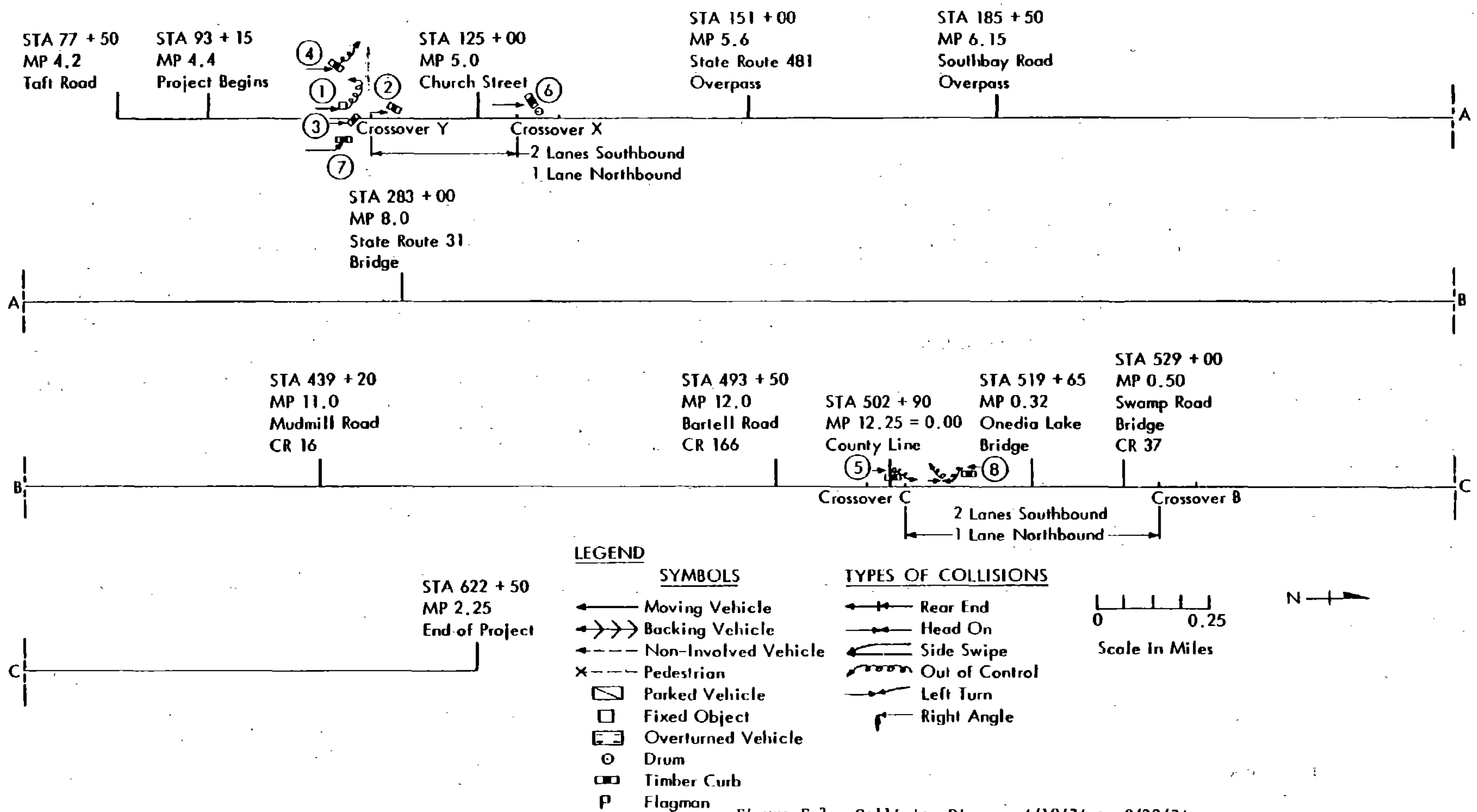


Figure F-2 - Collision Diagram 4/19/74 to 8/20/74
Northbound Lanes Closed at Church
Street and Onedia Lake

Figure F-2

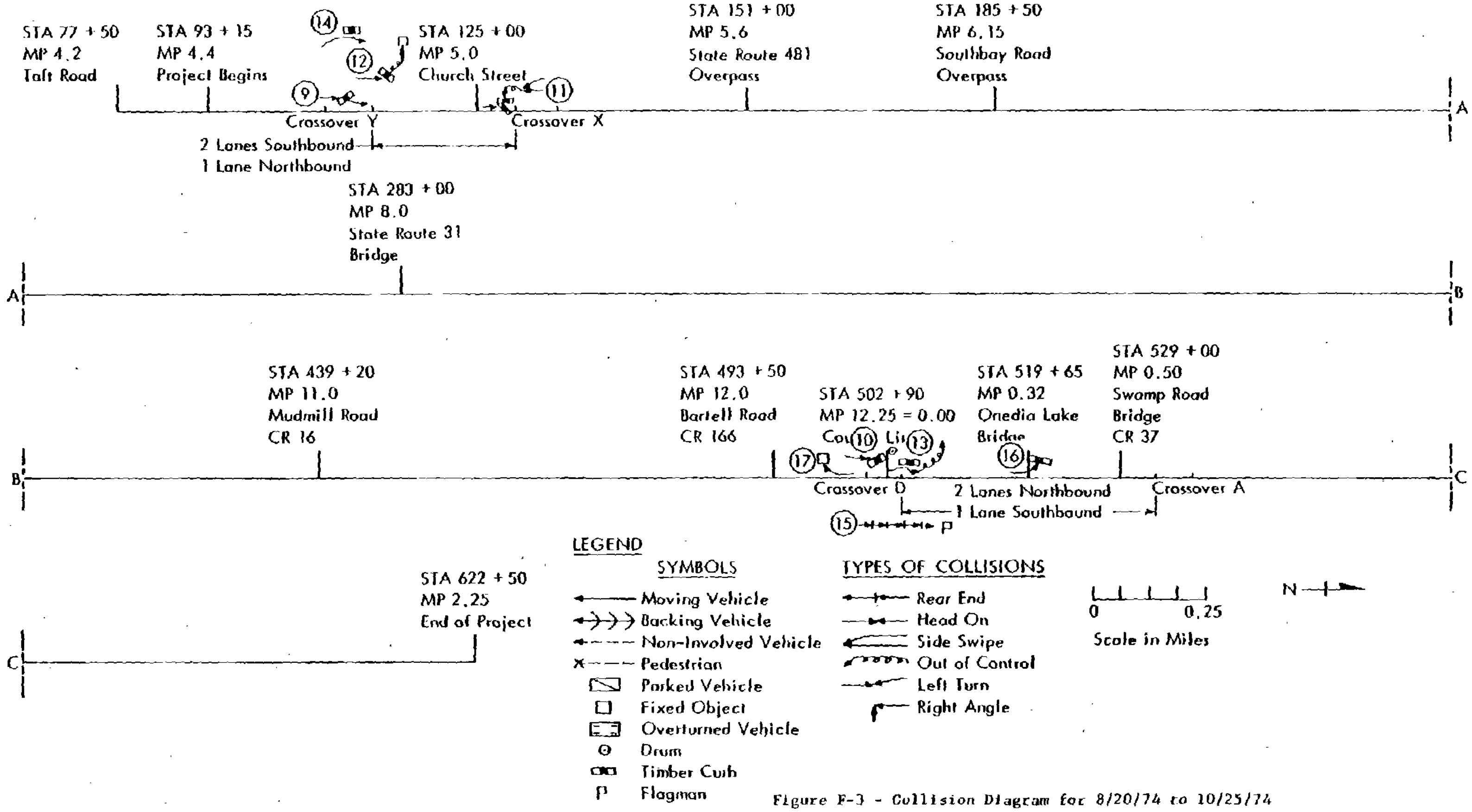


Figure F-3 - Collision Diagram for 8/20/74 to 10/25/74
Northbound Lanes Closed at Church Street,
Southbound Lanes Closed at Onedia Lake

Figure F-3

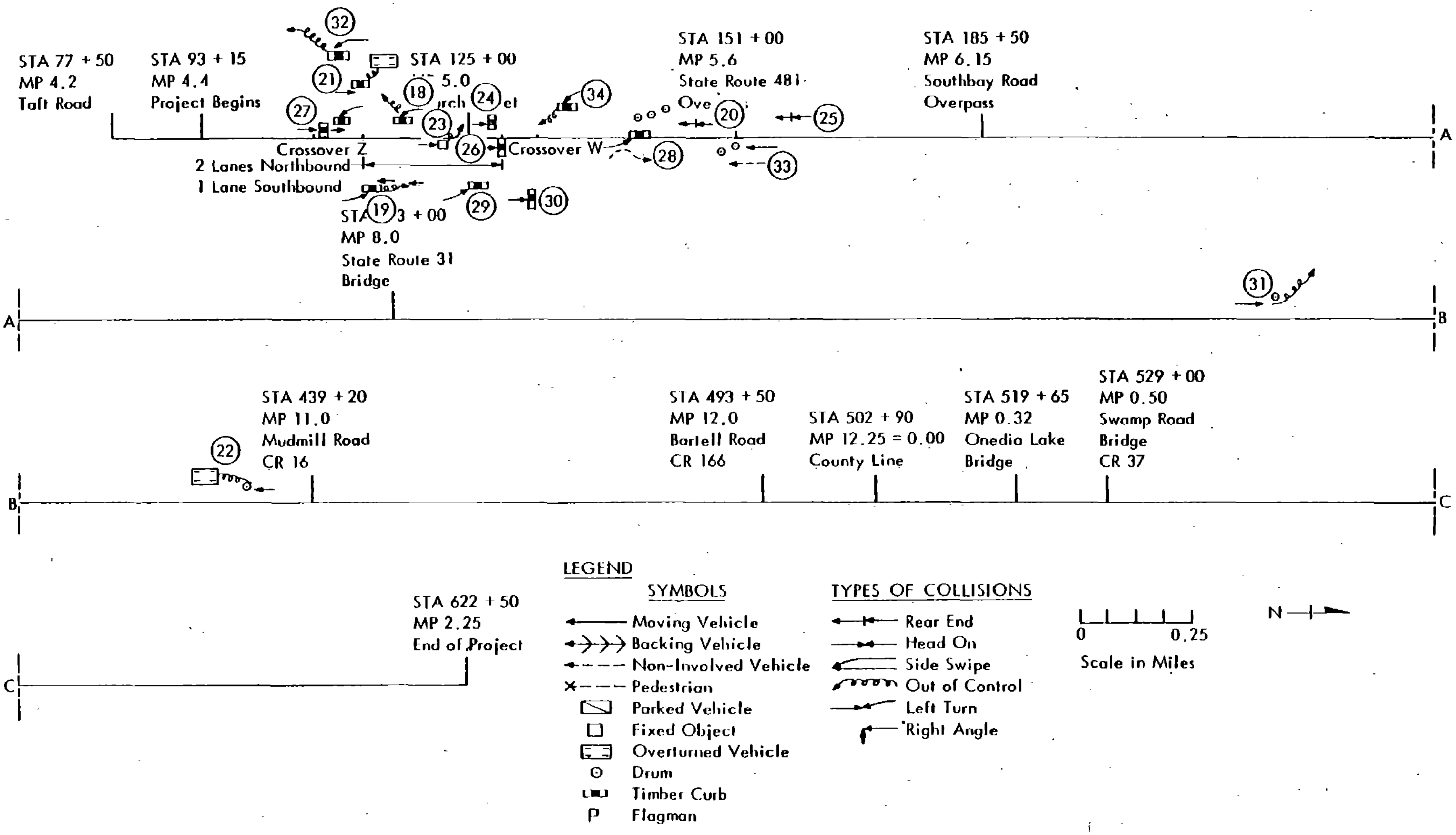


Figure F-4 - Collision Diagram for 4/30/75 to 8/1/75
Southbound Lanes Closed at Church Street

Figure F-4

resulted from the use of the timber curb barriers and possibly would have resulted with any type of barrier, but might have been avoided if barriers were not in place.

The second type of accident involved vehicles hitting the timber curb then going through the curb or out of control and hitting another vehicle or another fixed object. Eight of the curbing accidents were of this type. These accidents indicate an ineffective barrier system. A proper barrier system should redirect an errant vehicle without throwing the vehicle out of control or turning it over. In one of the accidents a vehicle became airborne after hitting the timber curbing.

The third type of accident involving the curbing included those accidents where the curbing was hit and knocked into another vehicle or was hit and knocked out of place and then hit by another vehicle. There were eight accidents of this type. This type of accident again points out an ineffective barrier system that cannot be expected to always remain in place. Also the use of watchmen on the project did not seem to prevent any of the accidents involving out-of-place curbing.

In conclusion the case study analysis shows that accidents increased in this construction zone because of the increase in fixed object (curbing) accidents. The analysis indicates that the timber curb barrier system used may have deterred some serious accidents, however, a more effective barrier system could have reduced many of the accidents related to the construction activity, and even no barrier system at all would probably have reduced the number of accidents.

APPENDIX G

CONSTRUCTION ZONE ACCIDENTS

(Case Study 2)

CASE STUDY NUMBER 2

Roadway

The project was located on a 6.09 mile urban section of six-lane interstate highway. A scaled drawing of the project is shown in Figure G-1. The ADT on the roadway at Arlington Avenue (MP 110.08) was 68,000 vph before construction, 44,000 vph during construction and 61,000 vph after the construction was completed.

Description of Work

The work involved construction of traffic barriers, light standards, and miscellaneous construction including expansion joint work, retaining wall construction and bridge deck repair.

Project Duration

The project began on July 11, 1975 and was completed on October 7, 1975, a period of 89 days.

Construction Sequence

During Stage 1, the left and center lanes along most of the project were closed, while a concrete median barrier was constructed. Also during this stage, light standards were placed in the median, and work on the two closed lanes included expansion joints, and bridge decks. This work was completed by September 3.

From September 3-16, the left lane was opened, and the right lane was closed. The center lane remained closed.

Stage 2 of the construction involved expansion joint and bridge deck work on the right lane and work on retaining walls. All lanes were reopened to traffic between October 1 and October 7.

Traffic Control

Through most of the zone, two of the three lanes in each direction were closed. The center lane was barricaded to restrict traffic. The other closed lane was open because construction vehicles often parked or traveled within the zone in this lane. Yield signs were used at ramps that were open to traffic. The control plan used when left lanes were open is shown in Figure G-2.

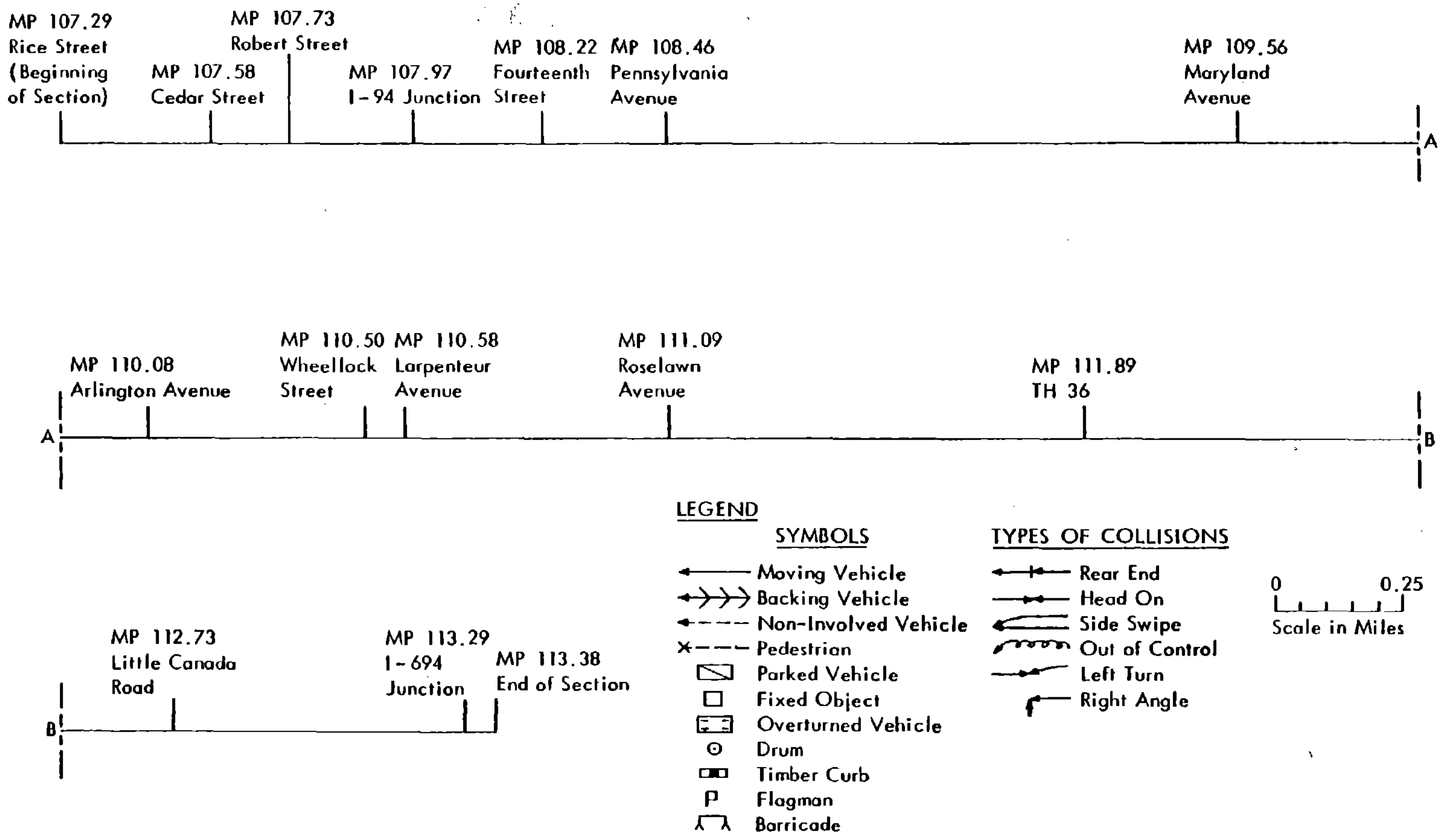


Figure G-1 - Case Study 2--Project Diagram

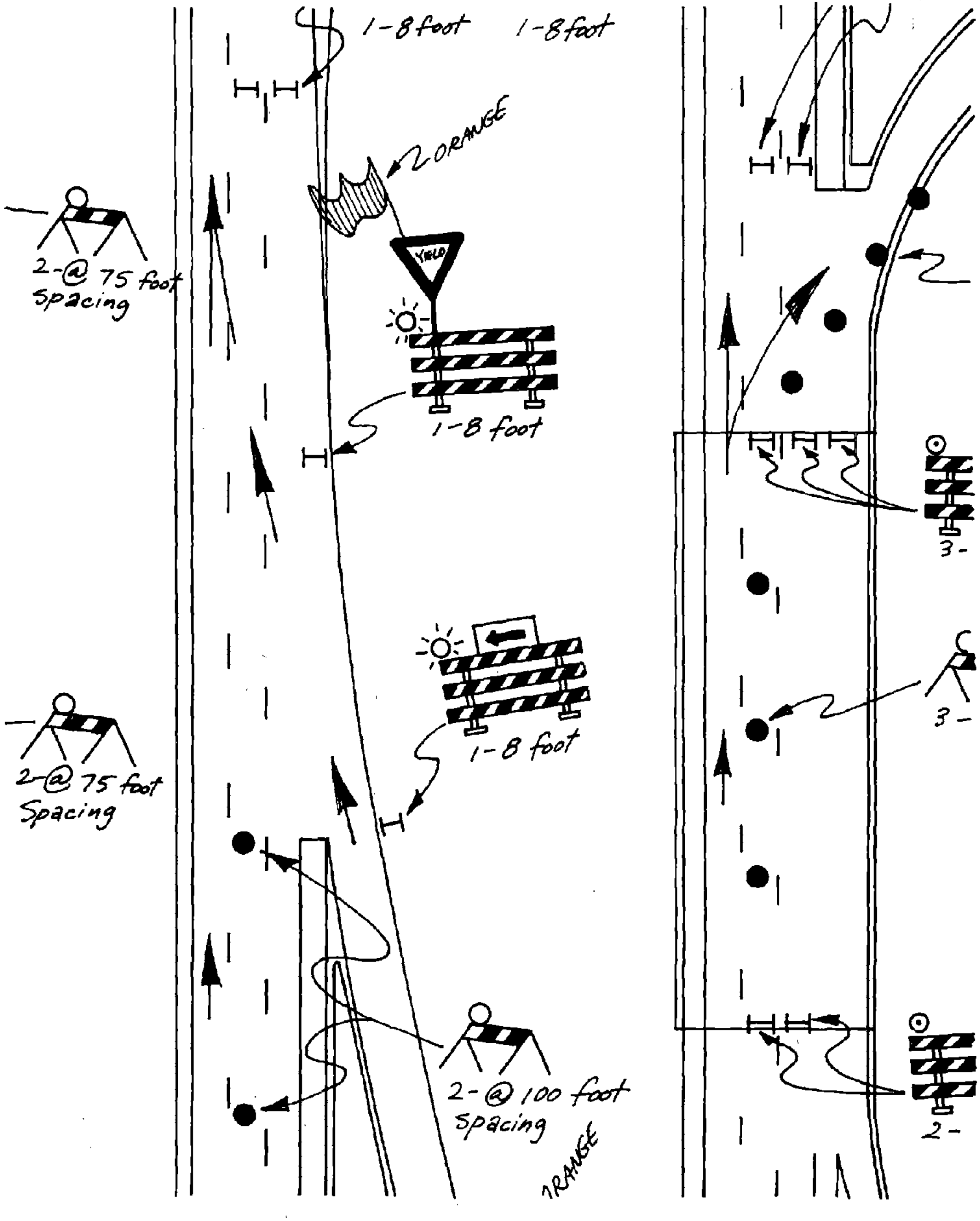


Figure G-2 - Traffic Control--Left Lane Closed

The construction contract specified that in each area where traffic was restricted for a temporary lane closure that two vehicle-mounted "Electric Flashing Arrow Boards" be available for use.

During each state of the construction certain ramps were closed. The construction contract specified the following minimum traffic control devices required for each stage of construction.

Stage 1

One hundred sixty-eight, Type III barricades with flashing or steady-burn lights and barricade weights.

Three hundred seventy-four, Type II barricades with steady burn warning lights and barricade weights.

Fifty-one signs.

Stage 2

One hundred ninety-six, Type III barricades with flashing or steady-burn warning lights and barricade weights.

Two hundred ninety-three, Type II barricades with steady-burn warning lights.

Sixty-six warning signs.

Traffic control layouts showing sign messages and placement of traffic control devices were prepared by the district traffic engineer. The posted speed limit on the project was not lowered during construction. The normal speed limit on the roadway was 55 mph.

Before and during the project, considerable public information was made available in an attempt to divert traffic from the project.

Handouts were given to motorists coming into the metropolitan area, giving dates and locations of the construction. Also billboards were rented to tell motorists about the zone.

The construction contract stated that the contractor was responsible for immediate repair and replacement of barricades and warning signs, and he was to provide sufficient surveillance of the barricades to ensure their immediate attention. The traffic control on the project was subcontracted to a firm that surveyed the signs and barricades at least once daily.

The contractor was also required to provide parking for his employees outside of the project limits.

Before-During Accident Experience

During the 3-month period of construction, 103 accidents occurred on the project. In the corresponding time period before construction, 69 accidents occurred. This indicates a 49% increase in the accident number from the before to during period.

Comparing the types of accidents in the before and during periods, the percentage of night accidents was 43% for the before period and 28% for the during period. Rear-end accidents accounted for 33% of the before accidents and 50% of during accidents. Fixed object accidents were 16% of the before accidents and 9% of during accidents.

The severity breakdown in the before period was 68% PDO and 32% injury. During construction PDO accidents were 79% of the total and injury accidents were 21%. No fatal accidents occurred in either period.

If accident rates are computed using the 68,000 ADT before construction the total accident rate for the before period was 187 accidents/100 million vehicle miles, and the during rate was 432 accidents/100 million vehicle miles. The accident rate increase from before to during accidents was 131%.

The injury accident rate was 59.6 accidents/100 million vehicle miles before and 92.2 accidents/100 million vehicle miles during construction, a 55% increase.

Accident Report Analysis

Accident reports for the construction period were examined and divided into the following categories:

1. Rear-end accidents related to construction.

2. Accidents whose precipitating cause was highly related to the construction activity or roadway.

3. Accidents whose occurrence or severity was affected by construction.

4. Accidents not affected by construction.

TABLE G-1

CONSTRUCTION RELATED ACCIDENT LISTING

No.	Date	Time	Type	Contributing Factors
1	7/11/75	2:35 PM	PDO-RE	Driver glanced away from road and drove into vehicle.
2	7/11/75	2:45 PM	PDO-RE	Vehicles slowing for traffic. Vehicles 1 and 2 ran into rear of Vehicle 3.
3	7/11/75	4:20 PM	PDO-RE	Construction vehicle blocking open lane. In stopping one vehicle rear-ended another. No flagman.
4	7/11/75	8:00 PM	PDO-FO	Slowing for traffic driver lost control and skidded into median fence.
5	7/11/75	8:40 PM	I-RE	Slowing for traffic one vehicle rear-ended another.
6	7/11/75	8:50 PM	I-RE	Five vehicles slowing for traffic involved in rear end accident.
7	7/11/75	11:00 PM	PDO-RE	One vehicle rear ended another at yield sign at on ramp.
8	7/11/75	11:20 PM	I-UN	Motorcycle hit by another vehicle, driver not sure of details.
9	7/12/75	3:45 AM	PDO-FO	Vehicle slowing in traffic lost control and hit guardrail.
10	7/12/75	4:00 AM	PDO-FO	Driver lost control and hit three barricades.
11	7/12/75	5:00 PM	I-RE	Vehicle no. 1 stopped for sweeper in traffic lane. Vehicle 2 skidded on mud and sand in road, rear ended Vehicle 1.
12	7/13/75	3:10 PM	PDO-RE	Vehicles in slowing queue one vehicle rear ended another.
13	7/13/75	4:15 PM	I-RE	Vehicles in slowing traffic one vehicle rear ended another.
14	7/14/75	2:40 PM	PDO-RE	Vehicle stopped in traffic was rear ended by another vehicle.
15	7/14/75	11:20 PM	PDO-Other	Part of a jackhammer fell from overpass and struck vehicle's windshield.
16	7/15/75	6:12 AM	PDO-RE	Vehicles 2 and 3 stopped in traffic. Vehicle 1 hit 2 in rear end, 2 hit 3 in rear.
17	7/15/75	2:00 PM	PDO-RE	Vehicle stopped in traffic rear-ended by another vehicle.
18	7/15/75	3:00 PM	PDO-RE	Vehicles in slowing traffic one vehicle rear ended another.

TABLE G-1 (continued)

No.	Date	Time	Type	Contributing Factors
19	7/16/75	12:05 AM	I-FO	Driver fell asleep hit barricade and pile of broken concrete.
20	7/16/75	9:15 AM	PDO-RE	Vehicles in slowing traffic one vehicle rear ended another.
21	7/17/75	2:50 PM	PDO-RE	Vehicle 1 stopping in traffic, rear ended by vehicle 2.
22	7/17/75	7:30 PM	PDO-SS	Vehicle 1 entering lane from ramp side swiped by vehicle 2.
23	7/18/75	2:40 PM	I-RE	Vehicle 1 stopped in traffic rear-ended by vehicle 2.
24	7/18/75	5:48 PM	PDO-RE	Vehicles in slowing traffic one vehicle rear ended another.
25	7/19/75	1:15 AM	PDO-RE	Vehicle 1 tailgating vehicle 2 struck vehicle 2 and fled accident scene.
26	7/19/75	3:45 PM	PDO-RE	Vehicles slowing in traffic. Vehicle 3 rearended vehicle 2, vehicle 2 rear ended vehicle 1.
27	7/20/75	7:10 PM	I-RE	Vehicle 1 stopped in traffic rear ended by Vehicle 2. Vehicle 2 was then struck by vehicle 3.
28	7/22/75	11:30 PM	PDO-FO	Vehicle traveling in barricaded lane hit pile of broken concrete.
29	7/23/75	10:30 AM	PDO-RE	Vehicle stopped in traffic and was rear ended by vehicle 2.
30	7/25/75	1:10 PM	I-RE	In slowing traffic vehicle 2 was rear ended by vehicle 3 and knocked into vehicle 1.
31	7/25/75	2:40 PM	PDO-RE	Vehicles slowing in traffic. Vehicle 1 rearended vehicle 2.
32	7/26/75	5:30 AM	PDO-FO	Vehicle hit two lighted barricades.
33	7/28/75	1:50 PM	PDO-RE	Vehicle 1 stopped in traffic was rear ended by vehicle 2.
34	7/30/75	5:00 PM	PDO-RE	Vehicles 1 and 2 stopped in traffic. Vehicle 2 was rearended by vehicle 3 and pushed into vehicle 1.
35	8/1/75	3:00 PM	PDO-RE	Vehicle 1 stopped in traffic was rear ended by Vehicle 2.
36	8/2/75	12:30 PM	I-RE	Vehicles 1 and 2 stopped in traffic. Vehicle 2 was rearended by vehicle 3 and pushed into vehicle 1.

TABLE G-1 (continued)

No.	Date	Time	Type	Contributing Factors
37	8/4/75	3:20 PM	PDO-SS	Vehicle 1 turning into barricaded lane was side swiped by vehicle 2. Vehicle 2 was traveling in barricaded lane.
38	8/7/75	4:25 PM	PDO-RE	Vehicle 1 stopped in traffic was rear ended by vehicle 2.
39	8/7/75	9:00 PM	PDO-FO	Vehicle ran over rail placed on left side of open traffic lane.
40	8/9/75	1:40 PM	PDO-RE	Vehicles slowing in traffic. Vehicle 1 rear ended vehicle 2, vehicle 2 rear ended vehicle 3.
41	8/11/75	3:15 PM	PDO-RE	Vehicle 1 stopped in traffic was rear ended by vehicle 2.
42	8/14/75	12:00 PM	PDO-RE	Vehicle 1 stopped in traffic was rear ended by vehicle 2.
43	8/15/75	6:30 PM	PDO-RE	In rain and slowing traffic vehicle 1 rear ended vehicle 2.
44	8/16/75	11:25 AM	I-RE	Three vehicles stopped in traffic. Vehicle 4 ran into rear of vehicle 3, which hit vehicle 2 and vehicle 1.
45	8/18/75	2:30 PM	PDO-RE	Vehicle 1 rear ended vehicle 2, driver 1 stated that dust on the road made it difficult to stop quickly.
46	8/21/75	3:00 PM	PDO-OT	Driver lost control of vehicle, ran into sand and gravel piled in road and overturned.
47	8/24/75	1:15 PM	PDO-RE	Vehicle 1 rear ended by vehicle 2.
48	8/25/75	12:00 AM	PDO-FO	Driver in barricaded lane swerved to avoid barricade, lost control and hit median barrier.
49	8/28/75	5:30 PM	I-RE	In slowing traffic vehicle 1 rear ended vehicle 2.
50	8/28/75	7:07 PM	PDO-RE	In slowing traffic vehicle 1 rear ended vehicle 2.
51	8/29/75	11:00 PM	PDO-FO	Driver swerved to avoid object in roadway and hit barricade.
52	8/30/75	6:00 PM	PDO-FO	Driver stated that he was forced into barricade by high speed vehicle.
53	9/1/75	12:20 AM	I-FO	Vehicle traveling in barricaded lane hit pile of sand and then median barrier.

TABLE G-1 (continued)

No.	Date	Time	Type	Contributing Factors
54	9/5/75	6:30 AM	PDO-RE	Vehicle 1 stopped in traffic was rear ended by vehicle 2.
55	9/5/75	6:25 PM	PDO-RE	Vehicle 1 stopped in traffic was rear ended by vehicle 2.
56	9/6/75	12:20 AM	I-FO	Vehicle traveling in lane left of barricades ran into pile of sand.
57	9/6/75	12:30 PM	PDO-RE	Vehicle 1 stopped in traffic was rear ended by vehicle 2.
58	9/9/75	5:30 PM	PDO-RE	Vehicle 1 stopped in traffic was rear ended by vehicle 2.
59	9/10/75	5:00 PM	I-RE	At merge vehicle 1 drove around barricades to quickly get into traffic stream; vehicle 1 was then rear ended by vehicle 2.
60	9/12/75	3:30 PM	PDO-SS	Vehicle 1 was struck in side by vehicle 2 at on ramp with yield sign.
61	9/13/75	12:25 PM	PDO-RE	Vehicle 1 stopped in traffic was rear ended by vehicle 2.
62	9/13/75	12:35 PM	PDO-RE	Vehicle 1 stopped in traffic was rear ended by vehicle 2. Driver 2 distracted by previous accident.
63	9/14/75	1:30 PM	PDO-RE	Vehicle 1 stopped quickly in traffic was rear ended by vehicle 2.
64	9/15/75	3:55 PM	I-RE	Vehicle 1 slowing in traffic was rear ended by vehicle 2.
65	9/16/75	2:45 AM	PDO-SS	Vehicle 1 traveling in barricaded lane attempted to re-enter traffic in open lane, was struck in side by vehicle 2.
66	9/17/75	8:50 PM	PDO-RE	Four vehicle rear end accident.
67	9/20/75	1:45 AM	PDO-RE	Vehicle 2 traveling 50-55 mph was rear ended by vehicle 1.
68	9/21/75	2:30 PM	PDO-RE	Vehicle 1 entering from ramp was rear ended by vehicle 2.
69	9/26/75	1:00 PM	PDO-FO	Uninvolved vehicle entered roadway from ramp. Vehicle 1 swerved to the left to avoid vehicle from ramp and hit concrete median barrier.
70	9/26/75	3:50 PM	PDO-FO	Driver lost control of vehicle and knocked down 2 barricades.

TABLE G-1 (concluded)

No.	Date	Time	Type	Contributing Factors
71	9/28/75	7:00 PM	PDO-RE	Three vehicles stopping for traffic involved in rear end accident.
72	9/30/75	1:00 PM	PDO-RE	Vehicle 1 stopped for traffic was rear ended by vehicle 2.
73	10/1/75	7:10 AM	PDO-SS	Vehicle 1 and 2 in avoiding out of control vehicle collided.
74	10/1/75	6:10 AM	PDO-SS	Vehicle 1 attempting to stop at ramp end, skidded on wet pavement and sand from construction, struck vehicle 2 in right rear.
75	10/1/75	2:45 PM	PDO-SS	Vehicle 1 entering from ramp struck vehicle 2 in side.
76	10/3/75	7:35 AM	PDO-RE	Vehicle 1, stopped in traffic was rear ended by vehicle 2.
77	10/6/75	11:00 AM	PDO-RE	Vehicle 1 stopped at yield sign on ramp was rear ended by vehicle 2.
78	10/7/75	4:45 PM	PDO-RE	Vehicle 1 stopped in traffic was rear ended by vehicle 2.

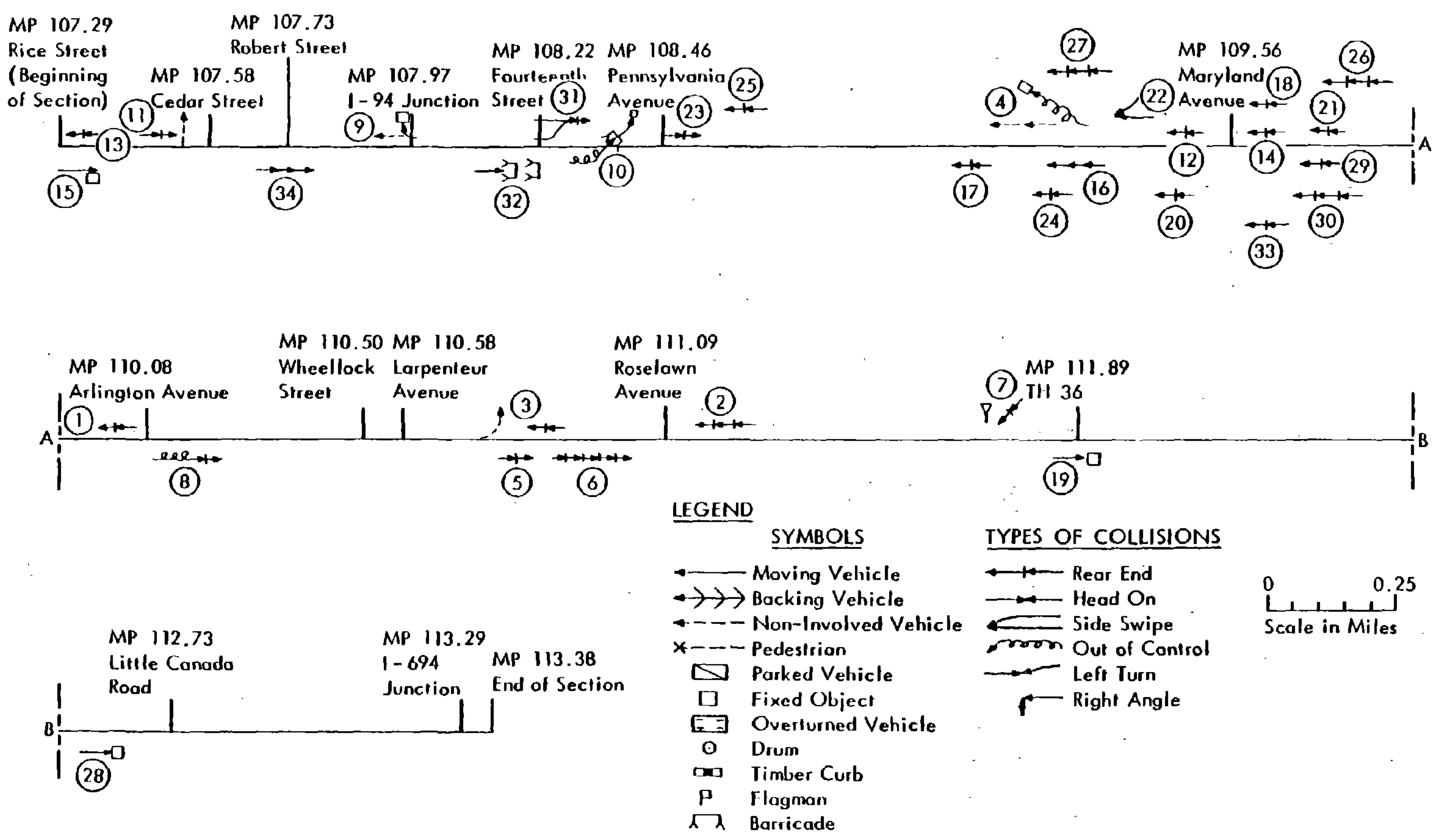


Figure G-3 - Collision Diagram--July 11-31, 1975

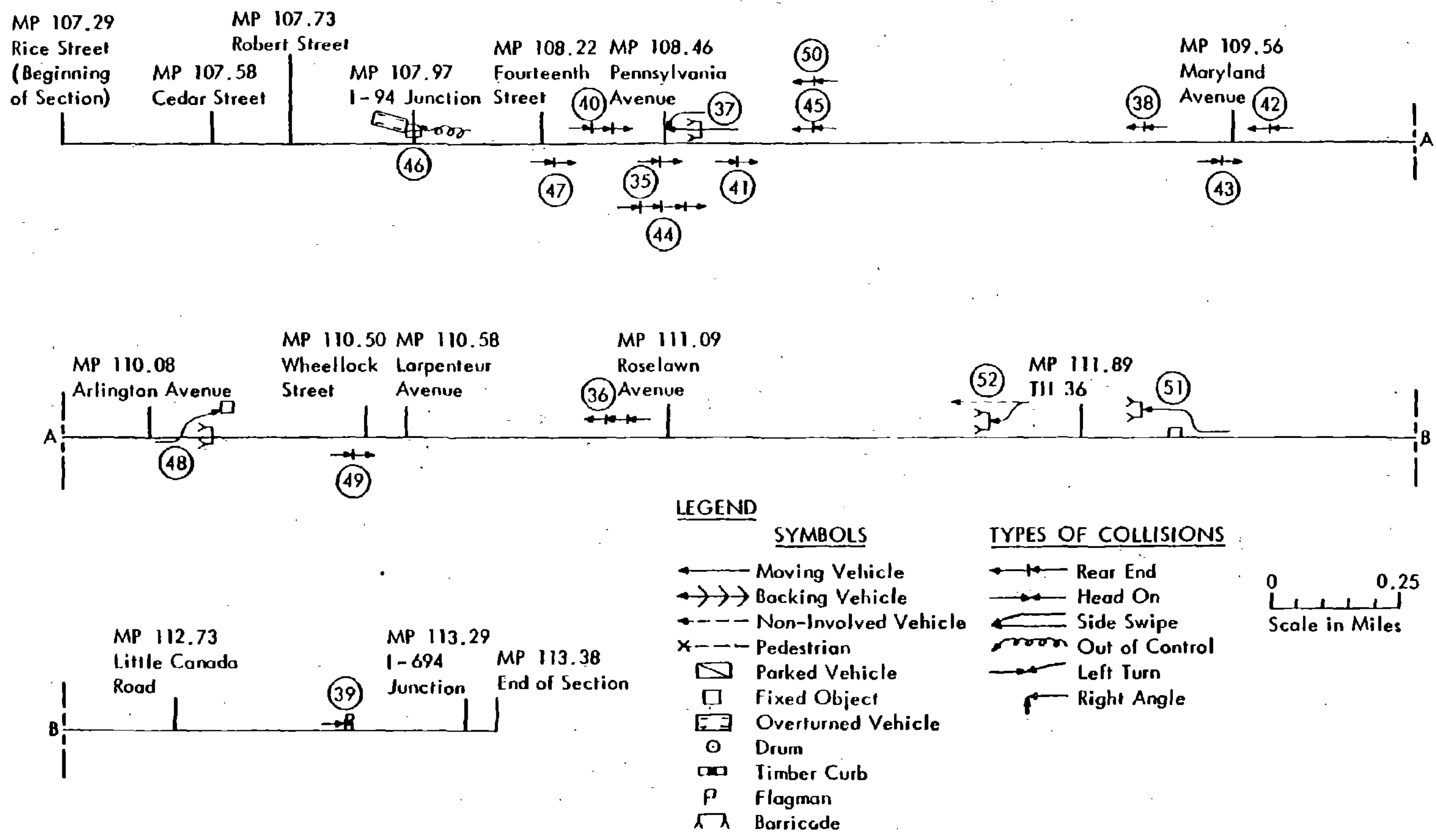


Figure G-4 - Collision Diagram--August 1-31, 1975

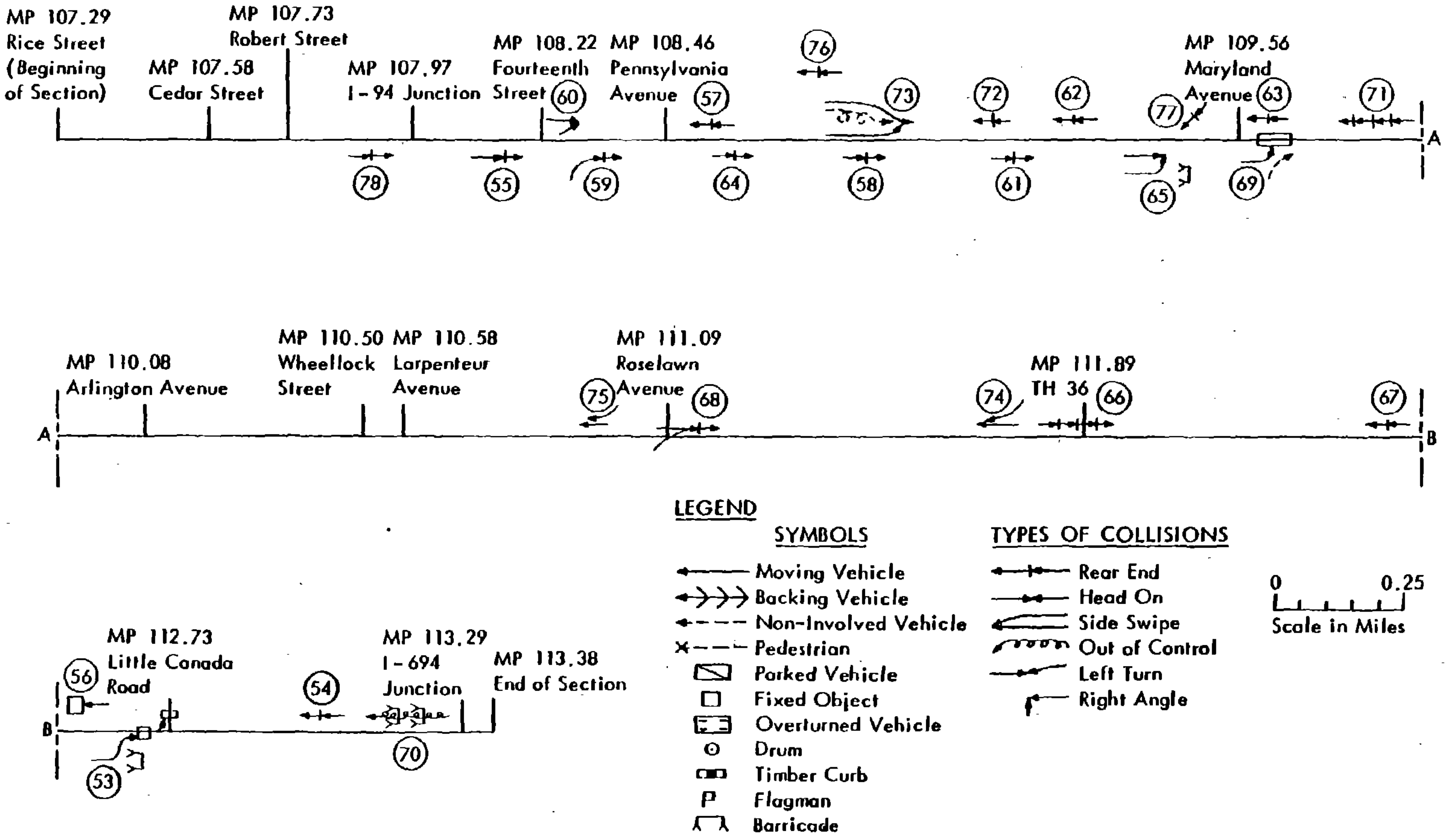


Figure G-5 - Collision Diagram--September 1 to October 7, 1975

Reports were available for all 103 accidents. Rear-end accidents related to construction accounted for 49 accidents. Five accidents were judged as being precipitated by construction, and 24 accidents were judged to have been affected by construction. Twenty-five accidents were at cross street ramp terminals or were not affected by construction.

Construction-related accidents (categories 1, 2, and 3) are listed in Table G-1. Figures G-2, G-3, and G-4 are collision diagrams for each of the 3 months of construction. Although the collision diagrams generally show that accidents were not confined to any one area of the zone, the section from Pennsylvania Avenue to Maryland Avenue showed the highest accident concentration. Highway department personnel who had worked on the project were recontacted and asked about the accident concentration, since none of the data collected on the project explained why this area was a high-accident section. They explained that major bridge reconstruction work had been done on the south bound roadway. This bridge had no shoulders and when two lanes were closed the roadway open to traffic was narrow. This restricted section caused long queues and resulted in the concentration of rear end accidents.

Case Study Summary

Analysis of this project indicates a very definite increase in both the total accident rates and the injury accident rate. Even though the injury accident rate did increase, there was a higher percentage of injury accidents in the before period than the during period. Most of the accidents during construction were rear-end accidents that probably occurred as a result of long traffic queues originating from the protion of the roadway where the number of lanes dropped from six to two. Even though the well-planned and aggressively promoted public information campaign diverted 35% of the traffic volume to other streets, the construction roadway was not of adequate capacity to handle traffic on the roadway without creating queues.

Other accidents that might have been avoided occurred when vehicles ran into piles of broken concrete or sand on the roadway. There also seemed to be a definite problem with the on-ramp yield sign when traffic was limited to the left-hand lane. Conversations with highway personnel revealed that the on-ramp tapers were shortened in some cases to do joint repair work near the ramp entrance.

In conclusion the case study analysis shows that, although a large percentage of traffic was removed from the roadway, there was still an increase in total accident and injury accident rates. Most of the increase in accident numbers could be attributed to rear-end accidents that occurred when queues formed.

APPENDIX H

CONSTRUCTION ZONE ACCIDENTS

(Case Study 3)

CASE STUDY NUMBER 3

Roadway

The project was located on a 2.85 mile section of four-lane divided roadway at the edge of a urban area. Within the section is one crossroad and three additional U-turn crossovers (two of which were modified for construction zone crossovers). In the year prior to construction, the roadway section carried an ADT of 7,625 vpd.

Description of Work

The work involved grading, drainage, partial roadway surfacing, and bridge surfacing.

Project Duration

The project began on August 20, 1975, and the phase of work being analyzed here was completed on December 19, 1975, when work was suspended for the winter.

Construction Sequence

On August 20, traffic was diverted from the northbound roadway by means of crossovers at mile point 55.18 and mile point 56.86 and two-way traffic was carried on the southbound roadway.

On November 18, the directions of the crossovers were reversed, the southbound roadway was closed, and two-way traffic was switched to the northbound raodway.

On December 19, construction was suspended, and all lanes were opened to traffic.

Traffic Control

Figure H-1 shows the traffic control plan with two-way traffic on the northbound raodway used in the Spring of 1976. Although there was no written record of the sign and barricade locations for the 1975 closures, the state construction personnel assured that it was virtually identical to the 1976 layout. The state personnel also assumed that the 1975 closing of northbound lanes (with two-way traffic on the southbound lanes) must have been generally reversed from the layout shown in Figure H-1.

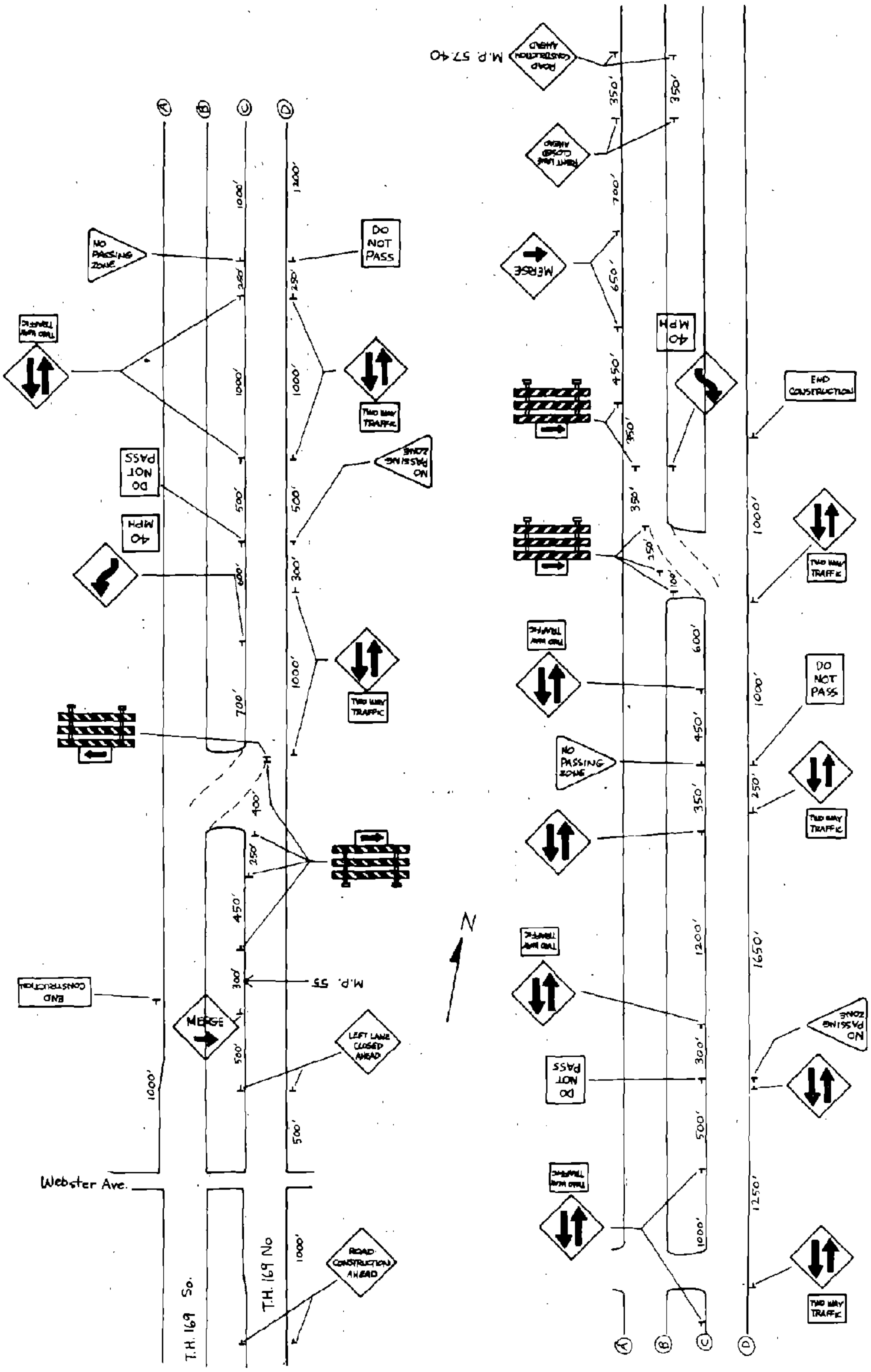


Figure H-1 - Project Traffic Control Plan

NOT REPRODUCIBLE

As is seen from Figure H-1, a multitude of signs was used to warn drivers of the traffic operations in the construction zone. At least seven "two-way traffic" signs were used in each direction. At the crossovers, reverse curve signs were used along with 40-mph advisory speed plates. Taper and crossover delineation was achieved with Type III barricades. No direct traffic control information, however, was provided for drivers entering from crossroads or other access points.

Although Figure H-1 is not entirely clear, it indicates that there was a 700 ft taper for a right-lane closure immediately upstream of the single-lane crossover. This layout does not comply with the MUTCD which specifies a distance of 500 ft between the end of the taper and the beginning of the crossover.

Before-During Accident Experience

Fourteen accidents occurred during the 4-month period of construction zone traffic control. Nine of these were during the 3-month period where two-way traffic was on the northbound roadway and five when two-way traffic was on the southbound roadway. The equivalent before and during period had four and one accidents, respectively, for the traffic control strategies.

The number and rate of accidents increased 180% from the before to during period. For the period where two-way traffic was on the southbound raodway, the increase was 125% and for the period where two-way traffic was on the northbound roadway the increase was 400%.

Comparing the types of accidents in the before and during periods, the night accident proportion of total accidents was 60% in the before period and 50% in the during period. The percentage of rear-end and side-swipe (same direction) accidents decreased from 60% of the total accidents in the before period to 14% of the during accidents. Fixed object accidents increased from 0% to 44% and head-on accidents increased from 0% to 21%.

The severity breakdown in the before period was 60% PDO, and 40% injury accidents. In the during period there were 86% PDO, and 14% injury accidents.

The ADT for the highway section was 7,625 vpd during the before period with no indicated or expected diversion during the construction period. If the 7,625 ADT is used to compute accident rates in the zone the before rate is 1.86 acc/million vehicle miles and the during rate is 5.23 acc/million vehicle miles.

Accident Report Analysis

The accident reports during construction were examined and divided into the following categories.

1. Precipitating cause of the accident highly related to construction activity or roadway. Example: Vehicle overturned while negotiating sharp curve on construction zone crossover.

2. Accident occurrence or severity affected by construction. Example: Vehicle leaves roadway and loses control because of low shoulder.

3. Accident did not appear to have been precipitated or affected by construction.

Table H-1 lists all the accidents that were judged to have been precipitated or affected by the construction. Eight of the 14 during accidents were related to the construction zone traffic control.

Case Study Summary

Analysis of this project indicates a definite increase in accidents during the construction period.

The during period had nine more accidents, eight of which were related to the construction. Of these construction related accidents, four involved the lane taper-crossover areas and three involved collision between opposing vehicles in the two-way traffic areas. Possible corrections to the traffic control layout would be to increase the distance between the lane taper and the crossover and to prohibit passing throughout the entire two-way traffic area. However, the average severity of accidents in the during period was considerably reduced.

TABLE H-1

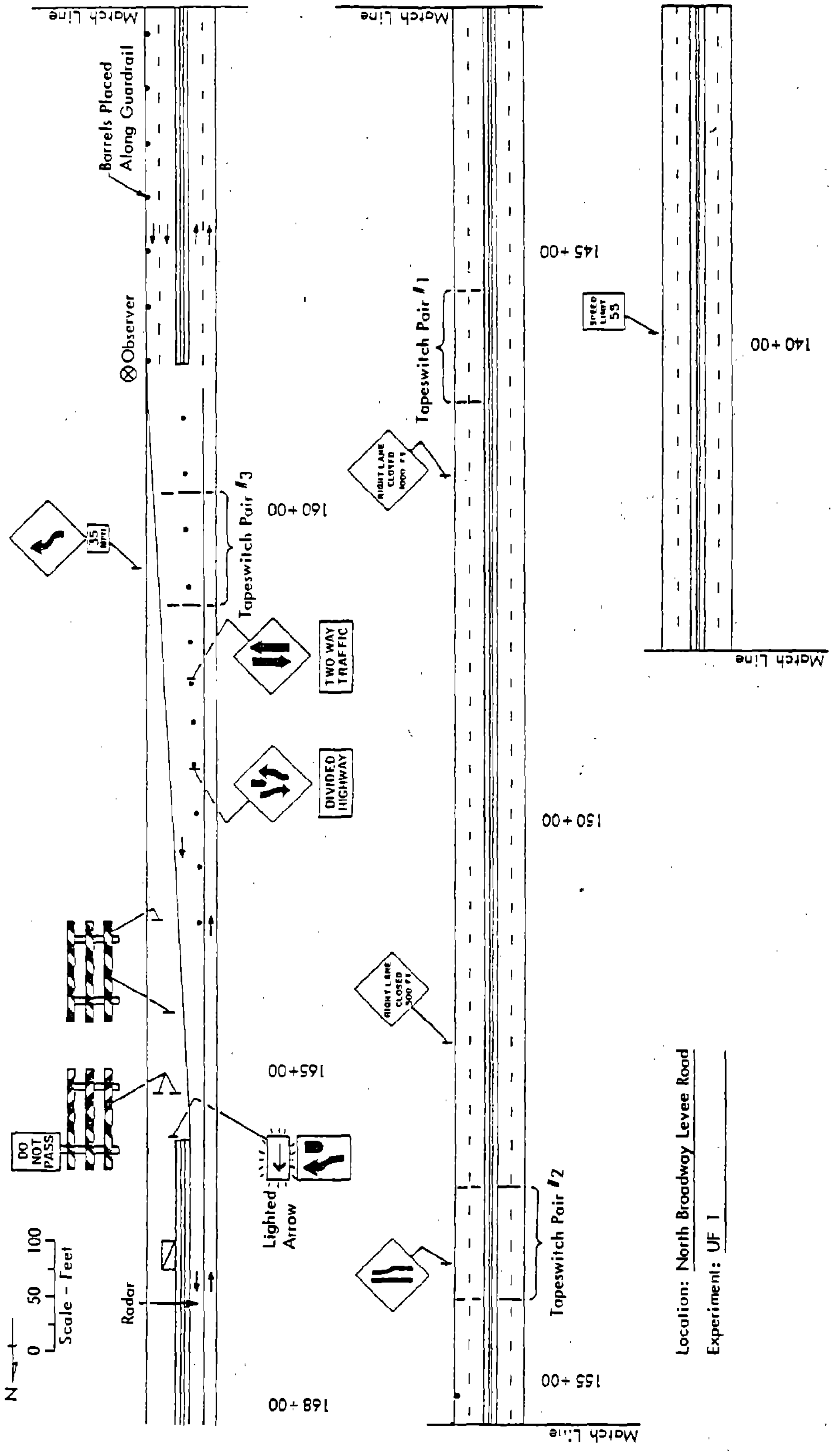
CASE STUDY ACCIDENTS RELATED TO CONSTRUCTION ZONE

Date	Time	Type	Severity	
TWO-WAY TRAFFIC ON SOUTHBOUND ROADWAY				
10/23/75	10:30 PM	Fixed-object	PDO	Northbound vehicles ran off road in rain at south crossover and hit metal stake.
10/23/75	10:35 AM	Head-on sideswipe	PDO	Vehicle southbound on two-way section just beyond north crossover for northbound traffic. Vehicle was in the wrong lane and sideswiped two northbound vehicles.
10/26/75	10:35 AM	Head-on sideswipe	PDO	Vehicle southbound on two-way section just beyond north crossover for northbound traffic. Vehicle pulled out to pass conflicting with a northbound vehicle. In attempting to return to right lane with passing vehicle lost control and sideswiped northbound vehicle.
10/28/75	9:00 PM	Fixed-object	PDO	Northbound vehicle ran off road at south crossover and hit barricade.
TWO-WAY TRAFFIC ON NORTHBOUND ROADWAY				
11/18/75	7:00 PM	Fixed-object	PDO	Northbound vehicle forced off road by another northbound vehicle in taper area of south crossover. Vehicle went through median ditch, across southbound lanes, through roadside ditch, and collided with a fence.
11/24/75	11:52 PM	Fixed-object	PDO	Southbound vehicles ran off road at south crossover and hit barricade.
12/6/75	7:00 PM	Rear-end	Injury	Northbound vehicle in center of two-way section unable to stop and sideswiped another northbound vehicle stopped in traffic and then hit southbound vehicle head on.
12/18/75	5:15 PM	Fixed-object	PDO	Northbound vehicle in center of two-way section moved into left lane for left-turn into path of southbound vehicle. The southbound vehicle ran into median to avoid collision and hit a sign.

APPENDIX I

FIELD STUDY PLAN DRAWINGS

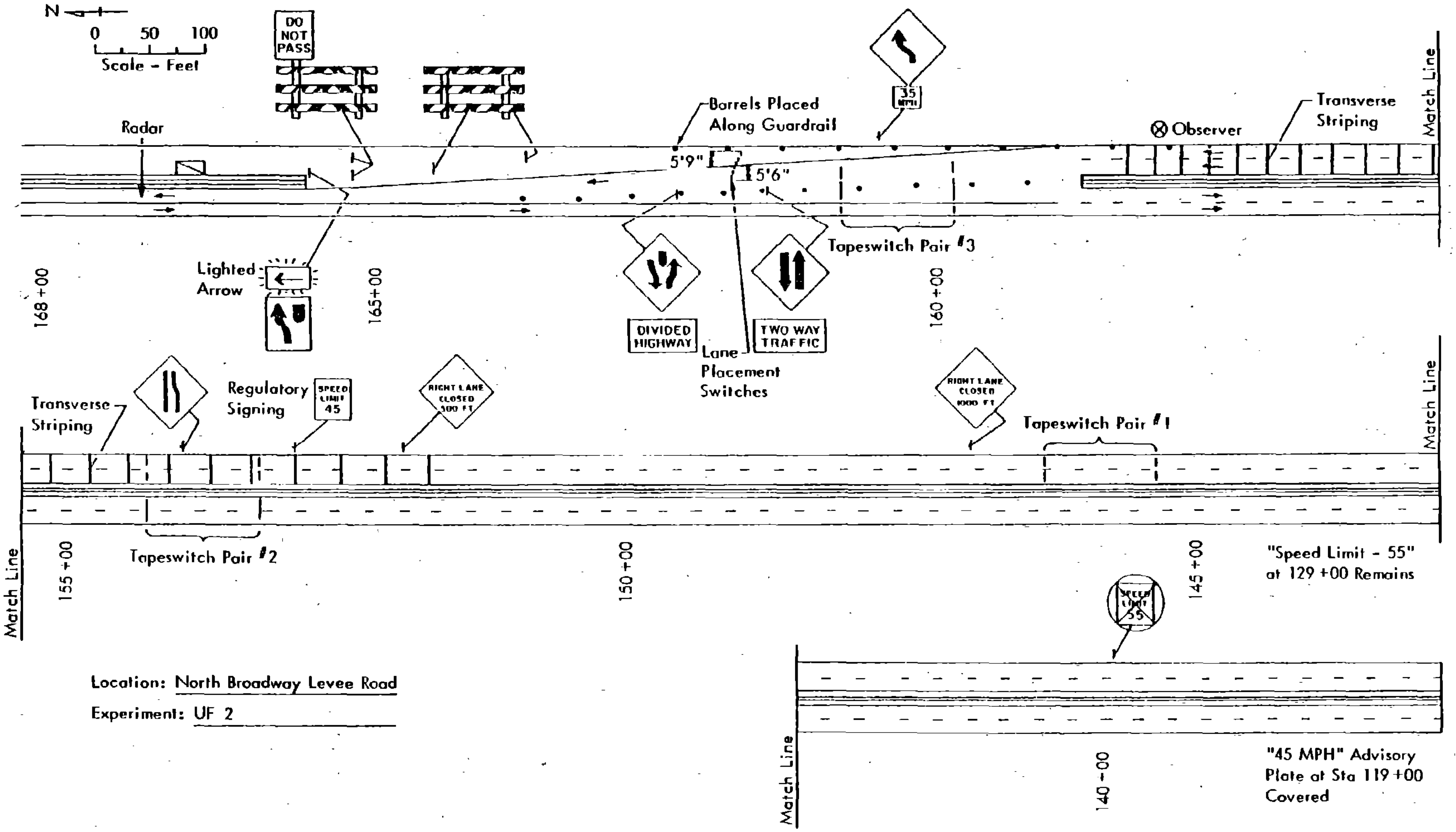
CONSTRUCTION ZONE SPEED TESTING



Location: North Broadway Levee Road

Experiment: UF 1

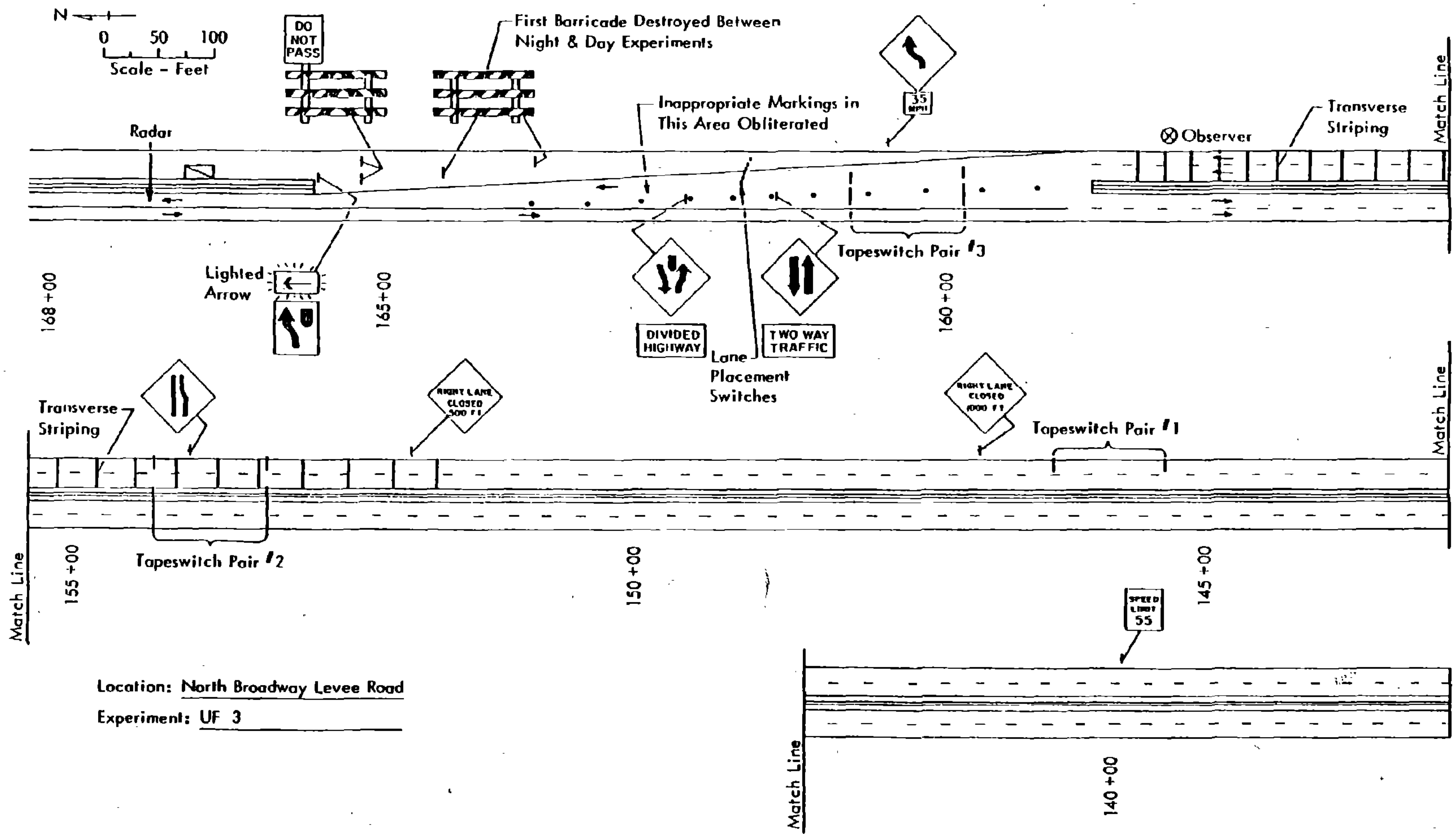
CONSTRUCTION ZONE SPEED TESTING



Location: North Broadway Levee Road

Experiment: UF 2

CONSTRUCTION ZONE SPEED TESTING

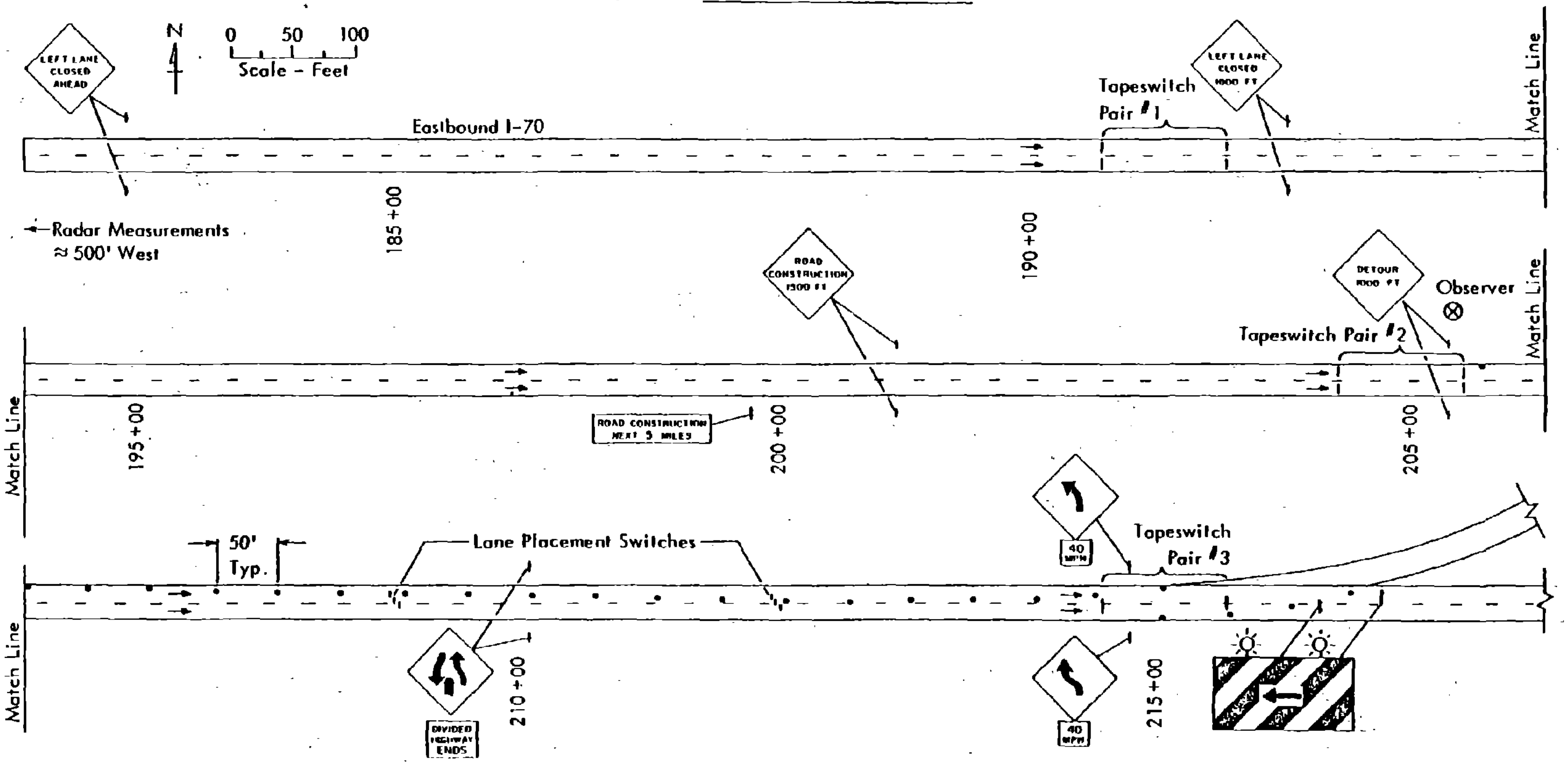


Location: North Broadway Levee Road

Experiment: UF 3

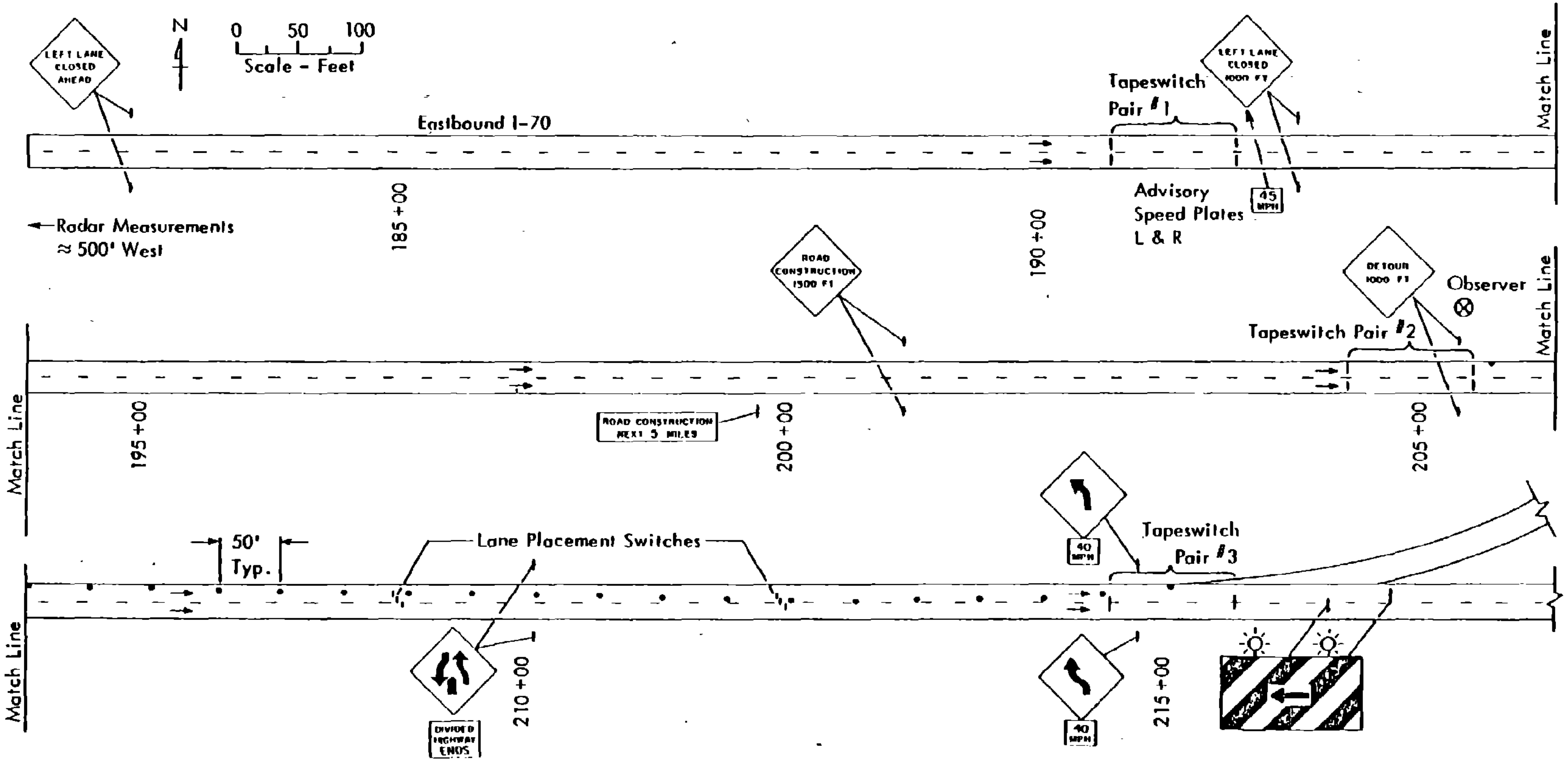
CONSTRUCTION ZONE SPEED TESTING

Location: Missouri Project I-IG-70-2(28)
(West of Odessa)
Experiment: RF 1 (8/25/76)



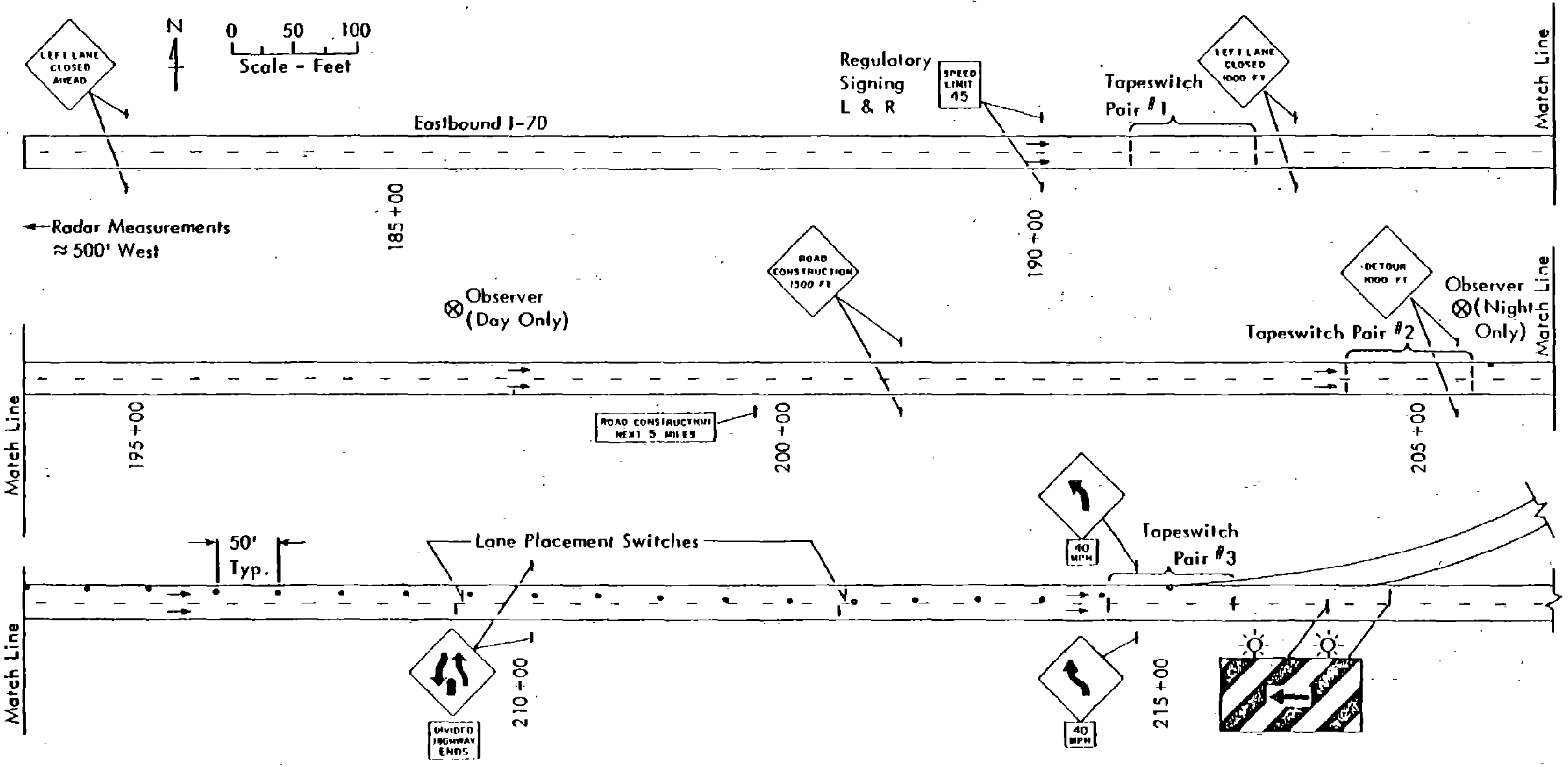
CONSTRUCTION ZONE SPEED TESTING

Location: Missouri Project I-IG-70-2(28)
(West of Odessa)
Experiment: RF 2 (8/31/76)



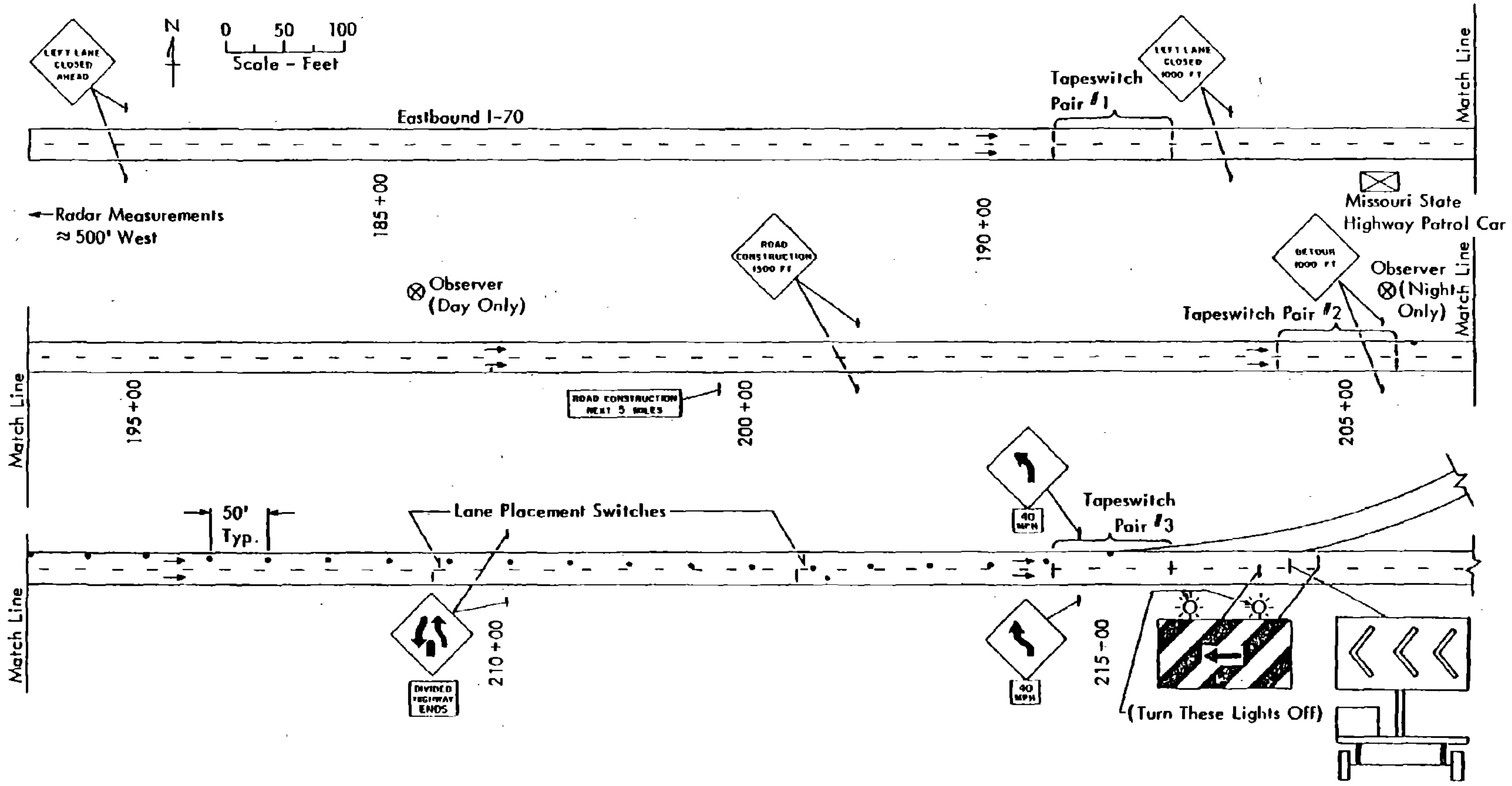
CONSTRUCTION ZONE SPEED TESTING

Location: Missouri Project I-IG-70-2(28)
(West of Odessa)
Experiment: RF 3 (9/14/76)



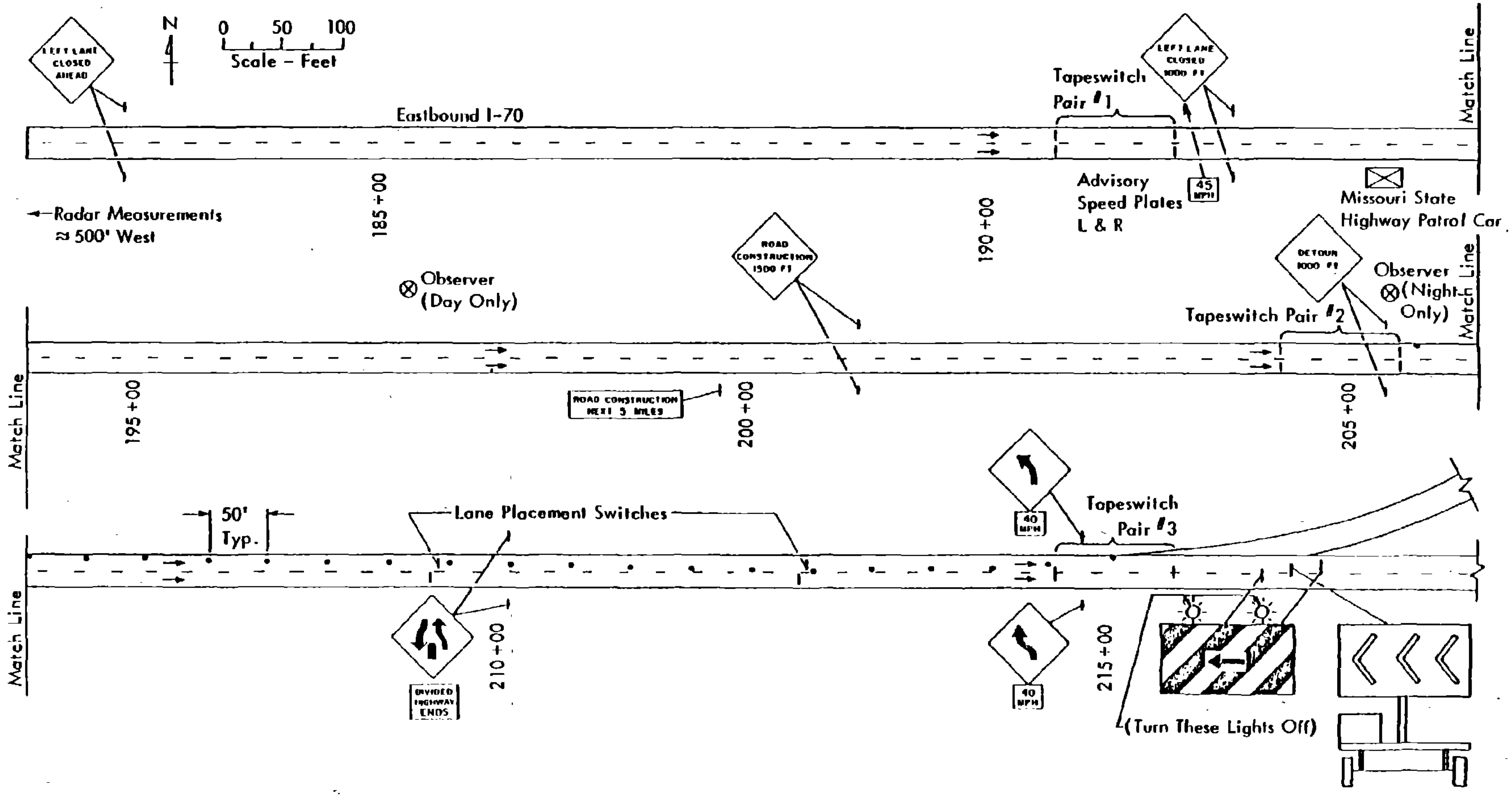
CONSTRUCTION ZONE SPEED TESTING

Location: Missouri Project I-IG-70-2(28)
(West of Odessa)
Experiment: RF 4 (9/21/76)



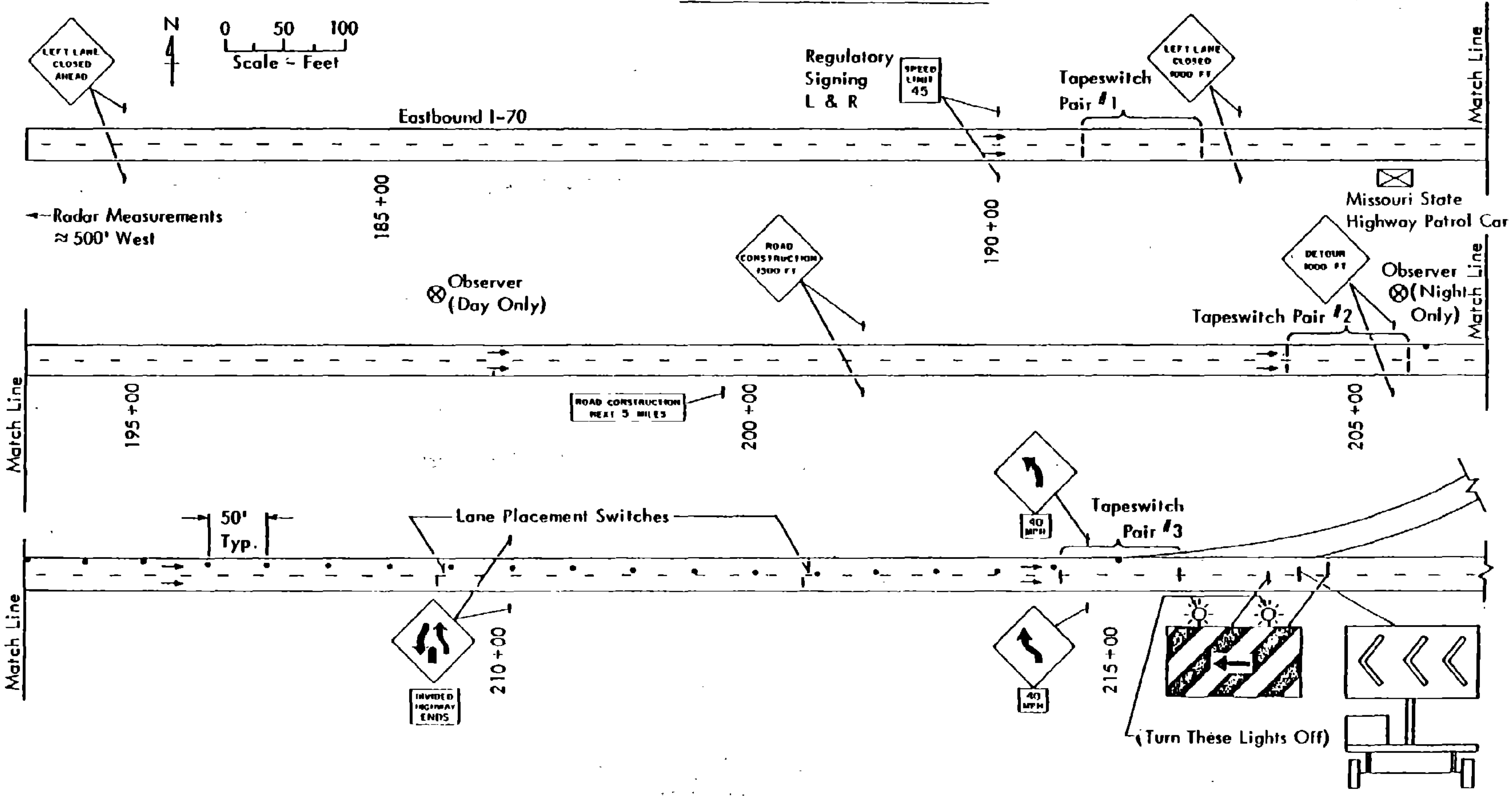
CONSTRUCTION ZONE SPEED TESTING

Location: Missouri Project I-IG-70-2(28)
(West of Odessa)
Experiment: RF 5 (9/22/76)



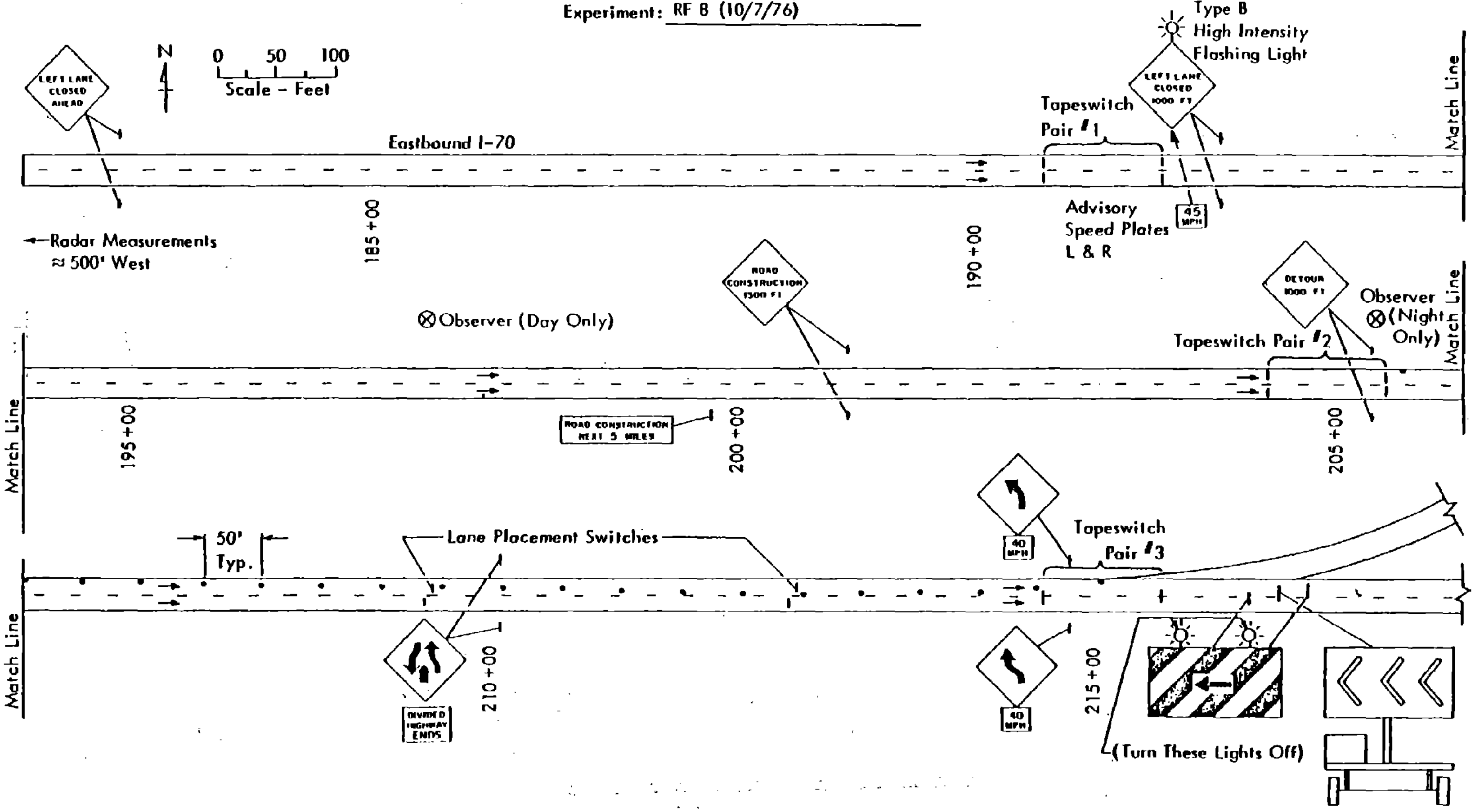
CONSTRUCTION ZONE SPEED TESTING

Location: Missouri Project I-IG-70-2(28)
(West of Odessa)
Experiment: RF 6 (9/23/76, 10/5/76 & 10/21/76)



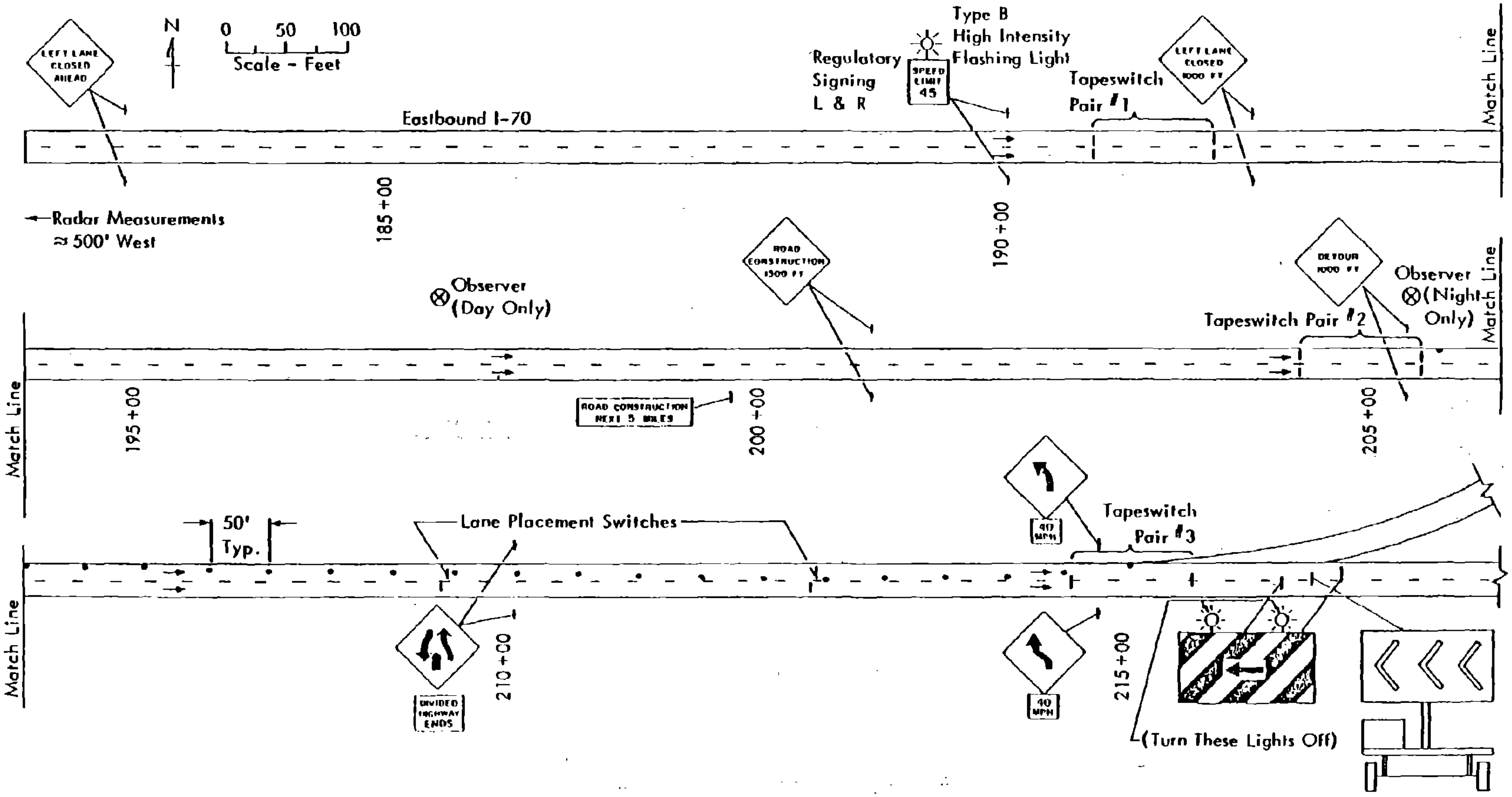
CONSTRUCTION ZONE SPEED TESTING

Location: Missouri Project I-IG-70-2(28)
(West of Odessa)
Experiment: RF 8 (10/7/76)



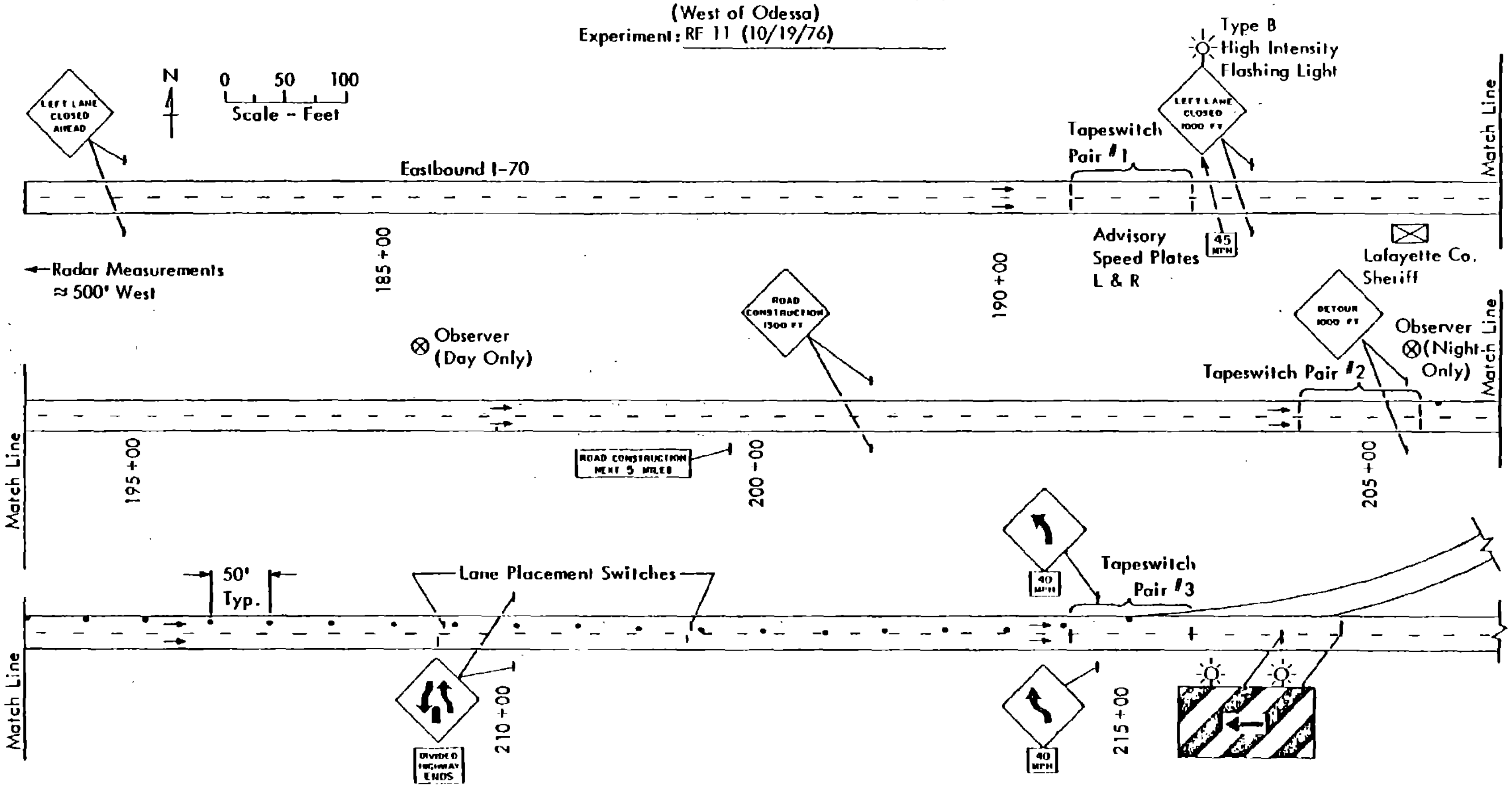
CONSTRUCTION ZONE SPEED TESTING

Location: Missouri Project I-IG-70-2(28)
(West of Odessa)
Experiment: RF 9 (10/6/76)



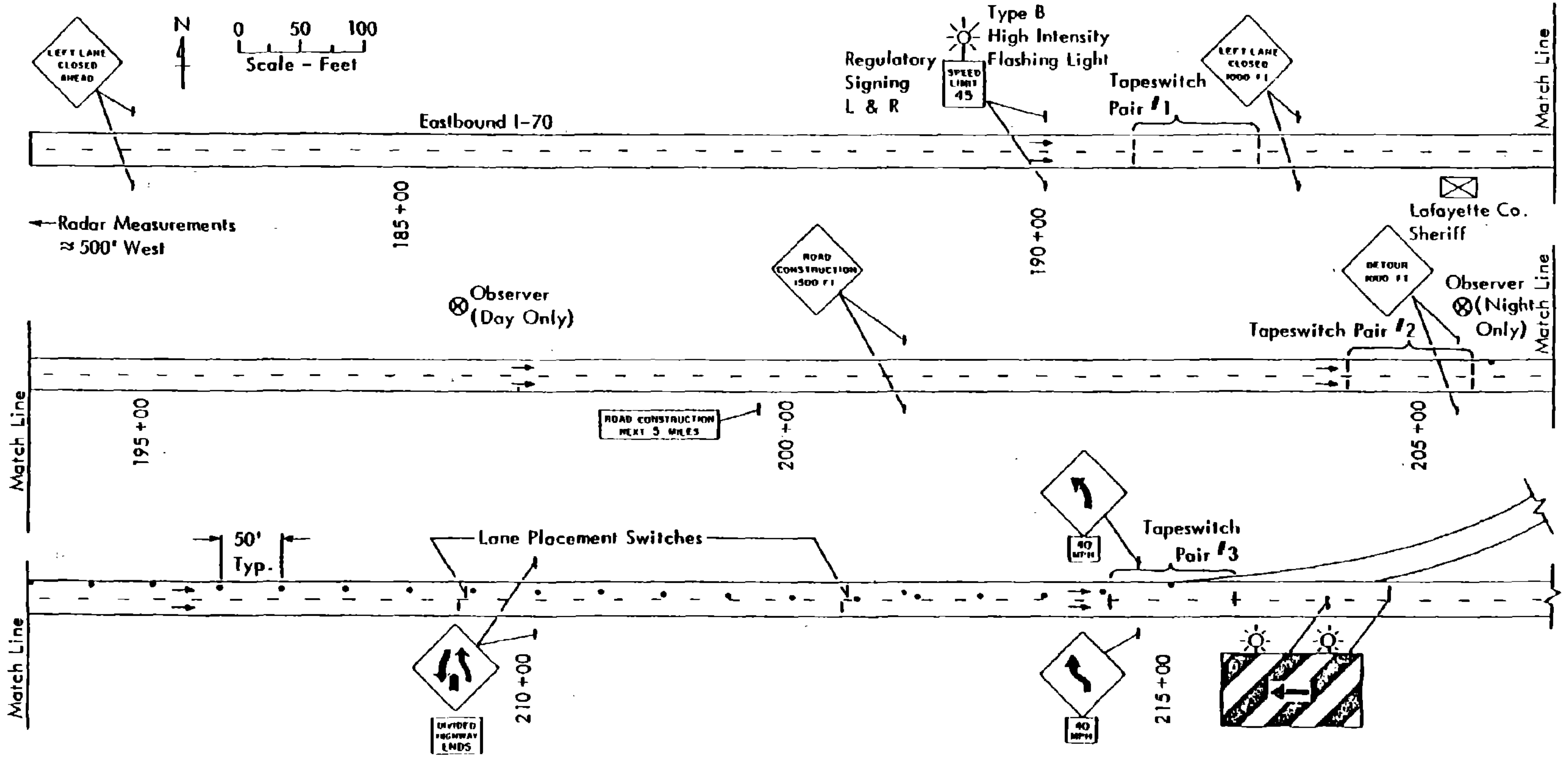
CONSTRUCTION ZONE SPEED TESTING

Location: Missouri Project I-IG-70-2(28)
(West of Odessa)
Experiment: RF 11 (10/19/76)

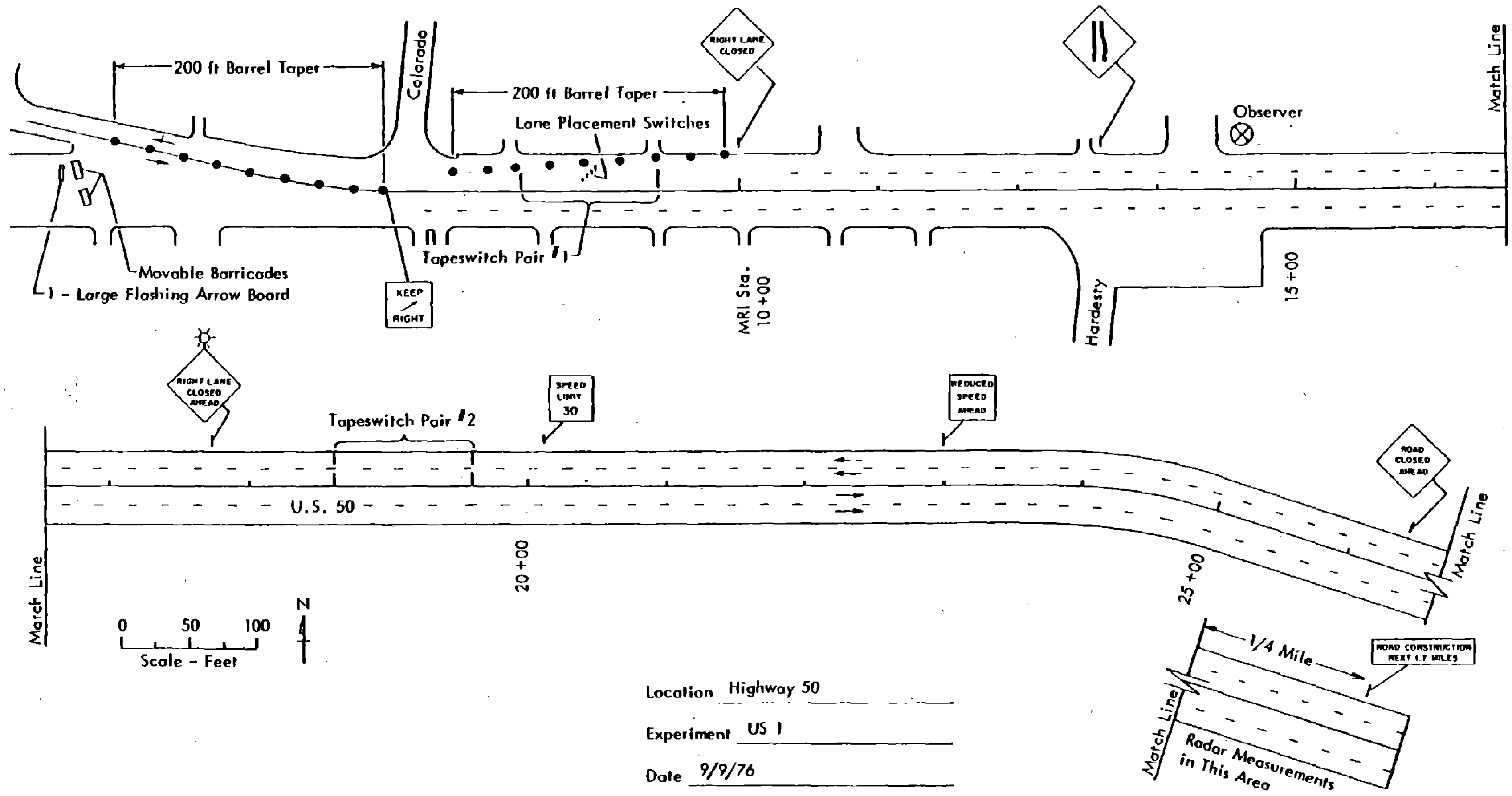


CONSTRUCTION ZONE SPEED TESTING

Location: Missouri Project I-IG-70-2(28)
(West of Odessa)
Experiment: RF 12 (10/20/76)



CONSTRUCTION ZONE SPEED STUDIES

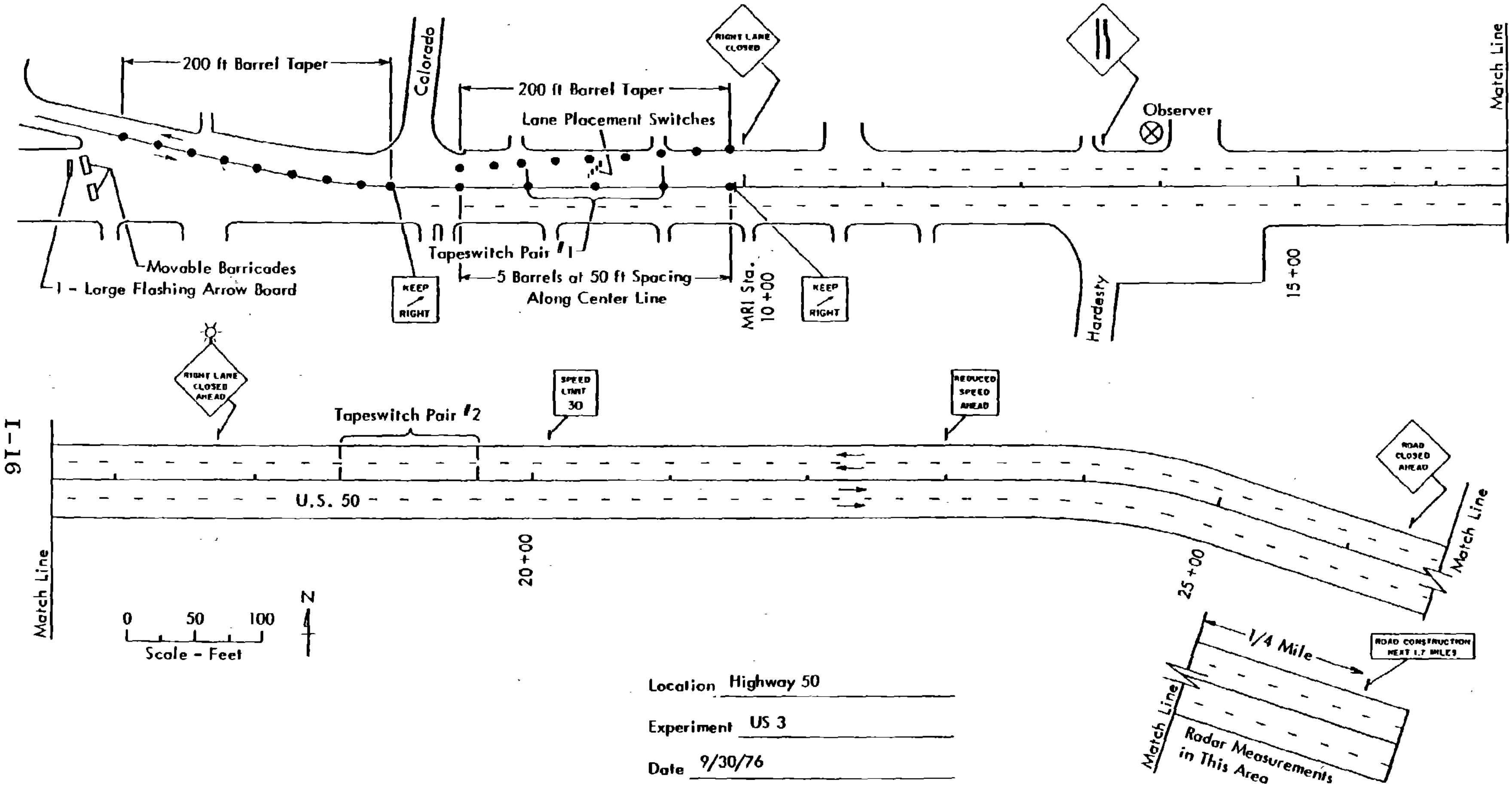


Location Highway 50

Experiment US 1

Date 9/9/76

CONSTRUCTION ZONE SPEED STUDIES

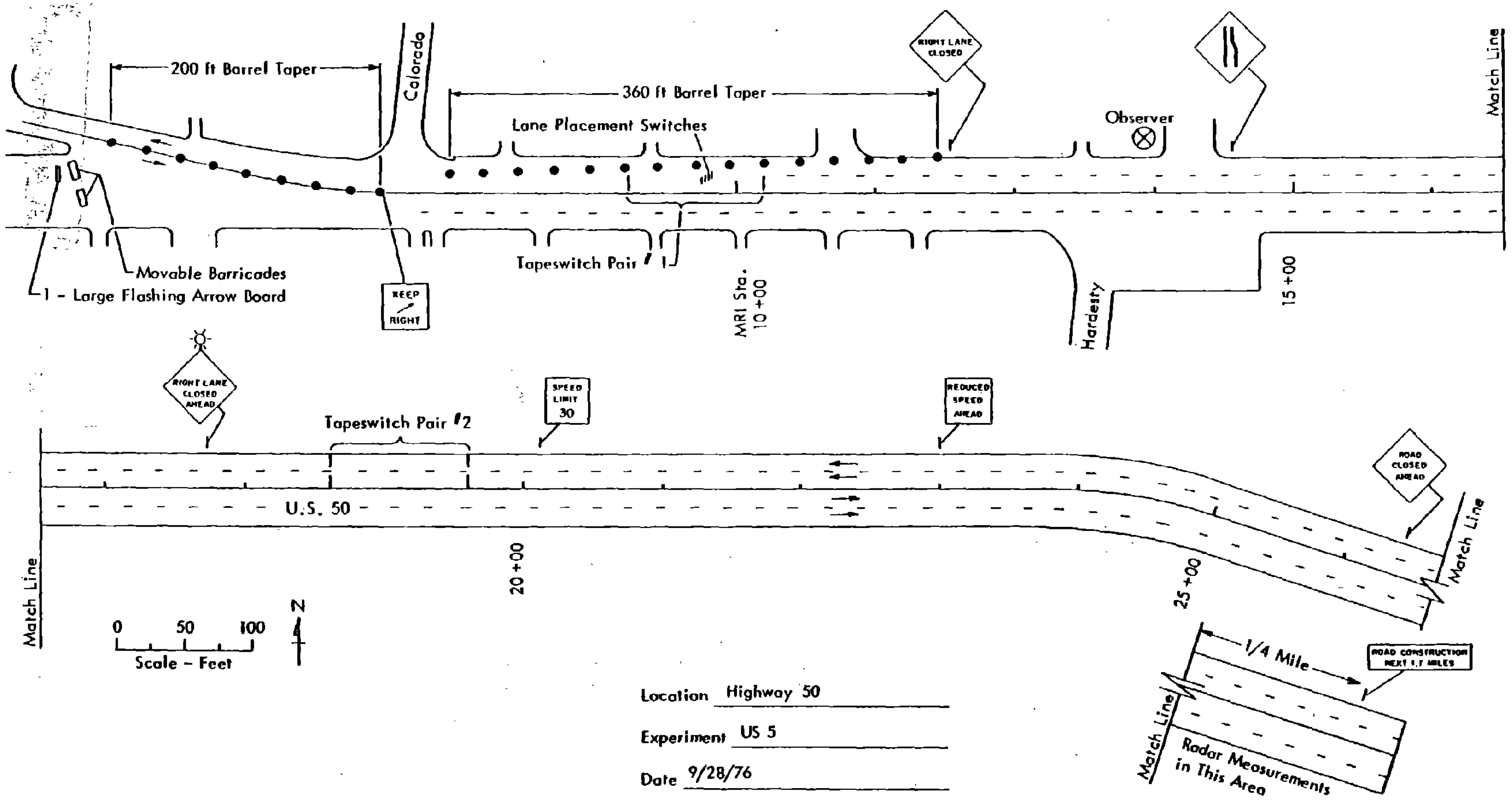


Location Highway 50

Experiment US 3

Date 9/30/76

CONSTRUCTION ZONE SPEED STUDIES

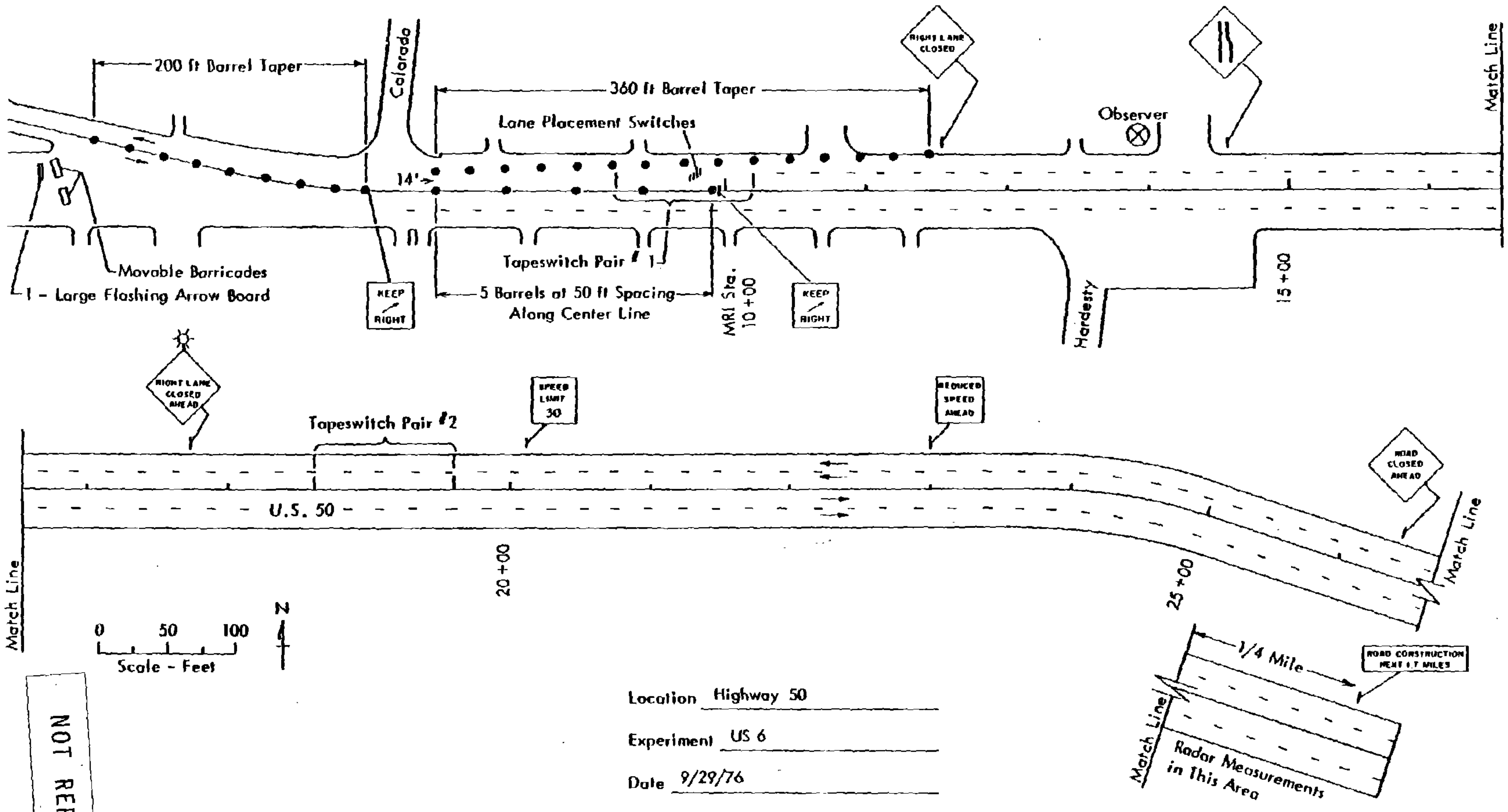


Location Highway 50

Experiment US 5

Date 9/28/76

CONSTRUCTION ZONE SPEED STUDIES



Location Highway 50

Experiment US 6

Date 9/29/76

NOT REPRODUCIBLE

APPENDIX J

FIELD STUDIES DIARY

Experiment UF1

Experiment UF1 was conducted on August 13 and 14, 1976. Placement of the switches began early on the 13th and was concluded in the late afternoon. Several unexpected delays were encountered, many of which were eliminated in later experimental setups. Because of the heavy traffic conditions, five people were needed for setup and for traffic control. Therefore, almost 40 man-hours were used just for the setup. A lighted arrow panel trailer was used to facilitate traffic control during setup. All traffic control, including some short traffic stoppages, went smoothly.

Data were collected for night conditions on the 13th and day conditions on the morning of the 14th. The data collection went very smoothly with all tapeswitches working. The erratic maneuver and conflict counts were very high in the nighttime experiment, with three near-accidents. These counts were very nominal during the daytime experiment. The high nighttime counts appear related to several design and operational deficiencies unrelated to the experimental changes. The prime problem appeared to be the 675-foot taper, which drops the right lane and moves the left lane over about 16 feet, all within the taper.

The major problem with the experiment was the extensive manpower required for setup and removal of experimental equipment. Since the tapeswitches were mounted in protective metal channels, a large portion of time was devoted to nailing down and prying up the switches (in fairly heavy traffic). The total setup and takedown required over 60 man-hours as compared to about 15 man-hours for the experiment itself. In addition, because the tapeswitch channels were so difficult to pry up, many of the channels were severely damaged. To alleviate these problems, the tapeswitches were removed from the channels and taped down with duct tape on all subsequent experiments.

Experiment UF2

On August 18, 1976, the transverse pavement stripes and 45-mph advisory speed plate were installed. Striping was installed using specifications established by the Michigan Department of Transportation. The MRI traffic control (flagging and lighted arrow panel) went smoothly.

On August 20, 1976, the experimental equipment was installed. Using the duct tape led to a much more efficient installation, which only required about 20 man-hours. The equipment removal was also done more efficiently, requiring about 15 man-hours. Again, the traffic control (flagging and lighted arrow panel) was done without major problems.

Data were gathered for nighttime operations on August 20, 1976, and aytime operations on the morning of August 21, 1976. The major problem was he malfunctioning of two tapeswitches, which caused some loss of data in two peed traps.

Experiment UF3

On August 26, 1976, the inappropriate pavement markings on the crossover transition were removed by sandblasting. The sandblasting was performed between 6:00 and 8:00 PM at the request of the Kansas City Department of Transportation.

The tapeswitches were placed in the morning of August 27, 1976. When the crew arrived that evening, they found that a violent afternoon storm had blown over and damaged two signs, one transition barricade, and barrels. Also, with the rain, four switches were pulled up and damaged beyond repair. The MRI crew replaced the barrels, and propped up the damaged barricade; but because the signs were down and switches destroyed the experiment had to be postponed until September 3-4, 1976.

Tapeswitches were again placed on September 3, 1976. Night measurements were made on the evening of September 3, 1976, and day measurements on the morning of September 4, 1976. No problems were experienced.

The postponement of UF3 caused the loss of Experiment UF4 since construction was completed before the experiment could be scheduled.

Experiment RF1

The experimental equipment was placed in the morning of August 25, 1976. The manpower requirement was now down to about 12 man-hours (which is approximated on all future experiments). Again, no problems were encountered with our traffic control (flagging and lighted arrow panel).

Experiments were conducted in the afternoon and evening of August 25, 1976. In these experiments, two tapeswitches malfunctioned (one new one after 30 minutes of operation), and another was torn up by a large truck under a locked-wheel skidding mode.

Observation by the field crew was that opposing traffic could see our radar setup (used for measuring speeds on the approach) during day measurements and was apparently signaling the other traffic stream via CB radio, etc.

Experiment RF2

The experimental setup went very smoothly. Experiments were similar to RF1, in which heavy truck traffic damaged two switches and where there appeared to be some signaling of our speed trap by opposing vehicles.

Experiment RF3

The tapeswitch installation required 12 man-hours the morning of September 14, 1976 with no problems. The experiments were performed on the afternoon and evening of that same day. One difficulty we encountered was in keeping the stand-mounted 45 mph speed limit signs upright as trucks passed near them.

Experiment RF4

The experimental setup went quite smoothly on the morning of September 21, 1976. The change in traffic control included placement of the lighted arrow panel near the start of the detour and the stationing of the Missouri Highway Patrol along the shoulder of the highway near the beginning of the zone.

The experiments were performed during the afternoon and evening of the same day. The patrolman was only able to assist us for approximately 1 hour 15 minutes during the afternoon and 1 hour during the evening.

Experiment RF5

Experiment RF5 was performed on September 22, 1976. Since Experiment RF4 had been performed the previous day, the tapeswitches were left in place, thus, no setup time was required.

The experiment went smoothly except that the Missouri Highway Patrol was only able to assist us for approximately 35 minutes in the afternoon and 1 hour in the evening.

Experiment RF6

Experiment RF6 was performed September 23, 1976. The tapeswitches had been left in place from the previous day. However, when the MRI survey crew arrived several of the tapeswitches had been pulled up from a rain shower. The crew replaced the damaged tapeswitches, but the afternoon survey was started late. To complicate matters, the Missouri Highway Patrol failed to assist us in either the afternoon or evening.

Experiment RF6 was repeated October 5, 1976. Inclement weather delayed the installation of the tapeswitches until late afternoon. The night survey was performed successfully except for the loss of one switch.

The day survey was scheduled for the following morning. However, when the MRI crew arrived, they found several of the tapeswitches had been pulled up by the traffic. The crew repaired the equipment, but the experiment was canceled because the county sheriff's deputy assisting us was called away.

The day survey was again rescheduled for October 21, 1976. The experiment was performed that morning without incidence.

Experiment RF9

Experiment RF9 was performed on October 6, 1976. The tapeswitches had been installed the previous day for Experiment RF6. The change in traffic control for this experiment included use of the lighted arrow panel and the use of 45-mph regulatory speed limit signs supplemented with Type B high intensity flashing lights. Both the day and night surveys were performed smoothly.

Experiment RF8

Experiment RF8 was performed October 7, 1976. The tapeswitches had remained in place from the previous day of testing. The traffic control was very similar to RF9 except that the regulatory speed limit signs on RF9 were replaced with 45 mph advisory speed plates. Both the day and night surveys were performed without incident.

Experiment RF11

Experiment RF11 was performed on the afternoon and evening of October 19, 1976. The tapeswitch installation required approximately 8 man-hours. The change in traffic control included the lighted arrow panels, 45 mph advisory speed plates supplemented with high intensity flashing lights, and enforcement by the county sheriff.

The afternoon survey was performed smoothly. However, during the evening a light rain curtailed the experiment after 1-1/2 hours.

Experiment RF12

Experiment RF12 was performed on the afternoon and evening of October 20, 1976. The tapeswitches remained in place from the previous day's testing. The only change in traffic control from RF11 was in replacing the 45 mph advisory speed plates with 45 mph regulatory signs. Both studies were conducted with no problems.

Experiment US1

The experimental equipment was placed on the morning and early afternoon of September 9, 1976, requiring approximately 12 man-hours. No problems were encountered with traffic control (flagging and lighted arrow panel).

Experiments were conducted in the afternoon and evening of September 9, 1976. One tapeswitch malfunctioned late in the afternoon survey. Otherwise, the experiments went smoothly.

Experiment US5

Experiment US5 was performed September 28, 1976. Mechanical problems with the vehicle in which experimental equipment was transported caused a delay in the setup, and the afternoon survey had to be shortened. However, the evening survey was performed without incident.

Experiment US6

Experiment US6 was performed on September 29, 1976. The major change in traffic control was in placing barrels along the centerline in the taper. This was done without incident. The afternoon and evening surveys were performed smoothly.

Experiment US3

Experiment US3 was performed September 30, 1976. The traffic control changes, afternoon survey, and evening survey went very smoothly.

* U.S. GOVERNMENT PRINTING OFFICE : 1977 0-729-791/1461