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16. Abstract

This study examines two US 59 work zone sites and their impact on rural highway traffic. After first recording typical traffic under free-flow conditions (using infrared sensors and reflectors mounted just off the pavement), the researchers then monitored vehicle volume and vehicle speed both during and after work zone construction to identify the traffic operational effects resulting from work zone detours and lane closures. Vehicle speeds, along with the effects of various truck volumes, were analyzed.

Two work-zone detour strategies were particularly studied: (1) those involving long-time lane closures using concrete barriers, and (2) those involving temporary lane closures using barrel-type barricades. Lane closures involving concrete traffic barriers produced a smaller reduction in free-flow speeds when compared with lane closures of temporary barrel-type barriers.

Vehicle speeds through the two work zones were also determined to be influenced by truck volumes and total traffic. Moreover, vehicle speeds were found to vary at different times of the day and during weekdays and weekends. As this study confirmed, lane distribution of traffic on a normal four-lane divided highway varies with increased traffic volume, with a tendency for traffic to distribute equally between the two lanes.

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EFFECTS OF WORK ZONE DETOURS ON RURAL HIGHWAY TRAFFIC OPERATIONS

by

Clyde E. Lee
Safry Kamal Ahmad

Research Report 987-2

Research Project 3-110-89/94-987

A Long-Range Plan for the Rehabilitation of US 59 in District 11

conducted for the

Texas Department of Transportation

by the

CENTER FOR TRANSPORTATION RESEARCH
Bureau of Engineering Research
THE UNIVERSITY OF TEXAS AT AUSTIN

May 1993

IMPLEMENTATION

Traffic studies at two rural-highway work-zone locations on US 59 were undertaken so as to evaluate the effects of lane closures and road detours on vehicle operations. In this evaluation, infrared reflex beam sensors and retroreflectors were used to record the number of vehicles and to obtain speed measurements of vehicle-axles. The sensors and retroreflectors were installed at various locations to indicate the different operating characteristics of vehicles at the work zones and under the normal two-lane (one-directional) traffic flow. *Through-beam* infrared sensor transmitter-receiver units were used to provide information about the volume of traffic at each travel lane and to classify vehicles as either single- or dual-tire (thus differentiating between passenger cars and trucks). Manual counts were performed to verify the data collected. This study facilitates the forecasting of future traffic growth along this rural highway, given that the traffic volume on the northbound and southbound lanes showed a consistency and similarity in pattern. The patterns of observed vehicle speeds at the two different types of work-zone will provide engineers with information concerning appropriate speed limits and design speed for future rural highway work-zone locations.

Prepared in cooperation with the Texas Department of Transportation.

DISCLAIMER

Clyde E. Lee, P.E. (Texas No. 20512)
Research Supervisor

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SUMMARY

This study examines two US 59 work zone sites and their impact on rural highway traffic. After first recording typical traffic under free-flow conditions (using infrared sensors and reflectors mounted just off the pavement), the researchers then monitored vehicle volume and vehicle speed both during and after work zone construction to identify the traffic operational effects resulting from work zone detours and lane closures. Vehicle speeds, along with the effects of various truck volumes, were analyzed.

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CHAPTER 1. INTRODUCTION

BACKGROUND

Road detours necessary for diverting traffic during lane closures can impact highway service in many ways. Besides slowing traffic flow, lane closures and detours can adversely affect the safety of road users and highway workers. Moreover, traffic delay and congestion caused by road detours can increase vehicle operating costs and vehicle emissions—problems currently being addressed by various governmental agencies.

While the impacts of lane closures have been analyzed with respect to urban highways, there has been less focus on the operational and environmental problems attributable to lane closures in work zones on rural highways. The purpose of investigating rural highway work zones is to improve the overall management of road construction and maintenance; to enhance the safety of long distance travelers; to minimize inconvenience to travelers; and to reduce accident risks for both drivers and construction workers. In addition, findings from the study of traffic operations at rural highway work zones can be useful in resolving potential conflicts between roadwork activities and motorists.

SCOPE AND OBJECTIVES OF STUDY

The objective of this research study is to evaluate the effects of work zone detours on traffic operations at rural highway sites, where traffic volume is relatively low and vehicle speeds are relatively high. Relationships among traffic volume, composition, and speed will be used to analyze and to assess the influence of lane closures on a four-lane, divided highway in East Texas. In this study, two types of work zone lane-closure strategies were carried out. The first type of lane closure involved the use of a mile-long series concrete traffic barriers, while the second type of lane closure, in which a series of short pavement test sections were constructed one-at-a-time, involved the use of temporary barrel-type barricades. These lane closures made it possible for traffic operations to be analyzed under two different work zone lane-closure strategies. A traffic analysis of normal four-lane divided-highway operations was initiated during the post-construction period to study (by comparative methods) work zone detour effects on traffic flow. Researchers analyzed traffic operations within the work zones, using northbound and southbound traffic volumes and traffic composition, together with traffic speed variables.

This study also evaluates the traffic control measures used in operating the work zones along the highway, particularly the influence of the traffic control measures on traffic flow. The study evaluation covers the operating procedures, regulations, technical guidelines, equipment and accessories that routinely make up temporary signing and worker-protection measures.

With respect to report organization, acquisition of traffic data is discussed in Chapter 2. Results from the analysis of field data are presented in Chapter 3, including traffic volume patterns (especially during peak hours), the percentage of trucks, and the speed characteristics of vehicles. The analyses and discussions are based on results of traffic studies made (1) during the construction period within two types of work zones, and (2) after the completion of the construction, when the detours were no longer in operation.

Chapter 4 includes a discussion of the various traffic control and operational features of work zones described in the traffic sign guidelines presented in the *Manual on Uniform Traffic Control Devices* (Refs 13 and 18). The conclusion and recommendations are then provided in Chapter 5.

CHAPTER 2. TRAFFIC DATA ACQUISITION

INTRODUCTION

US 59 is a principal arterial highway that runs from Laredo, through Houston, to Texarkana, Texas. The section of road between Houston and Texarkana carries a considerable amount of truck traffic and has served a number of metropolitan areas and industries in East Texas for many years. Recently, many pavement sections of US 59 have required frequent, sometimes extensive, maintenance. In 1989, the Texas Department of Transportation initiated a research study, conducted by the Center for Transportation Research, The University of Texas at Austin, to develop a long-range rehabilitation plan for approximately 225-km (140-mi) of pavement on US 59 in the Lufkin District. The objective is to rehabilitate the pavement structures, so that they will have a service life of at least 20 years under projected traffic volumes.

A feature of this research study was the construction of two 1.61-km (1-mi) long pavement test sections—one for rigid pavement structures, and another for flexible pavement structures. The location of the two pavement test sections is shown in Fig 2.1. Five different pavement structures were built in 300-m (1,000-ft) segments in each test section. Traffic loading on the test pavements would be monitored continuously for at least 3 years using weigh-in-motion technology, with the condition of each pavement structure to be assessed at frequent intervals during this time.

Construction of the test pavements took place under normal traffic conditions; that is, traffic was detoured from the test lane(s) under construction, as it probably will be detoured when the pavement rehabilitation plan is eventually implemented. The construction of the test pavements provided a unique opportunity to study the effects, which are described in this study, of work-zone detours on rural highway traffic operations. The findings from this research project will be a contribution to the engineering community's knowledge of planning and scheduling rehabilitation projects on rural highways. The data collection process that was used for the traffic operation study is described in this chapter.

DATA COLLECTION SITES

US 59 is a rural four-lane, divided highway which has two traffic lanes in each direction, typically separated by a 12-m (40-ft) grass median. The cross-section on either side of the median comprises a 1.2-m (4-ft) left-hand (median) paved shoulder, two 3.6-m (12-ft) main lanes, and a 3-m (10-ft) right-hand (outside) paved shoulder. The riding surface is asphalt concrete, and the general terrain is flat to rolling. Photographs in Figs 2.2 and 2.3 show the character of the highway in the vicinity of the rigid pavement test section north of Corrigan, Texas, and the flexible pavement test section south of Corrigan, respectively. Most of the data concerning the effects of work zone detours on traffic operations were collected at the site of the flexible pavement test sections, although some additional traffic data were collected at the weigh-in-motion sites at both pavement test sections after construction of the test pavements had been completed.

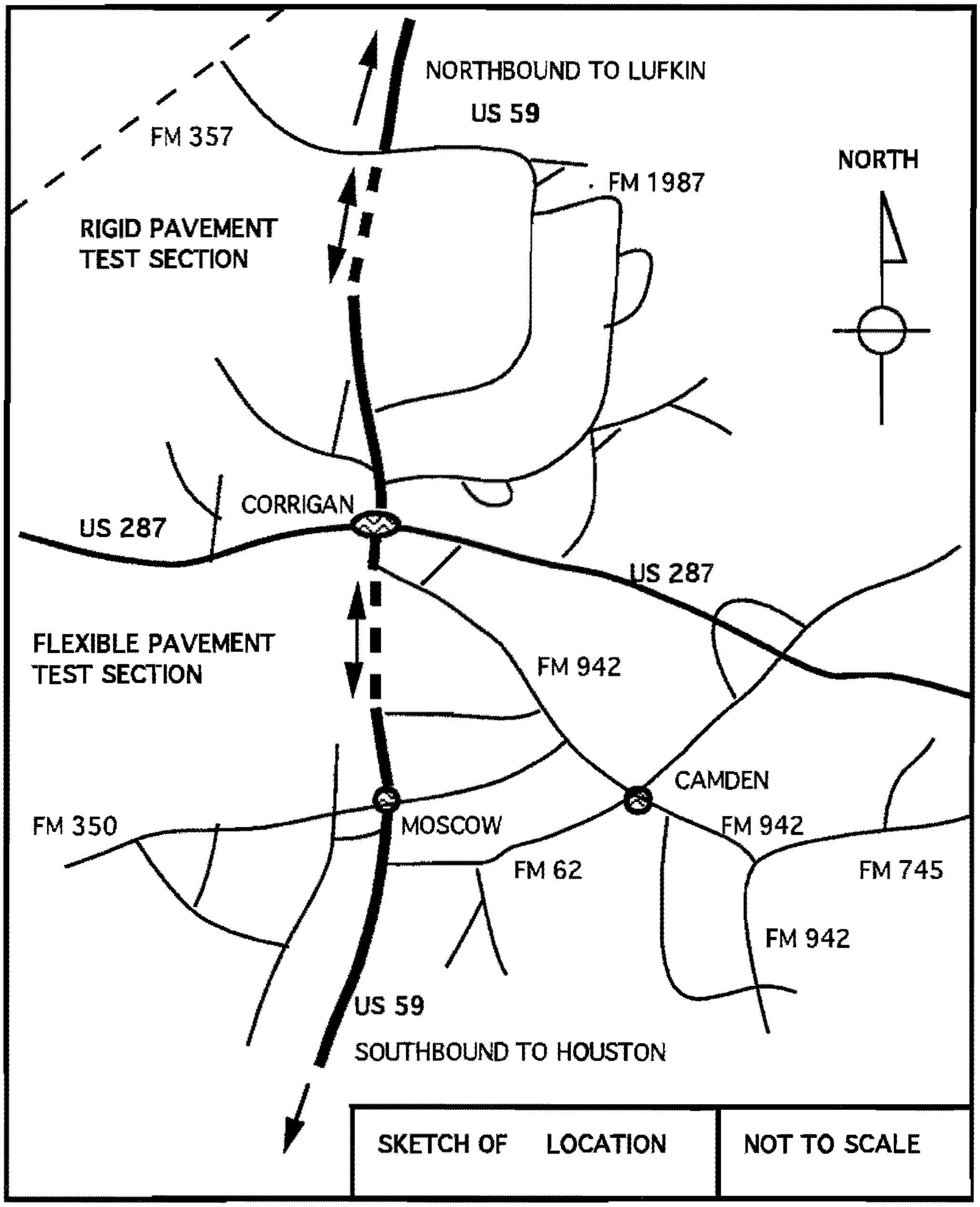


Fig 2.1 Location map.

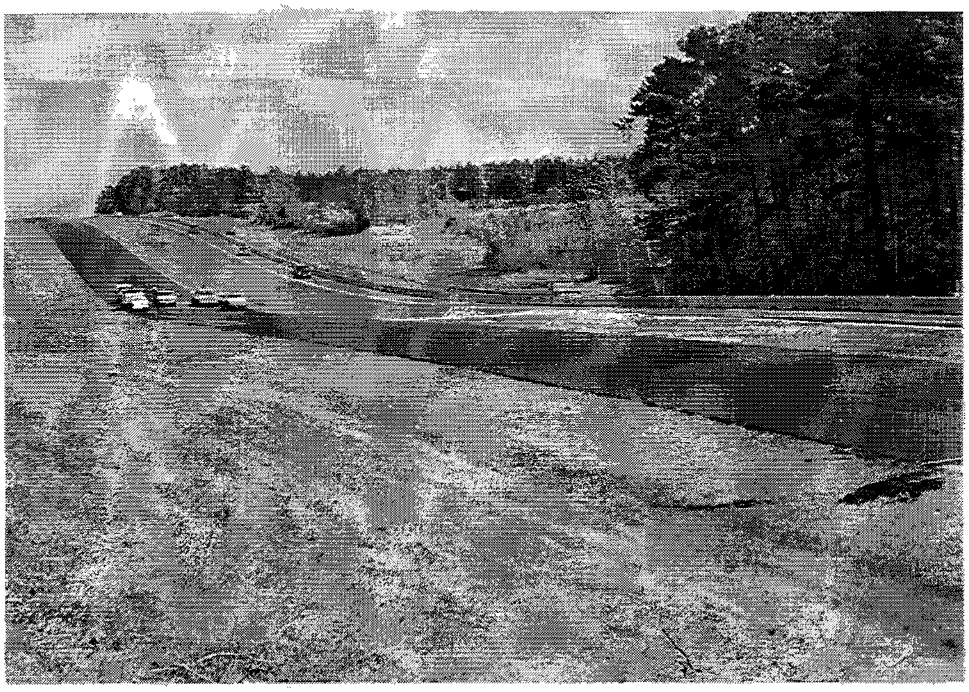


Fig 2.2. General site description of rigid pavement test section.

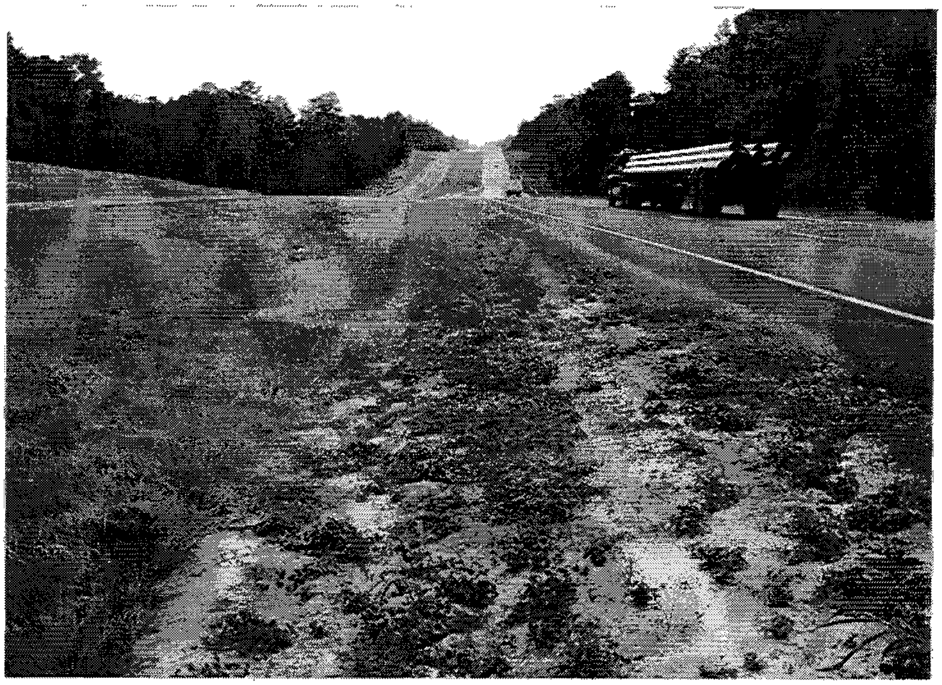


Fig 2.3. General site description of flexible pavement test section.

DATA COLLECTION METHOD

To accomplish the study objectives, researchers needed data about the number, speed, and classification of vehicles operating at selected sites. The sites were chosen to reflect the different operating characteristics that might be expected under normal two-lane highway conditions and as vehicles travel through the work zones. Data collection involved placement of a 3-sensor traffic data acquisition (TDA) system near the middle of the work zones to measure the number, speed, and classification of vehicles, while two 2-sensor TDA systems were located on the highway lanes in advance of and beyond the work zones to measure the speed of vehicles at these locations under normal-flow conditions.

Work Zone 1

The intended strategy for construction of the flexible pavement test sections in the southbound lanes of US 59 at the site south of Corrigan, Texas, involved reducing the two 3.6-m (12-ft) wide northbound traffic lanes to one 3.6-m (12-ft) traffic lane with an adjacent concrete traffic barrier along the left side, as shown schematically in Fig 2.4. Southbound traffic would be detoured across the median so as to operate in one lane on the opposite side of the concrete traffic barrier. The one-lane section for the northbound traffic, which was approximately a mile long, is referred to in this study as Work Zone 1.

For data collection, Sensors #1 and #3 (two-sensor type) were placed so as to measure the speed of each axle on vehicles traveling at a normal highway speed in the two northbound lanes before and beyond Work Zone 1. Sensor #6 (three-sensor type) was placed approximately midway between Sensors #1 and #3 near the middle of Work Zone 1 to count, to classify according to axle arrangement, and to measure the speed of each vehicle traveling northbound in the single lane beside the concrete traffic barrier.

Work Zone 2

Because of the difficulties in maintaining the pavements used for detouring traffic from the two southbound lanes at the flexible pavement test site described above during wet weather, it was necessary to abandon the cross-median detour strategy and to construct the test pavement structure a lane-at-a-time. The concrete traffic barriers were removed, and northbound traffic was restored to two-lane operation. Work Zone 2 (see Fig 2.5) operated under the strategy of blocking a segment of one southbound lane with barrel-type barricades and other associated traffic control devices while construction crews worked in the other southbound lane. The traffic control devices were left in place overnight in most cases when work was to continue the following day.

For data collection in Work Zone 2, Sensors #2 and #4 (two-sensor type) were located

5-km (3.1-mi) apart, approximately equidistant from the center of the 1.61-km (1-mi) long flexible pavement test section in each direction. These sensors were located directly across the median from Sensors #1 and #3 (northbound lanes), respectively, and were used to measure the speed of each axle on vehicles traveling at normal highway speed in the two southbound lanes before and beyond Work Zone 2.

Sensor #5 (three-sensor type) was placed in Work Zone 2 to count, to classify according to axle arrangement, and to measure the speed of each vehicle traveling southbound in the single lane adjacent to the barrel-type barricades.

EQUIPMENT

The main components of the equipment that was used to acquire the traffic data for this study were as follows: (1) infrared light beam sensors, (2) retro-reflectors, and (3) microprocessor recorders. The sensor (Opcon 1480A), which is a direct-current powered reflex-type unit, contains an infrared light source and a detector element with special lenses arranged side-by-side in a small housing. It operates by establishing a beam of modulated infrared light between the source/receiver unit and a distant retro-reflector. Aligning the system consists of aiming the sensor at the reflector to establish a reflected infrared light beam at the receiver. Maximum sensitivity results when the retro-reflector is aligned with the optical centerline of the sensor. A control module shows a properly-aligned light beam and retro-reflector with an indicator light. When an opaque object, such as a tire, interrupts the light beam, a transistor switch in the control module changes from the "on" to the "off" state. Switch signals from the sensors are fed to a special microprocessor for calculating and recording the vehicle speed, count, and classification.

The retro-reflectors used for the study are designed with corner-cube geometry, which reverses the direction of incoming light rays and returns them almost directly back to their source. Three 76 mm (3-inch) diameter reflectors were arranged in a triangular array (see Fig 2.8) and aligned with the sensor's field of view. Both sensors and reflectors were mounted rigidly in relation to each other, using iron posts that had been driven into the ground.

Two arrangements were used in setting up the sensor systems to collect the needed traffic data. The two-sensor system consisted of two sensor/retro-reflector units placed 1.8 m (2 ft) apart longitudinally along the roadway to measure the speed of each vehicle axle. The microprocessor was programmed to record axle speed measurements at every 5- or 10-minute interval. Calculated speed values were summed into the following categories: (a) less than 72 km/h (45 mph); (b) 72 to 78.9 km/h (45 to 49 mph); (c) 80.5 to 86.9 km/hr (50 to 54 mph); (d) 88.5 to 95 km/h (55 to 59 mph); (e) 96.6 to 103 km/h (60 to 64 mph); and (g) greater than 112.7 km/h (70 mph). Photographs of the two-sensor, speed measuring system are shown in Figs 2.6 through 2.8.

The three-sensor system also used the same reflex-type equipment and the same arrangement of the two speed-measuring sensors just above the pavement surface, so that the tires of passing vehicles would interrupt the two lower beams sequentially. For the three-sensor system, however, two additional sensor/reflector units were used to detect the presence of a vehicle body. These two sensors were mounted about 0.91-m and 2.12-m (3-ft and 7-ft) above the road surface, respectively, and connected to the microprocessor in such a way that when either light beam was interrupted by a part of a vehicle body, a presence signal would be effected. The vehicle-presence sensors in the three-sensor system were aimed at a single three-reflector array that was glued in place near the top of the upper face of the concrete traffic barriers at Work Zone 1 or that was nailed onto a portable wooden barricade where the plastic barrels were used for the temporary lane closure in Work Zone 2. Photographs showing the arrangement of the three-sensor system appear in Figs 2.9 through 2.11.

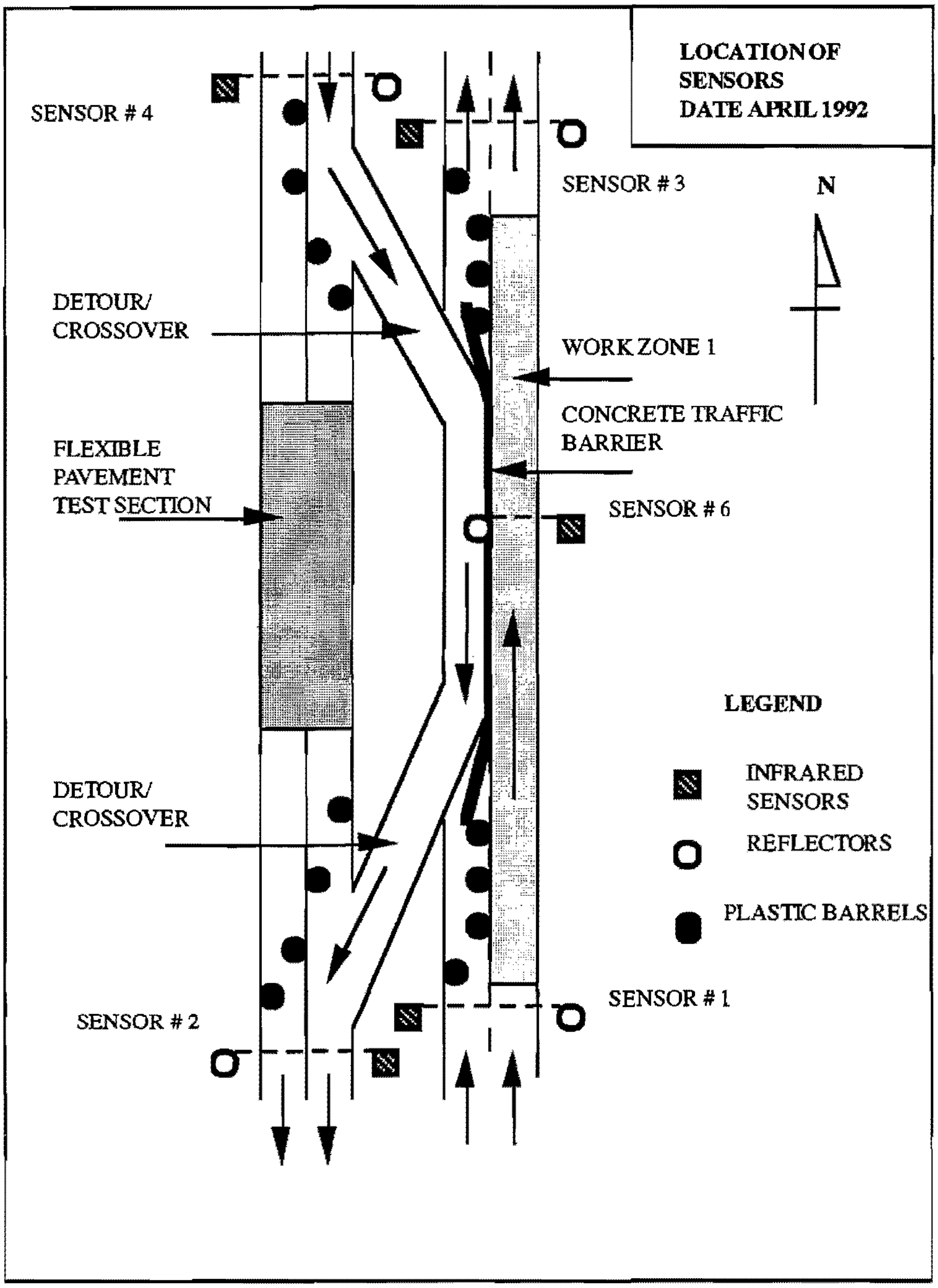


Fig 2.4 Layout of sensors at the flexible pavement test section, Work Zone 1.

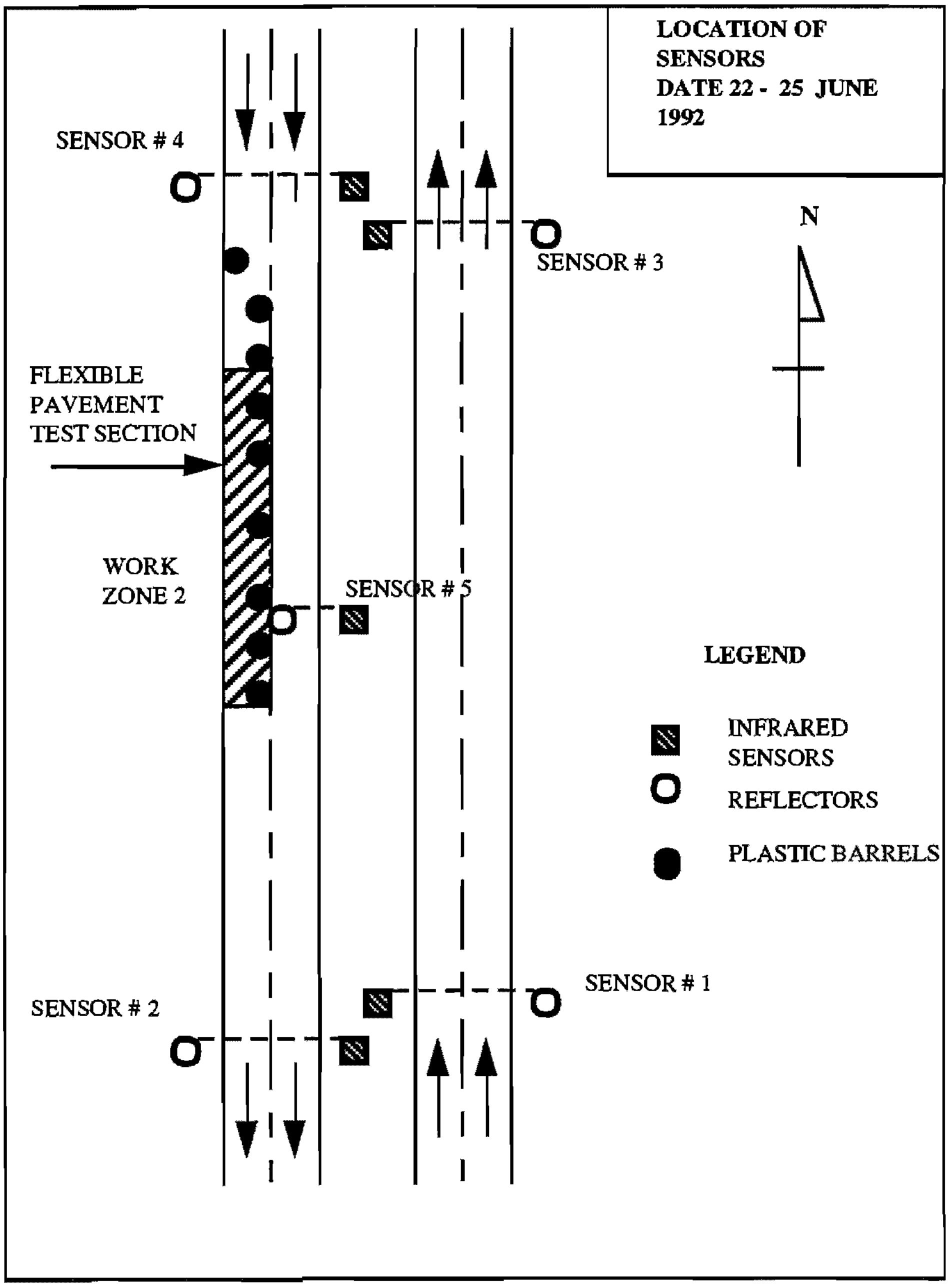


Fig 2.5 Layout of sensors at the flexible pavement test section, Work Zone 2.

Fig 2.6. The two-sensor speed system and reflectors on the southbound lane at exit of Work Zone 1 (4/9/92).

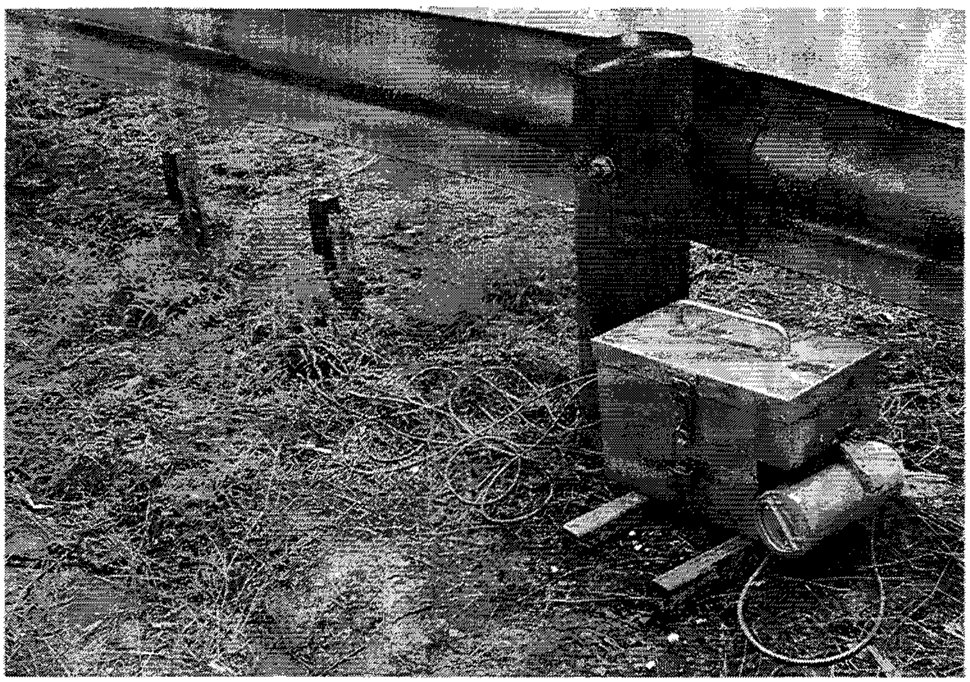


Fig 2.7. The two-sensor system arrangement.

Fig 2.8. Retro-reflector array.

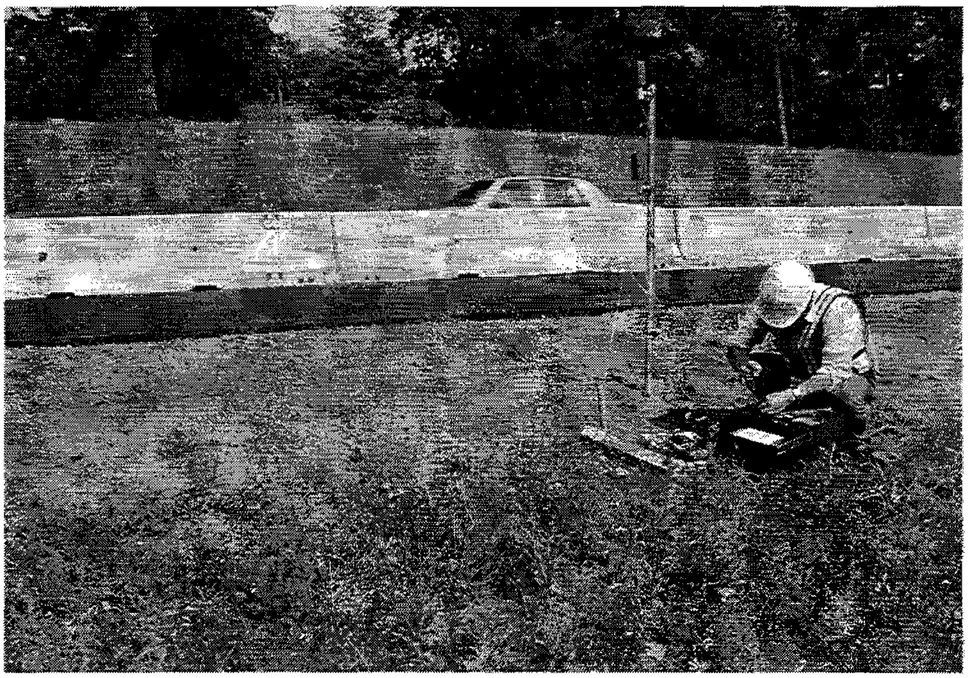


Fig 2.9. The three-sensor system at Work Zone 1.

Fig 2.10. The three-sensor system at Work Zone 2.

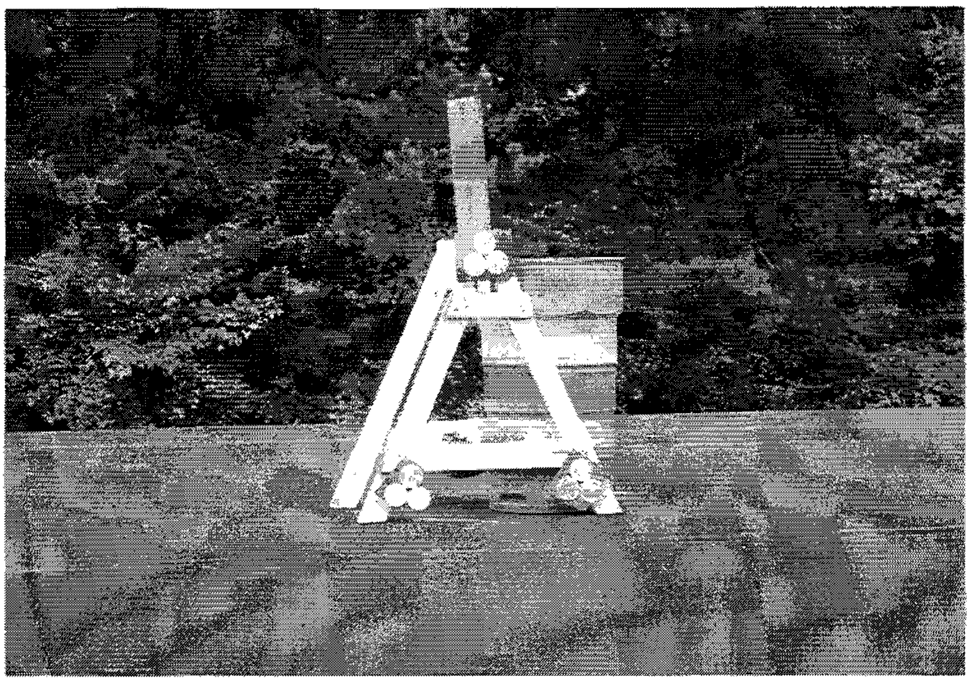


Fig 2.11. Retro-reflectors on wooden saw-horses at Work Zone 2.

PERIODS OF OBSERVATION

Two periods of observation during work zone detours were used for this study. During the observation period from 4/17/92 to 4/24/92, the left-hand lane of the two northbound lanes was converted to carry all southbound traffic while the remaining lane carried all northbound traffic. A concrete traffic barrier separated the two-direction flows of traffic for about 1.6 km (1 mi). This configuration of work zone detour is illustrated in Figure 2.4 and is referred to in this study as Work Zone 1. The concrete traffic barrier was in place for several weeks before any traffic observations were made. The effects on traffic operations were studied as vehicles changed from two lanes to one lane in the northbound direction, traveled for about 1.6 km (1 mi) beside a concrete traffic barrier, and then returned to two-lane operation.

The second observation period extended from 6/22/92 until 6/25/92 as southbound traffic was detoured from two-lane operation to one-lane operation for distances of about 300 to 600 m (1,000 to 2,000 ft) while construction work was accomplished in the closed lane, the work lasting a few days at a time. Temporary lane-closure traffic control was effected using plastic barrels, signs, and other official traffic control devices. This type of detour is illustrated in the study as Work Zone 2 and is shown schematically in Figure 2.5. Thus, comparison of traffic operations was possible under two different types of lane closures.

DATA PROCESSING

Traffic data from the field observations were processed using special equipment and software developed at The University of Texas at Austin. This system is referred to as the Traffic Data Acquisition (TDA) system . A microprocessor operating from an internal time base processes signals from the sensors, performs calculations, and stores data. The data communication procedure involves connecting a cable from the RS232C port of an IBM PC, or compatible, to the TDA system, which allows transfer of data between the microprocessor recorder and the microcomputer. Various items of equipment used in the Traffic Data Acquisition System are shown in Figures 2.12 and 2.13.

POST-CONSTRUCTION DATA COLLECTION

In an effort to study the normal four-lane traffic flow at the flexible pavement test site, operation of two 2-sensor systems, which monitored axle speed and axle count in the southbound and the northbound lanes, was continued (July through September) after test section construction had been completed. In addition to these systems, the *through-beam* infrared transmitter/receiver systems—which were installed to supplement the weigh-in-motion sensors in each lane at both the flexible and the rigid pavement test sites—were used for traffic data collection during the post-construction period. The *through-beam* sensors, comprising a transmitter and a receiver that were aimed at approximately a 30-degree angle across each lane, provide data for classification of vehicles by number of axles and by single or dual-tires on each axle. The location of the *through-beam* sensor equipment is shown in Fig 2.16. Photographs of this equipment appear in Figs 2.14 and 2.15.

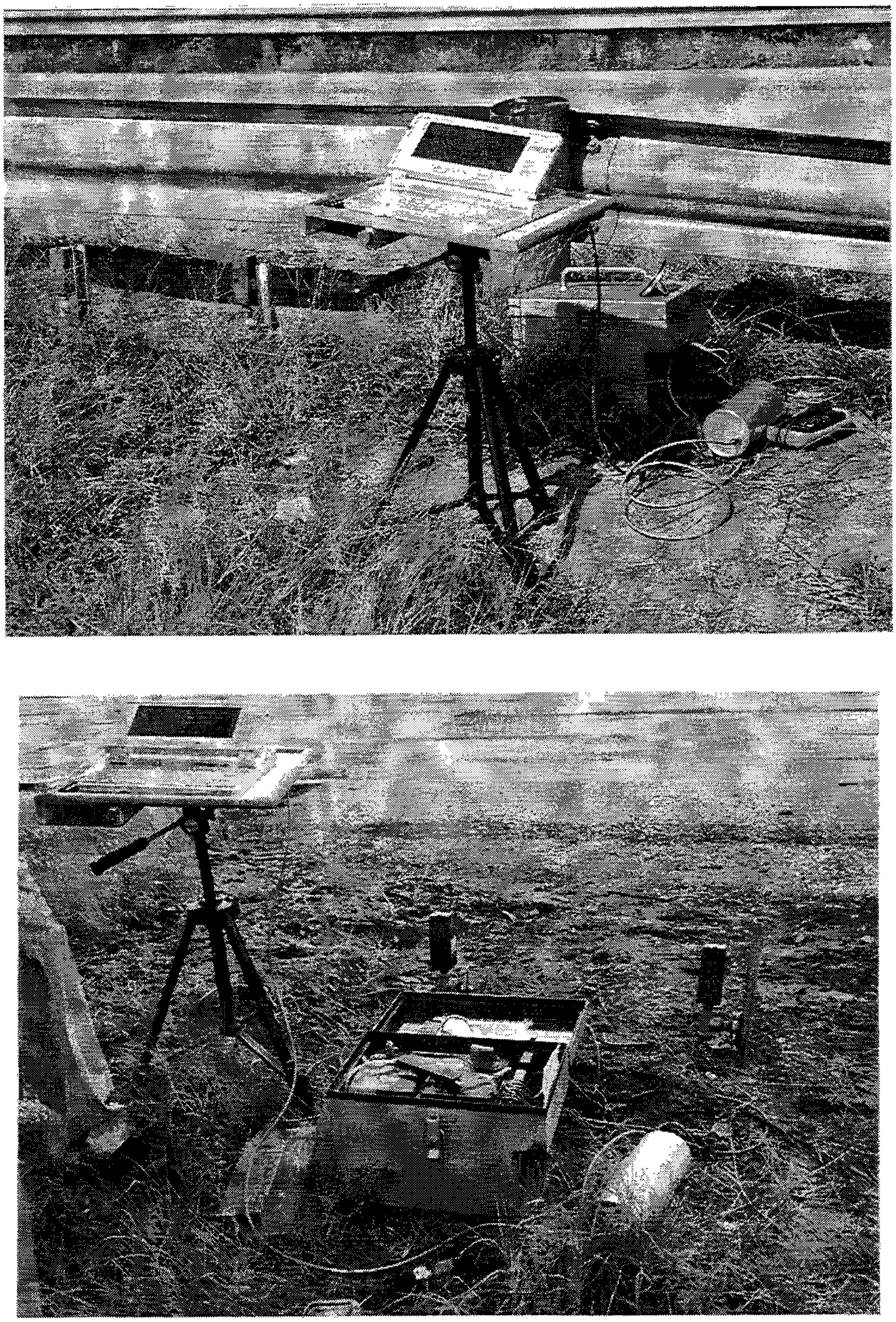


Fig 2.12. Traffic data acquisition system equipment.

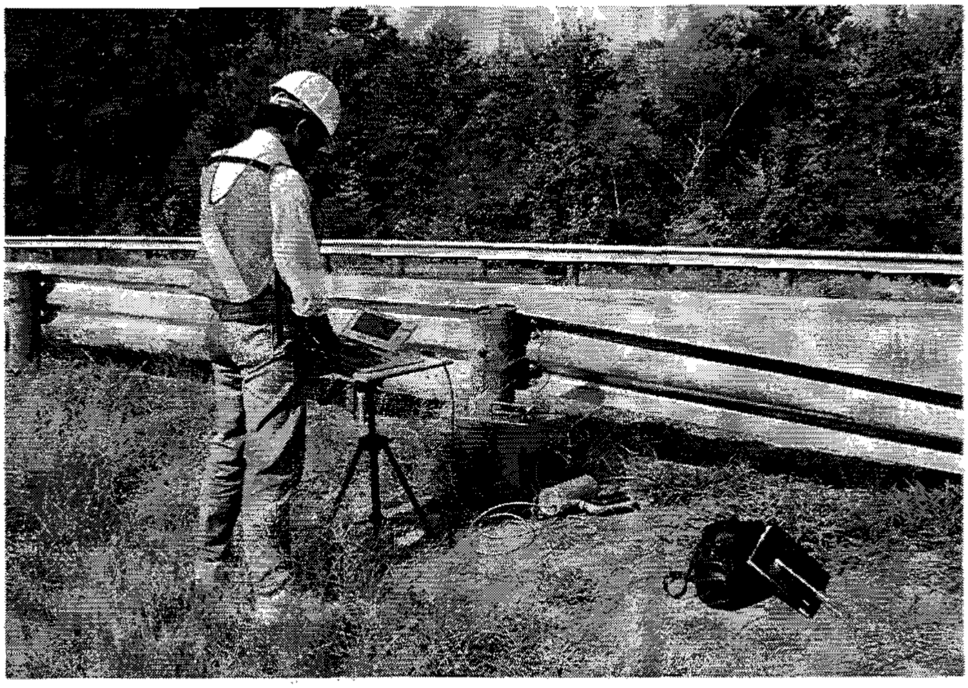


Fig 2.13. Process of transferring data.

Fig 2.14. Through-beam sensors at rigid pavement test section.

Fig 2.15. Through-beam sensors at flexible pavement test section.

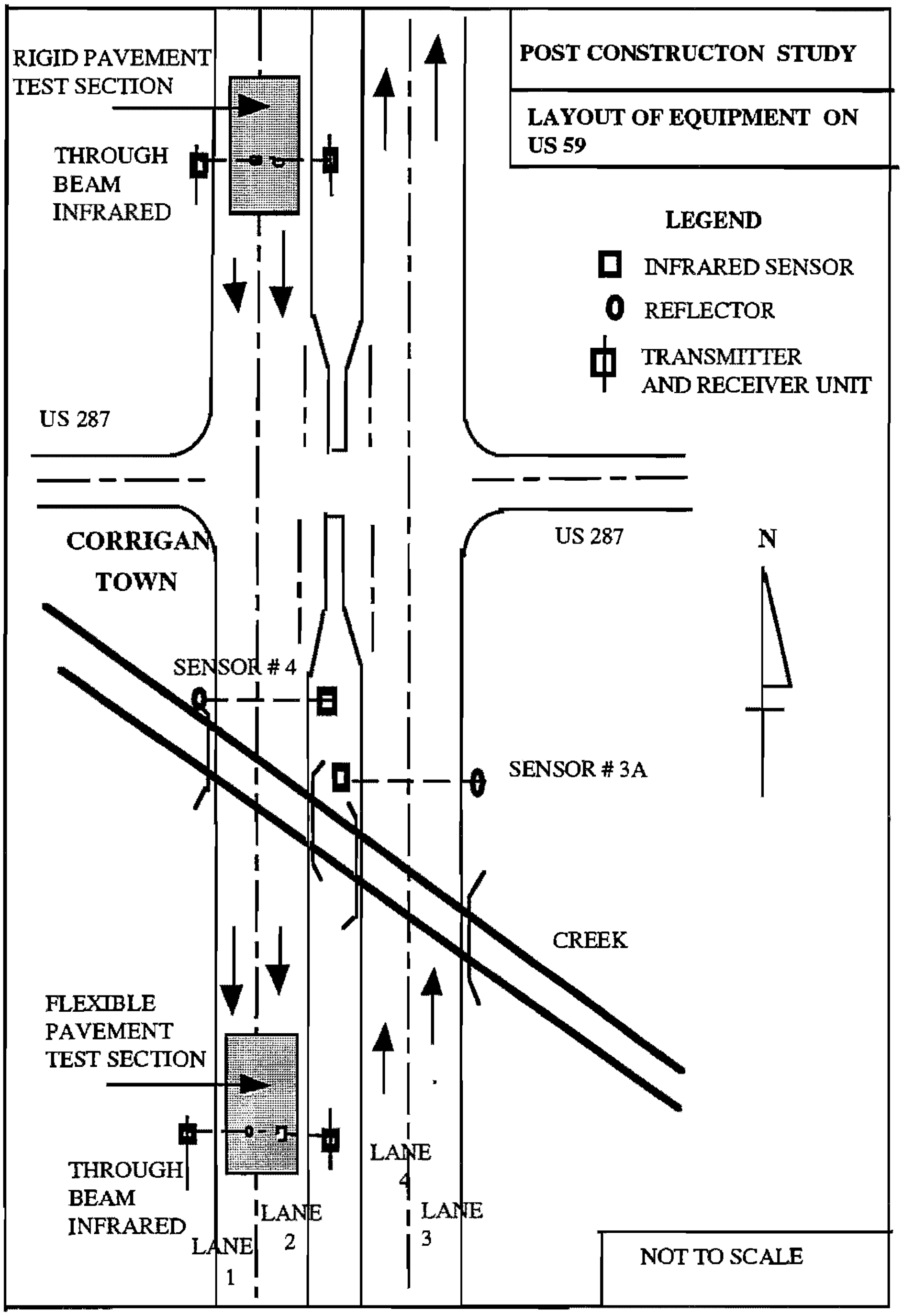


Fig 2.16 Locations of equipment used in the post-construction study.

DATA AND ACCURACY

In order to evaluate the accuracy of data obtained from the infrared sensors, manual counts of one-hour duration, recorded at 5-minute intervals, were carried out on 6/23/92 and 6/24/92 at the locations of Sensors #2, #4, and #5 (see Fig 2.5) at different observation times during the

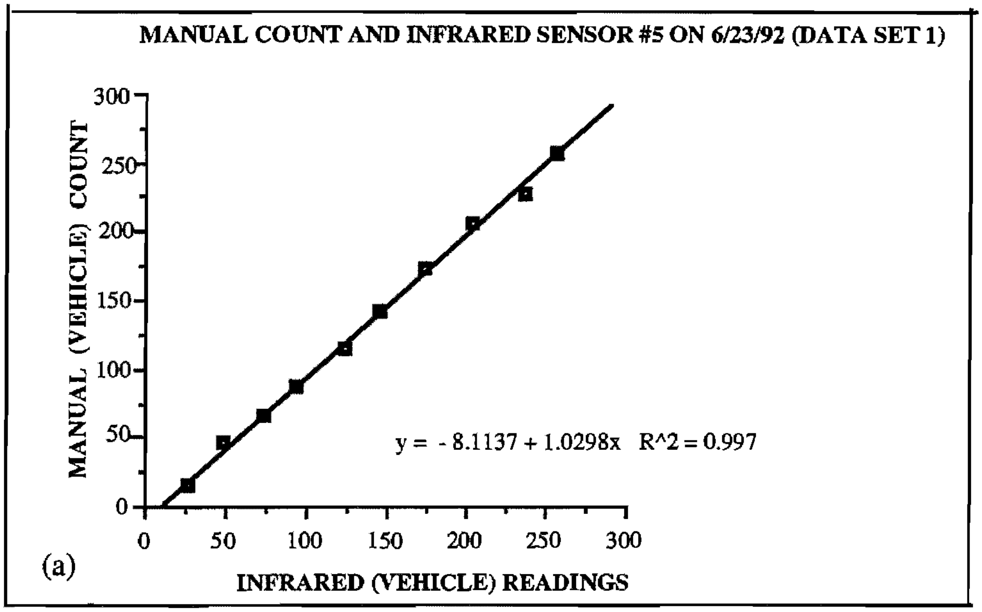
Work Zone 2 study. Two categories of counts were made. At the location of Sensor #5 (3-sensor system), a comparison of results was made regarding the number of vehicles; while at the locations of Sensor #2 and #4 (2-sensor systems), a comparison of results was made regarding the number of vehicle axles. Table 2.1 shows the results obtained from manual counting with the data collected from the two types of infrared sensor systems during the same periods of time.

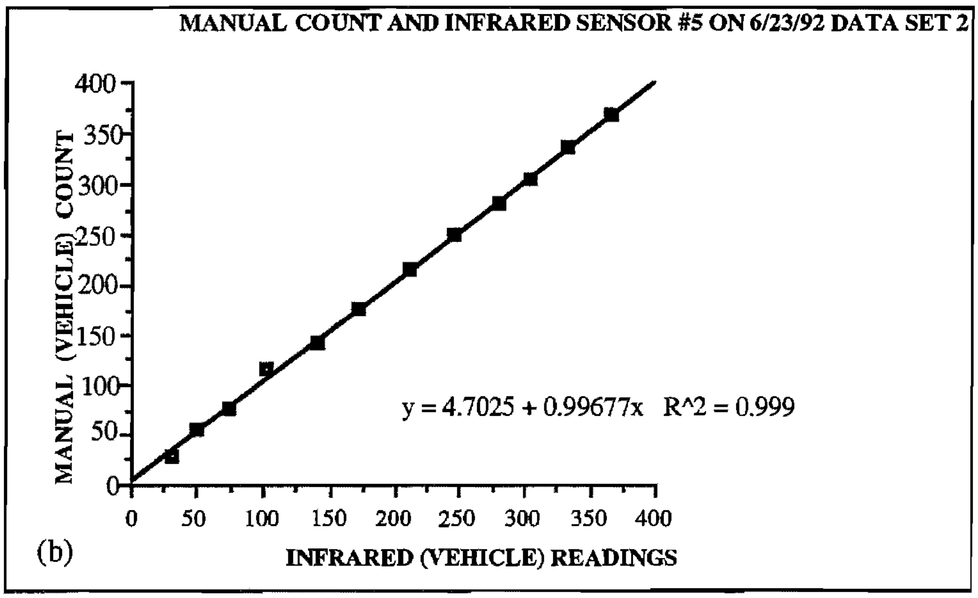
TABLE 2.1 COMPARISON OF MANUAL COUNT AND INFRARED SENSORS

Location	Manual Count Results (vehicles)	Infrared Sensors (vehicles)	Percentage Difference	Periods
Sensor 5	258	256	- 0.8 %	9:15 - 10:05 (6/23/92)
Sensor 5	368	365	- 0.8 %	10:10 - 11:10 (6/23/92)
Sensor 5	330	328	- 0.6 %	9:25 - 10:25 (6/24/92)
Sensor 5	387	381	- 1.5%	10:35 - 11:35 (6/24/92)
Location	Manual Count Results (vehicle-axles)	Infrared Sensors (vehicle-axles)	Percentage Difference	Periods
Sensor 2	436	433	- 0.7 %	11:41 - 12:11 (6/23/92)
Sensor 4	993	997	+0.4%	14:05 - 15:05 (6/23/92)

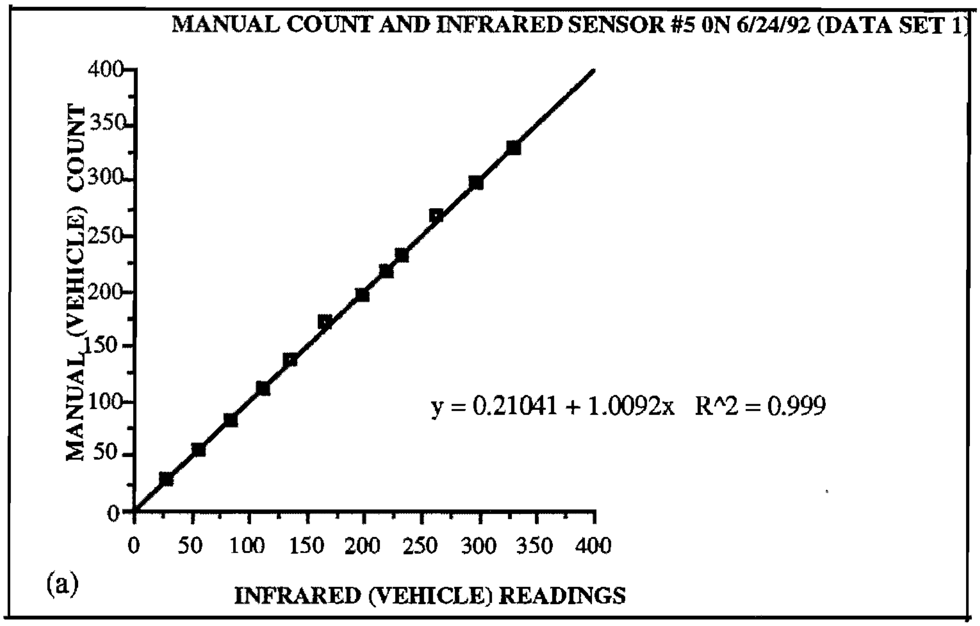
The difference in counts obtained from the two methods ranged from 0.4 percent to -1.5 percent. One possible reason for these differences could be that the time reference used by the observer in carrying out the manual count and the time reference set in the microprocessor recorder were not synchronized. Another likely reason is that the human observer failed to count accurately under the demanding circumstances of high-speed traffic.

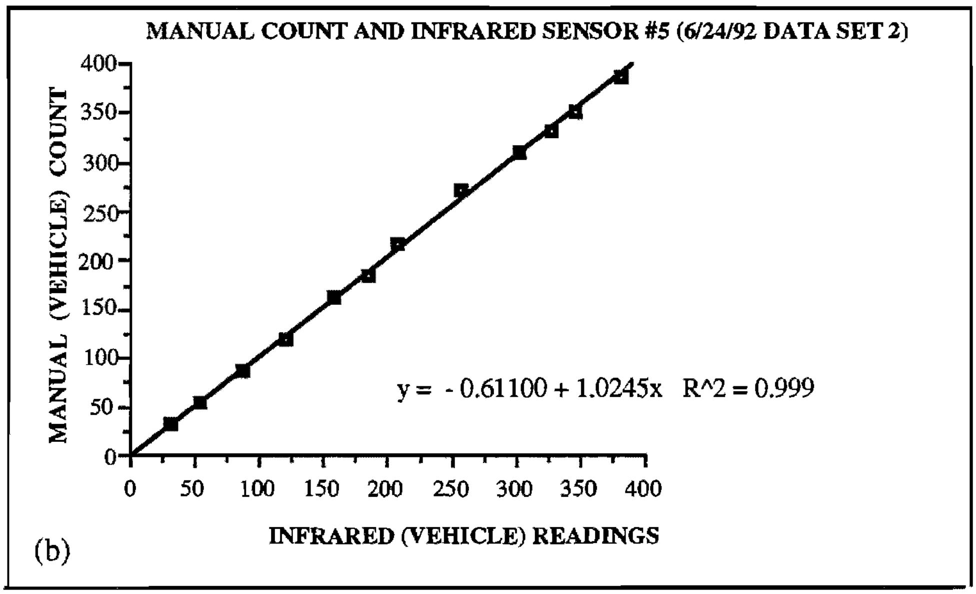
Figs 2.17 through 2.19 show graphically the extent of variation between the results obtained from the two methods. The graphs were plotted using values obtained from the manual count and the infrared sensors (drawn on different axes). As may be seen, the data points fall in a fairly straight line with some slight deviation. If there had been no difference, all points would have fallen on a single line at a 45 degree angle. From the results shown in Table 2.1 and from the interpretation of these graphs, it can be concluded that the instruments that were used for counting vehicles or axles were sufficiently accurate for application in this study.



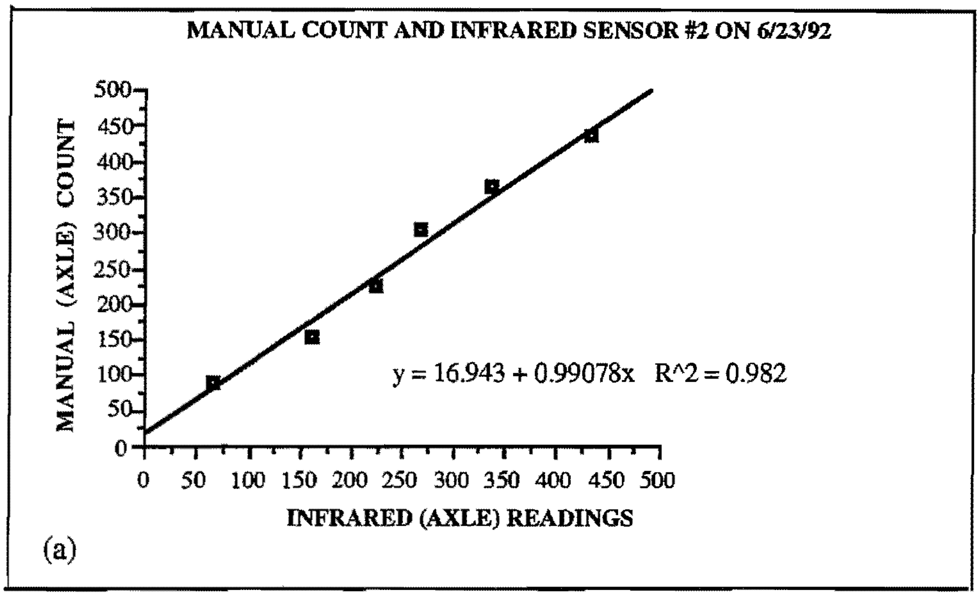


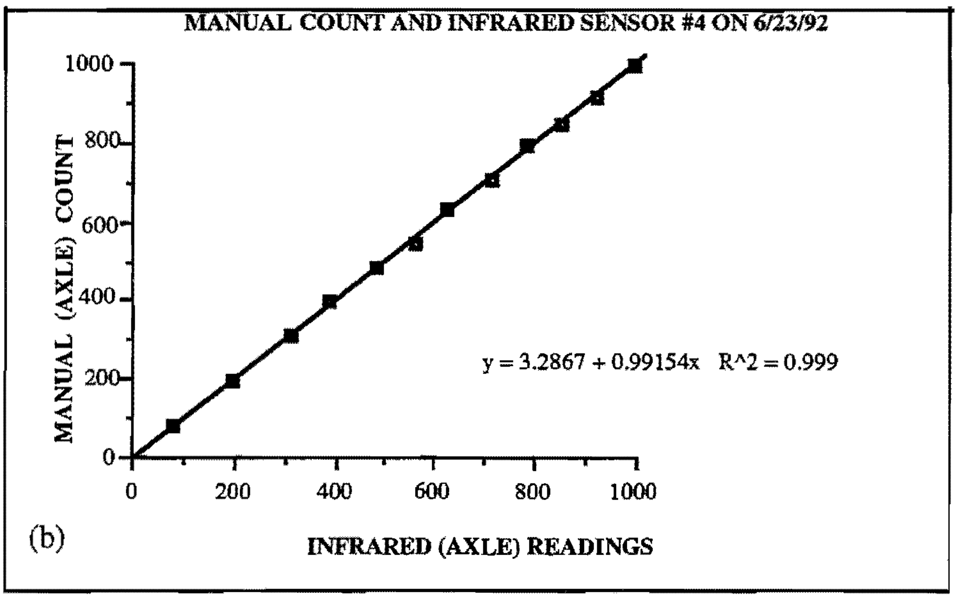
Figs 2.17 Comparison between manual count and infrared at Sensor #5 on 6/23/92 for (a) data set 1 from 9:15 am till 10:05 am and for (b) data set 2 from 10:10 am till 11:10 am.





Figs 2.18 Comparison between manual count and infrared at Sensor #5 on 6/24/92 for (a) data set 1 from 9:25 am till 10:05 am and for (b) data set 2 from 10:35 am till 11:35 am.





Figs 2.19 Comparison between manual count and infrared at (a) Sensor # 2 on 6/23/92 from 11:41 am till 12:11 pm and (b) Sensor # 4 on 6/23/92 from 14:05 pm till 15:05 pm.

SUMMARY

Data were collected at two work-zone sites on US 59 under three different traffic operation situations. Northbound traffic data were obtained from Sensors #1, #6, and #3 between 4/17/92 and 4/24//92 (see Fig 2.4). During this period, the northbound, left-hand traffic lane was converted to serve southbound traffic by use of a concrete traffic barrier between the lanes while all northbound traffic (Work Zone 1) was detoured into the right-hand lane for a distance of about 1.6-km (1-mi). Between 6/22/92 and 6/25/92 southbound traffic data were obtained through Sensors #4, #5, and #2 while a segment of the right-hand, southbound lane, about 300-m (1,000-ft) long (Work Zone 2), was closed with plastic barrels and other traffic control devices (see Fig 2.5). Data obtained during both periods included vehicle count, percentage of trucks, and speed of vehicle axles traveling through the respective work zones. Also, sensors placed in advance of and beyond each work zone area allowed measurement of the spot speed and count of vehicle axles traveling in the two traffic lanes in each direction outside the influence of the work zone detour. Traffic data were also collected after construction of the test sections had been completed. For this post-construction situation, through-beam infrared sensors that are integral to the weigh-in-motion system at each pavement test site were used to count vehicles, to classify each vehicle via axle arrangement, and to determine single or dual tires on every vehicle axle in each of the two southbound lanes. Reflex-type infrared light-beam sensors were also deployed to collect speed and axle-count data (see Fig 2.16) during the post-construction survey. Manual counts of vehicles and axles were made to ascertain the accuracy of counts made by the automated data-collection equipment. Differences in the manual and automated counts ranged from 0.4 to -1.5 percent. After evaluating the possible sources of error, including human error, it was decided that the accuracy of the automated vehicle and axle counts was entirely adequate for collecting traffic data for this research project.

CHAPTER 3. TRAFFIC DATA EVALUATION

INTRODUCTION

In the previous chapter, the process that was used to acquire data needed to characterize various traffic patterns associated with detours constructed on US 59 between April and June 1992 is described. The first data acquisition session was in April during the time when one of the two northbound lanes was converted to carry all southbound traffic while the remaining lane (Work Zone 1, Fig 2.4) carried all northbound traffic. A concrete traffic barrier about a mile long separated the two lanes. The second session was carried out in June during the temporary closure (via plastic barrels and signs) of a 300-m (1,000-ft) long segment of one of the two southbound lanes where the flexible pavement test sections were being constructed (Work Zone 2, Fig 2.5). Another series of traffic observations was made during a post-construction period from July until October 1992. All the traffic volume and speed measurements were arranged into data sets which were appropriate for analysis.

DAILY VOLUME STUDIES

Traffic volume is an important indicator of pavement life and road use. Traffic volume, defined as the rate of traffic flow for a designated period of time, is usually obtained by counting the number of vehicles that pass a certain point in an hour. Values obtained from traffic counts and used in the pavement design process are often converted to average daily traffic (ADT), which is the average 24-hour traffic volume during a given time greater than one day and less than one year.

An analysis of the daily traffic volume at Work Zone 1 on the northbound lane from Saturday 4/18/92 until Thursday 4/23/92 (see Table 3.1) and the volume at Work Zone 2 on the southbound lane on Tuesday 6/23/92 and Wednesday 6/24/92 (see Table 3.2) shows values of similar magnitude. The one-way average daily traffic in the northbound lane at Work Zone 1 was 6,774 vehicles, with an average flow rate of 281 vehicles per hour. At Work Zone 2 in the southbound lane the average daily traffic at midweek was 6,033 vehicles with an average flow rate of 252 vehicles per hour.

Daily traffic volumes observed during the post-construction study period (August and September 1992) are shown in Tables 3.3 and 3.4 for southbound traffic at the rigid pavement test section site and at the flexible pavement test section site, respectively (see Fig 2.16). These values are quite similar in magnitude to those shown for both the work zone sessions described above. Table 3.5 shows average daily traffic values from the post-construction observations of traffic in the southbound lanes of US 59 that are located about 8-km (5-mi) apart. As shown in Fig 2.16, US 287 intersects US 59 about midway between the sites. Turning traffic at this intersection can easily account for the 2.5 percent smaller southbound ADT at the south site. Average daily traffic volume ranged between 6,000 and 7,000 vehicles per day in all the studies conducted on this portion of US 59.

TABLE 3.1 DAILY TRAFFIC VOLUME AT WORK ZONE 1

Northbound Lane

Date	Day	Daily traffic (vehicles)
4/18/92	Saturday	6996
4/19/92	Sunday	6329
4/20/92	Monday	5364
4/21/92	Tuesday	5931
4/22/92	Wednesday	6147
4/23/92	Thursday	9879

Average Daily Traffic: 6,774 vph per day (6 days)

TABLE 3.2 DAILY TRAFFIC VOLUME AT WORK ZONE 2

Southbound Lane

Date	Day	Daily traffic (vehicles)
6/23/92	Tuesday	5972
6/24/92	Wednesday	6093

Average Daily Traffic: 6,033 vph per day (2 days)

TABLE 3.3 DAILY TRAFFIC AT THE RIGID PAVEMENT TEST SECTION

Southbound Lane

Date	Day	Daily traffic (vehicles)
8/19/92	Wednesday	6106
8/20/92	Thursday	6523
8/21/92	Friday	7352
8/22/92	Saturday	6226
8/23/92	Sunday	8489

TABLE 3.4 DAILY TRAFFIC AT FLEXIBLE PAVEMENT TEST SECTION

Southbound Lane

Day	Week 1		Week 2		Week 3		Week 4	
	Date	Daily traffic (vehicles/ day)	Date	Daily traffic (vehicles/ day)	Date	Daily traffic (vehicles /day)	Date	Daily traffic (vehicles /day)
Mon			9/7/92	-	9/14/92	-	9/21/92	-
Tues			9/8/92	6645	9/15/92	5591	9/22/92	-
Wed	9/2/92	5547	9/9/92	5629	9/16/92	-	9/23/92	5408
Thurs	9/3/92	7061	9/10/92	6029	9/17/92	-	9/24/92	5913
Fri	9/4/92	2133	9/11/92	7169	9/18/92	8825	9/25/92	7605
Sat	9/5/92	7004	9/12/92	5966	9/19/92	6825	9/26/92	-
Sun	9/6/92	7398	9/13/92	-	9/20/92	-	9/27/92	-

TABLE 3.5 COMPARISON OF DAILY TRAFFIC VOLUME AT RIGID PAVEMENT AND FLEXIBLE PAVEMENT TEST SECTIONS

Southbound Lane

Location	Average daily traffic	Vehicle per hour
Rigid Pavement Test Section	6941	289
Flexible Pavement Test Section	6296	262

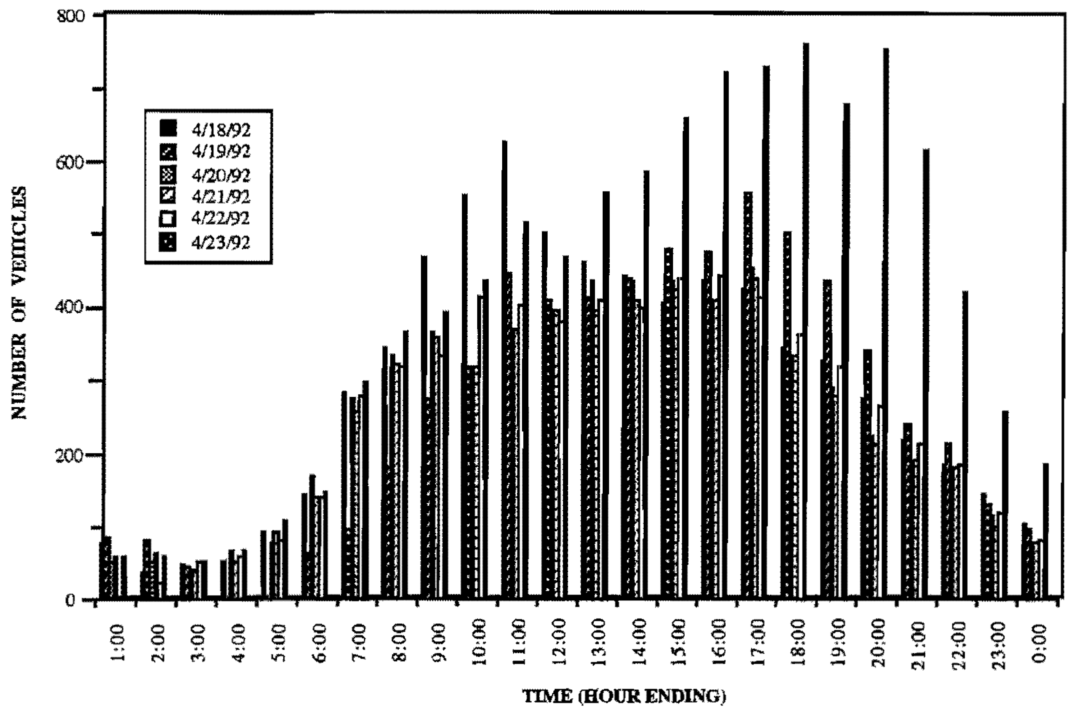


Fig 3.1 Hourly traffic volume variation at Work Zone 1 in northbound lane.

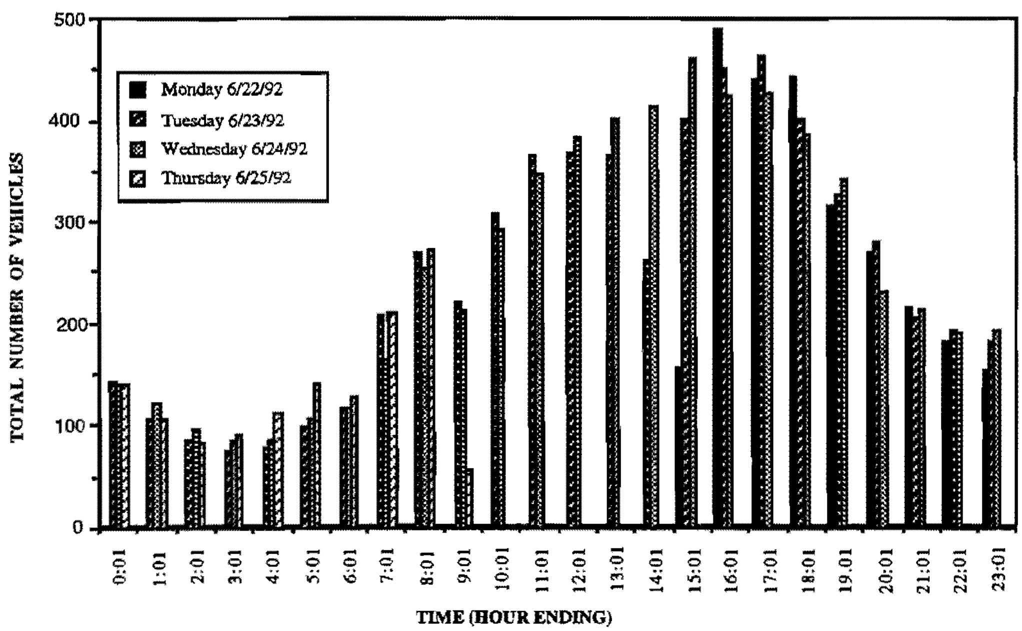


Fig 3.2 Hourly traffic volume variation at Work Zone 2 in southbound lane.

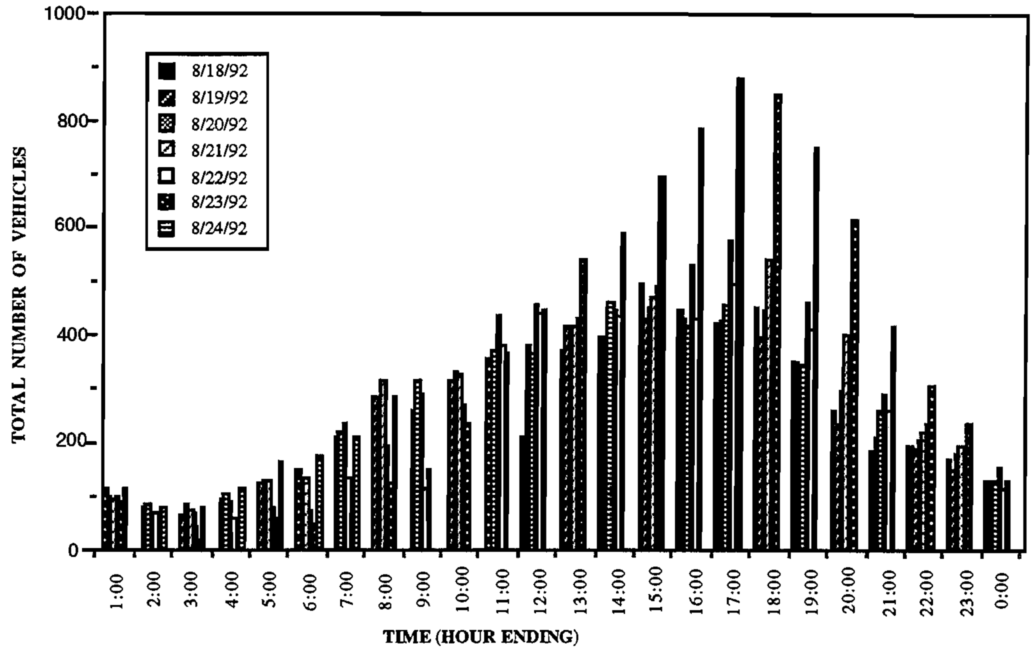


Fig 3.3 ***Hourly traffic volume variation at rigid pavement test section in the southbound lane.***

HOURLY VOLUME PATTERNS

Hourly traffic volume varies throughout the day. An understanding of the patterns of such variability can assist in scheduling temporary lane closures and detours for maintenance and construction activities. Observed hourly traffic volumes at the various sites and times described previously are shown graphically in Figs 3.1 to 3.3. At these rural highway sites, observed hourly volumes increased steadily after about 7:00 A.M., remained high throughout the daylight hours, and declined after about 8:00 P.M. to a low value around 3:00 A.M.

Hourly traffic volume can be expressed as a percent of daily traffic. The points shown in Fig 3.4 represent this ratio for hourly traffic volumes observed on six days at Work Zone 1 (northbound traffic). A fairly consistent pattern is formed by these points. No explanation can be given for the severe volume reduction which occurred between 9:00 and 12:00 A.M. on 4/20/92 as no human observer was on site. Hourly volume exceeded 5 or 6 percent of daily traffic between 8:00 A.M. and 8:00 P.M. A plot of hourly volume divided by daily volume and expressed as a percent is shown in Fig 3.5 for Work Zone 2 (southbound traffic) on 6/22/92 through 6/25/92.

Higher hourly volumes occurred in the afternoons than in the mornings at this southbound-traffic location. Southbound hourly volumes were above 5 percent of daily volumes after 10:00 A.M. and until about 6:00 P.M.

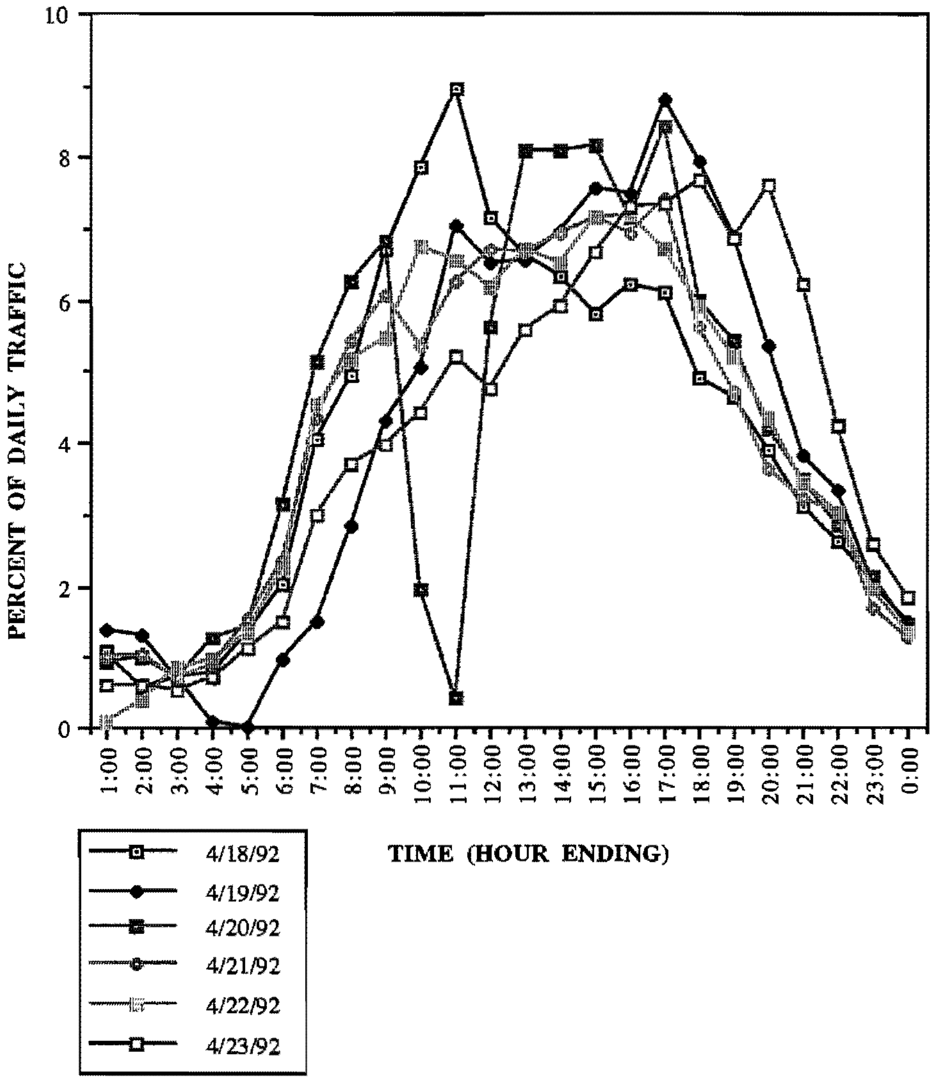


Fig 3.4 Hourly traffic volume as a percent of daily traffic at Work Zone 1.

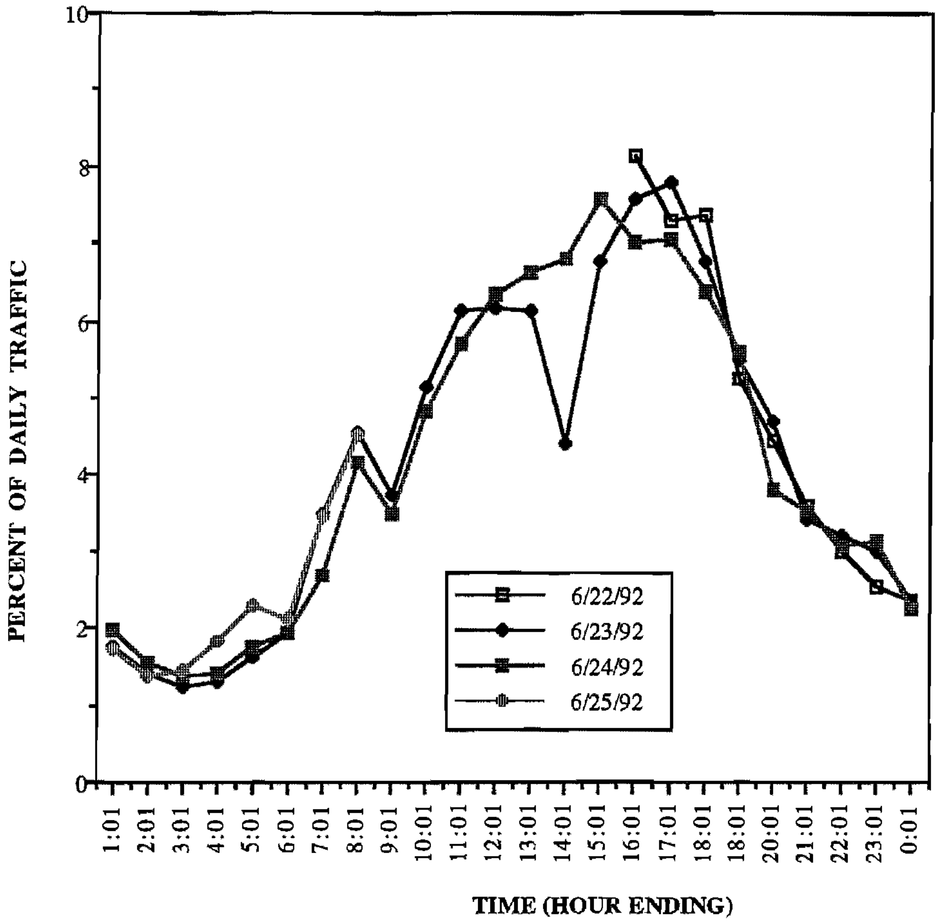


Fig 3.5 Hourly traffic volume as a percent of daily traffic at Work Zone 2.

VOLUME OF VARIOUS VEHICLE TYPES

The 3-sensor traffic data acquisition (TDA) units were arranged (see Figs 2.10 and 2.11 so that one pair of light beams detected the presence of a vehicle body about 3- to 6-ft above the road while two beams just above the road surface, and 2 feet apart longitudinally, sensed the tires on the axles of passing vehicles. A microcontroller in the TDA unit was programmed to filter out any short-duration (less than 0.25 second) presence-beam signals after the first interruption and record the number of axles on each vehicle, i.e., the time between successive vehicle bodies was greater than 0.25 second. The 2-axle vehicle type comprised mostly passenger cars and pickup trucks, but it also included single-unit, 2-axle trucks. Figs 3.6 through 3.8 illustrate the hourly volume of various vehicle types observed going northbound at Work Zone 1, expressed as a percent of the total northbound hourly vehicular traffic volume. Two-axle vehicles predominated. Except during the early morning hours, 2-axle vehicles accounted for 60 to 85 percent of all northbound vehicles. Trucks with three or more axles, and a few 3-axle car-trailer vehicles comprised the remainder of the traffic stream. Of the four truck types: 3-axle, 4-axle, 5-axle, and 6 or more-axle; the 5-axle truck type was by far predominant.

The 5-axle tractor-semitrailer type vehicle accounted for 10 to 30 percent of all vehicles on weekdays (see Figs 3.7 and 3.8) between 7:00 A.M. and midnight and up to 60 percent of all vehicles during the early morning hours when fewer cars were traveling.

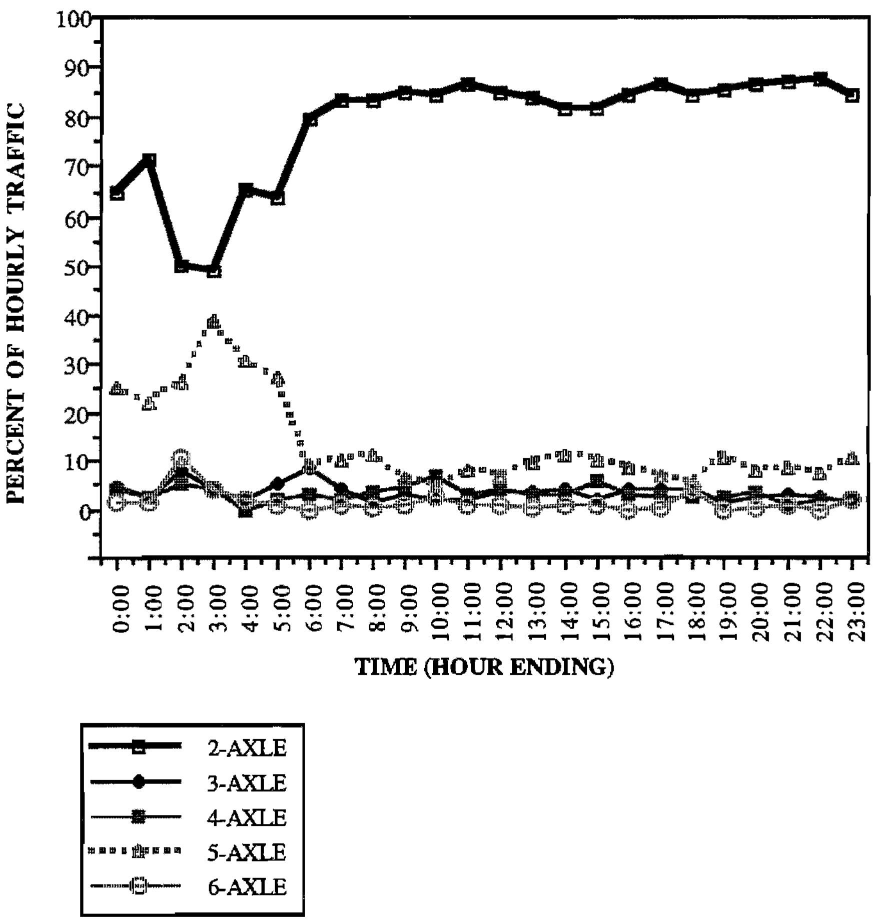


Fig 3.6 Vehicle types at Work Zone 1 on Saturday 4/18/92.

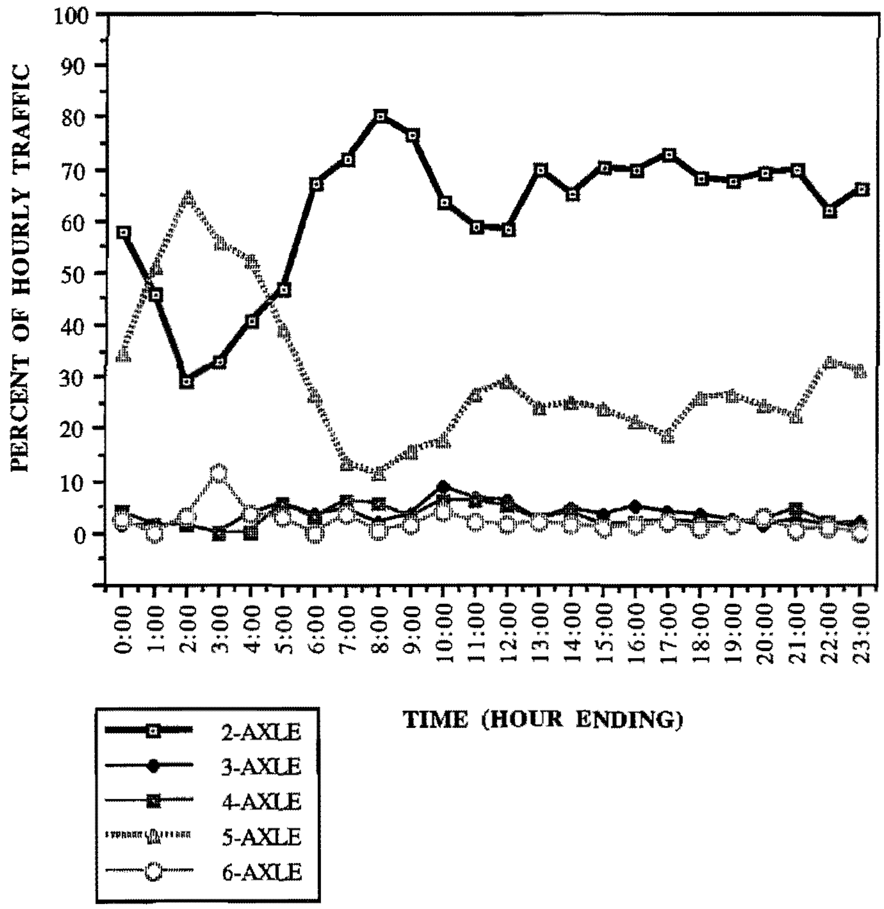


Fig 3.7 Vehicle types at Work Zone 1 on Tuesday 4/21/92.

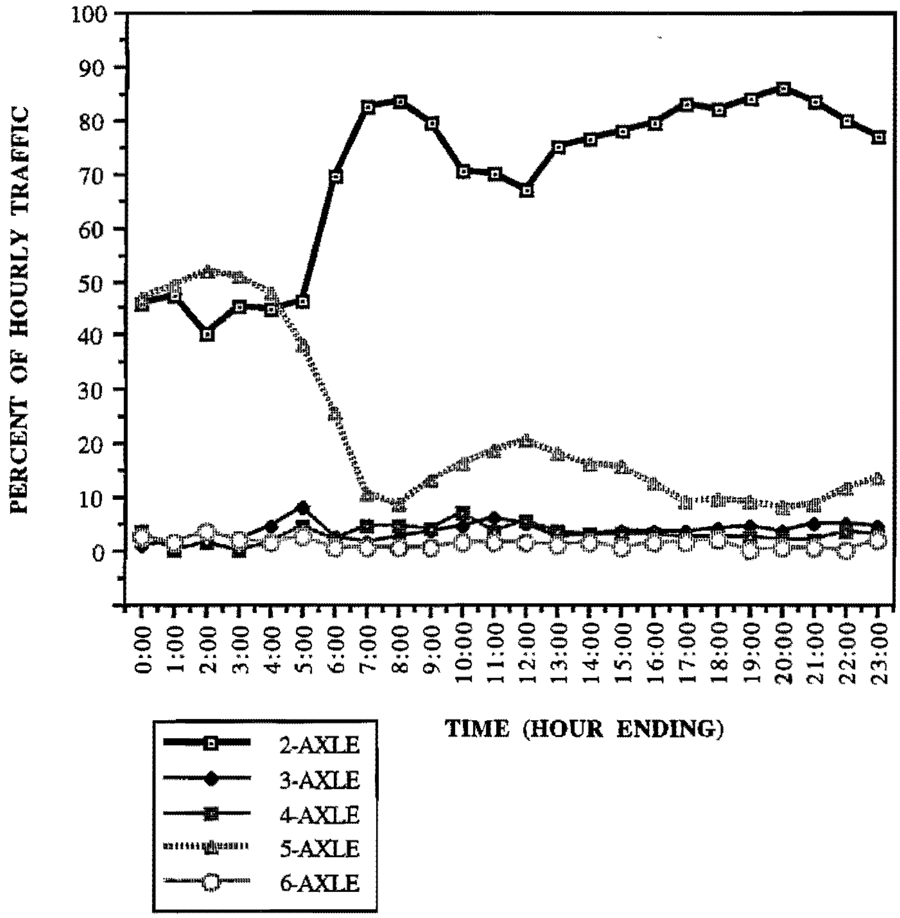


Fig 3.8 Vehicle types at Work Zone 1 on Thursday 4/23/92.

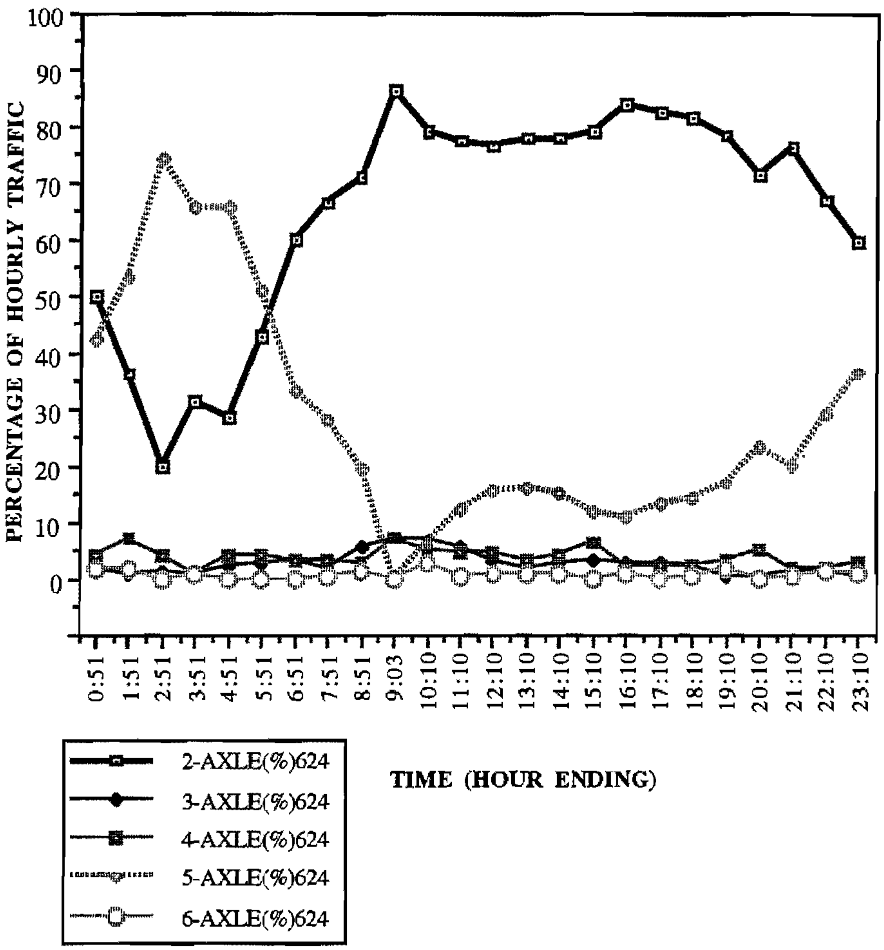


Fig 3.9 Vehicle types at Work Zone 2 on Wednesday 6/24/92.

WEEKDAY AND WEEKEND VOLUME

On weekends (see Fig 3.6 for example) truck traffic was generally at a lower volume, and 5-axle tractor-semitrailers comprised only about 10 percent of all traffic from 6:00 A.M. until midnight. During the early morning hours, this truck type respresented between 10 and 40 percent of all vehicles. As illustrated in Fig 3.9, the southbound weekday traffic at Work Zone 2 included generally similar proportions of the various vehicle types as those observed going northbound at Work Zone 1. However, during the late night and early morning hours the percent of 5-axle tractor-semitrailer trucks ranged from about 3 to 75 percent of all vehicles. During the day, cars accounted for 70 to 85 percent of the vehicles, and the 5-axle trucks comprised about 10 to 20 percent of the southbound traffic.

WEEKLY VOLUMES

Traffic under normal four-lane operations during the past construction period showed a consistent and well-defined weekly pattern. Fig 3.10 illustrates the weekly pattern for southbound traffic under normal two-lane (one-way directional) flow at the flexible pavement test section during September 1992. All values shown are the average hourly volume for the week expressed as a percentage of the average daily traffic for the week. Week 1 was between 9/2/92 and 9/6/92, Week 2 was between 9/7/92 and 9/13/92, and Week 4 was between 9/21/92 and 9/27/92.

LANE DISTRIBUTION

Sensors integral to the the special weigh-in-motion (WIM) systems made it possible to identify the lane (left-hand or right-hand) in which every vehicle traveled during the post-construction traffic study period at both the rigid pavement test site and teh flexible pavement test site located about 8-km (5-mi) to the south. In addition to the weight, axle spacing, and speed of every vehicle in the lane, it was also possible to detect single or dual tires on each axle. Data from two observation periods: 8/18/92 through 8/24/92 at the rigid pavement test site and 9/2/92 through 10/5/92 were aggregated for hourly periods, grouped, averaged, and analyzed according to various traffic characteristics.

Lane distribution analysis of southbound traffic for the four-lane divided highway revealed that the majority of vehicles traveled in the right-hand lane and that the left-hand lane accommodated faster traffic. There was also a difference in the lane distribution of single- and dual-tire vehicles, which is indicated in Table 3.6. For the single-tire vehicles, 73 percent of the hourly vehicles traveled in the right lane, while 27 percent used the left lane. Eighty-one percent of the dual-tire vehicles used the right lane. The overall lane distribution percentage was 75:25.

An investigation of lane distribution on weekdays and weekends at the flexible pavement test site indicated that on average during weekdays, 83 percent of the vehicles traveled in the right lane, while 17 percent used the left lane (see Table 3.7). On weekends, the percentage of vehicles that traveled in the left lane increased to 22 percent. As the volume of traffic increased, especially during the peak hours, the lane distribution varied, indicating an increase in the left-lane traffic volume. This increase in left-lane traffic volume was accompanied by a decrease in the right lane traffic. Average lane distribution percentages of vehicles at the two pavement test sections are illustrated graphically in Figs 3.11 and 3.12 and in tabular format in Tables 3.8 and 3.9.

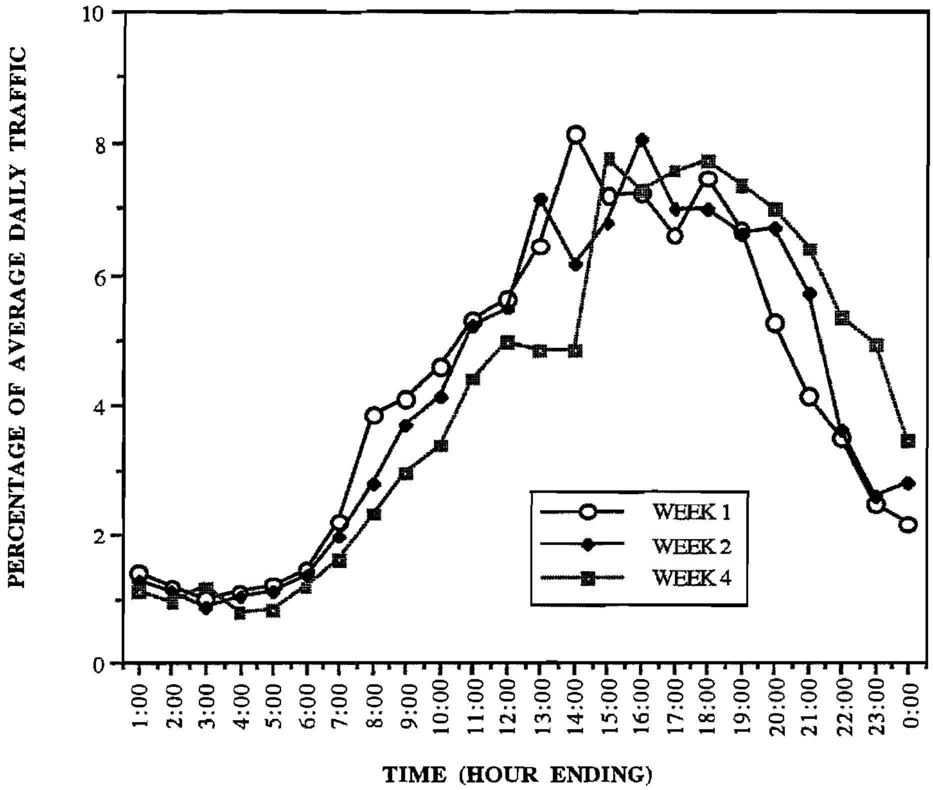


Fig 3.10 ***Weekly traffic variation during September 1992 at the flexible pavement test section.***

TABLE 3.6 LANE DISTRIBUTION AT RIGID PAVEMENT TEST SECTION

Location	Single tire (veh. per hour)	Dual tire (veh. per hour))	Total
Right Lane (lane 1)	166	55	221
Left Lane (lane 2)	60	13	73
Total	226	68	294
Percentage distr.	73:27	81:19	75:25

TABLE 3.7 LANE DISTRIBUTION AT FLEXIBLE PAVEMENT TEST SECTION

Period	Right Lane (lane 1)	Left Lane (lane 2)
Weekdays	83 %	17 %
Weekends	78 %	22 %

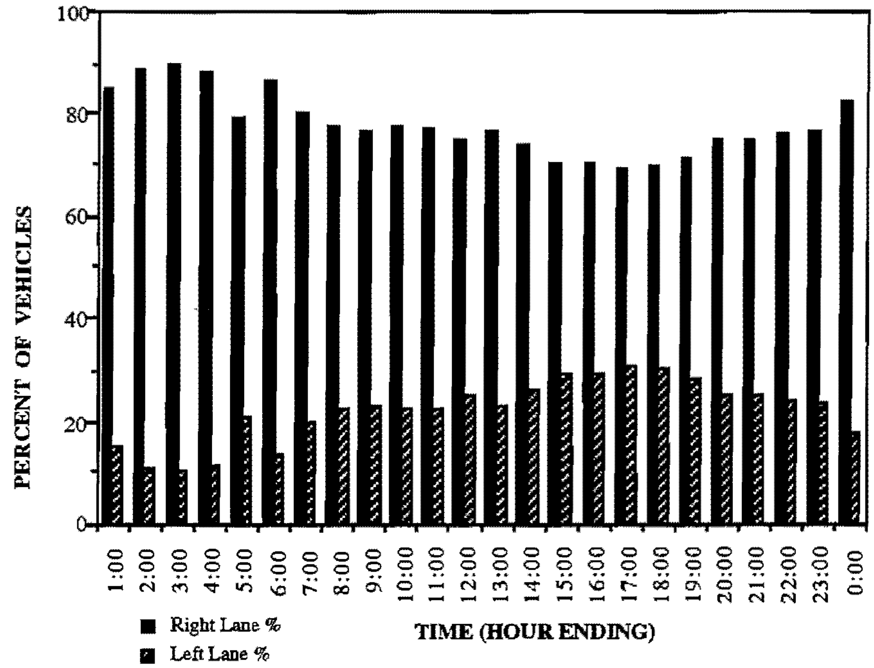


Fig 3.11 Lane distribution of vehicles at the rigid pavement test section (8/18/92 through 8/24/92).

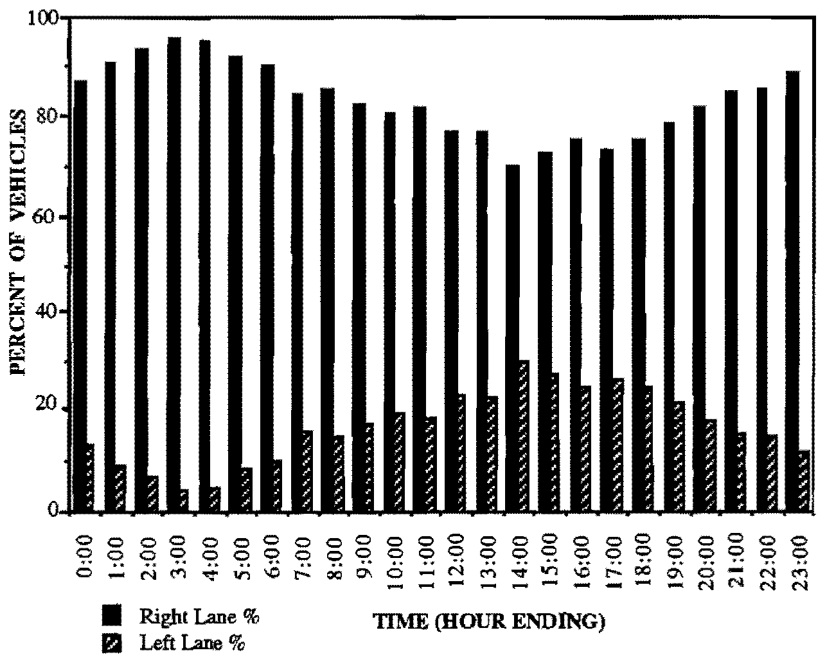


Fig 3.12 Lane distribution of vehicles at the flexible pavement test section (9/2/92 through 10/5/92).

TABLE 3.8 LANE DISTRIBUTION AT RIGID PAVEMENT TEST SECTION

Lane 1			Lane 2			Total Volume
Time	Veh.	%	Time	Veh.	%	
1:00	87	84.90	1:00	15	15.09740	102
2:00	65	88.687	2:00	8	11.31221	73
3:00	59	89.67	3:00	6	10.32745	65
4:00	75	88.476	4:00	9	11.52343	84
5:00	91	79.136	5:00	24	20.86330	115
6:00	103	86.610	6:00	16	13.38912	119
7:00	146	80.16	7:00	36	19.83621	182
8:00	192	77.837	8:00	54	22.16216	246
9:00	173	76.929	9:00	52	23.07009	225
10:00	229	77.959	10:00	64	22.04081	293
11:00	294	77.404	11:00	86	22.59590	380
12:00	286	75.065	12:00	95	24.93438	381
13:00	327	76.748	13:00	99	23.25127	426
14:00	334	74.014	14:00	117	25.98599	452
15:00	357	70.739	15:00	147	29.26023	504
16:00	356	70.701	16:00	147	29.29894	503
17:00	374	69.216	17:00	166	30.78346	540
18:00	362	69.508	18:00	159	30.49169	521
19:00	311	71.412	19:00	124	28.58778	435
20:00	262	74.762	20:00	88	25.23719	350
21:00	200	74.98	21:00	67	25.01555	267
22:00	170	75.83	22:00	54	24.16604	224
23:00	141	76.30	23:00	43	23.69369	184
24:00	105	82.12	24:00	23	17.87564	128

TABLE 3.9 LANE DISTRIBUTION AT THE FLEXIBLE PAVEMENT TEST SECTION

Lane 1			Lane 2			Total Volume
Time	Veh.	%	Time	Veh.	%	
1:00	182	86.893414	1:00	27	13.10658	209
2:00	160	91.049382	2:00	15	8.950617	175
3:00	160	93.252183	3:00	11	6.747816	171
4:00	200	95.917481	4:00	8	4.082519	208
5:00	175	95.214602	5:00	8	4.785397	183
6:00	124	91.655540	6:00	11	8.344459	135
7:00	147	89.872364	7:00	16	10.12763	163
8:00	159	84.002869	8:00	30	15.99713	189
9:00	238	85.189400	9:00	41	14.81059	279
10:00	265	82.137340	10:00	57	17.86265	322
11:00	266	80.541431	11:00	64	19.45856	330
12:00	332	81.532635	12:00	75	18.46736	407
13:00	315	76.712214	13:00	95	23.25877	410
14:00	380	76.816475	14:00	114	23.18352	494
15:00	323	69.636084	15:00	141	30.36391	464
16:00	392	72.360575	16:00	150	27.63942	542
17:00	483	75.251926	17:00	159	24.74807	642
18:00	414	73.217742	18:00	151	26.78225	565
19:00	445	75.332420	19:00	145	24.66757	590
20:00	438	78.296836	20:00	121	21.70316	559
21:00	411	81.714801	21:00	92	18.28519	503
22:00	371	84.569241	22:00	67	15.43075	438
23:00	295	85.363289	23:00	50	14.63710	345
24:00	250	88.520900	24:00	32	11.47909	282

VEHICLE HEADWAYS

Headway is the time in seconds between a selected reference point on successive vehicles as they pass a designated point on the roadway. It also directly corresponds to the rate of traffic movement that is described by the following equation:

$$q = 3{,}600 / h$$

or

$$q = k / h$$

where

k = number of seconds per hour, when

q = volume in vehicles per hour, and

h = average headway in seconds per vehicle.

Average vehicle headways for southbound and northbound traffic at both work zone locations (Table 3.10) are 14 secs and 13 secs for Work Zones 1 and 2, respectively. These headways are deemed typical for the low-to-moderate traffic volumes along US 59.

TABLE 3.10 VEHICLES HEADWAY BETWEEN WORK ZONES

Location	Volume, q (vph)	Headway, h (sec per veh.)	Flow direction	Work Zone
Sensor #6	281	14 secs	Northbound	1
Sensor #5	252	13 secs	Southbound	2

COMPOSITION OF TRAFFIC

Vehicles of different size and weight have different operating characteristics. They are classified as follows: (a) passenger cars, including light delivery trucks; and (b) trucks, including buses, single-unit trucks, and other truck combinations. For the purpose of this study, trucks have been classified by number of axles as follows: (1) three-axle, (2) four-axle, (3) five-axle, and (4) six-or more axle vehicles. Trucks, besides being heavier, are generally slower and occupy more roadway space; consequently, they usually have a greater effect on traffic operations than passenger cars. Thus the term "passenger car equivalent" has been used in traffic flow theories (Ref 9) to describe the effect of trucks on traffic operations.

Results of this study revealed that on average for the northbound lane Work Zone 1), 34 percent of the total Monday - Thursday vehicles were trucks (see Table 3.11). For the southbound traffic (Work Zone 2), the percentage of trucks ranged from 19 percent to 51 percent on different days between 6/22/92 through 6/25/92. A 35-percent daily truck average was obtained for the Monday - Thursday southbound traffic (see Table 3.12).

Among the trucks, there was a high percentage of five-axle trucks. Five-axle trucks accounted for 65 percent of the northbound truck population and 60 percent of the southbound.

The truck percentage for traffic during the post-construction traffic study period between July and October 1992 yielded average truck percents similar to the ones observed during the construction activities. Truck percentages observed during September 1992 on various days are shown in Table 3.13. The pie charts in Fig 3.13 also illustrate the composition of traffic at Work Zones 1 and 2.

TABLE 3.11 PERCENTAGE OF TRUCKS AT WORK ZONE 1

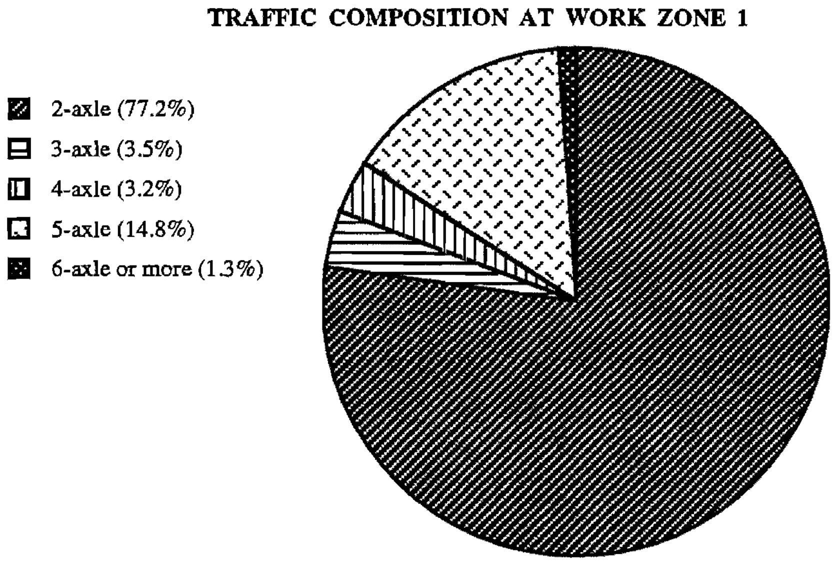
Date	Day	Vehicle per hour	Percentage of trucks
4/20/92	Monday	224	33.4
4/21/92	Tuesday	247	39.2
4/22/92	Wednesday	256	35.1
4/23/92	Thursday	411	28.9

TABLE 3.12 PERCENTAGE OF TRUCKS AT WORK ZONE 2

Date	Day	Vehicle per hour	Percentage of trucks
6/22/92	Monday	287	19.0
6/23/92	Tuesday	249	34.0
6/24/92	Wednesday	253	36.0
6/25/92	Thursday	121	50.0

TABLE 3.13 COMPOSITION OF TRAFFIC AT THE FLEXIBLE PAVEMENT TEST SECTION

	Week 1		Week 2		Week 3		Week 4	
Day	Date	% Truck	Date	% Truck	Date	% Truck	Date	% Truck
Mon			9/7/92	11.3	9/14/92	-	9/21/92	-
Tues			9/8/92	32.5	9/15/92	34.3	9/22/92	-
Wed	9/2/92	33.5	9/9/92	31.0	9/16/92	-	9/23/92	33.6
Thurs	9/3/92	43.3	9/10/92	35.3	9/17/92	-	9/24/92	33.2
Fri	9/4/92	23.8	9/11/92	25.2	9/18/92	31.4	9/25/92	23.6
Sat	9/5/92	13.9	9/12/92	16.8	9/19/92	25.2	9/26/92	15.1
Sun	9/6/92	9.5	9/13/92	50.4	9/20/92	41.7	9/27/92	61.9



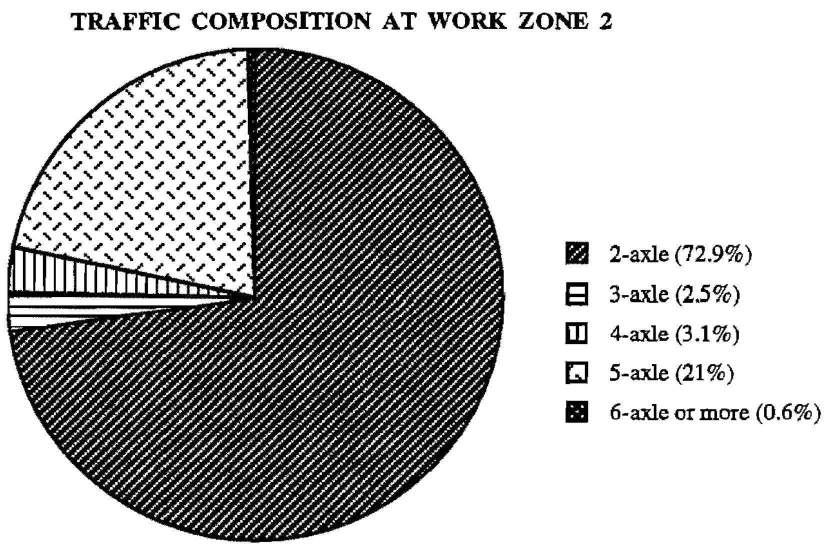


Fig 3.13 Traffic composition.

SPEED DISTRIBUTION

As indicated in Figs 2.4 and 2.5, traffic data acquisition (TDA) systems with infrared light-beam sensors were deployed to measure vehicle speeds in advance of, within, and beyond the work zones. Any difference in the free speeds outside the work zone and within the work zone could likely be attributed to the different traffic operational environment created by the geometric and traffic control changes effected through the zones.

Analysis of the speed data revealed a consistent pattern of reduced speed through the work zones, as expected; however, the magnitude of speeds was somewhat different for the two situations studied. As shown in Table 3.14, the mean free speed in advance of Work Zone 1 was 99-km/h (61.5-mi/h), and it decreased only slightly to 97-km/h (60-mi/h) within the 1.6-km (1-mi) long traffic lane beside a concrete traffic barrier.

At Work Zone 2, where a 300-m (1,000-ft) segment of one southbound lane had been closed with plastic barrels, signs, and other traffic control devices, the mean free speed of approaching vehicles was 90-km/h (56-mi/h), but it reduced to 80-km/h (50-mi/h) in the unblocked lane beside the barrels through the zone. This was a 10-km/h (6-mi/h) decrease in mean speed (see Table 3.15).

Tables 3.16 and 3.17 show observed speeds and calculated statistical values for various days at Work Zones 1 and 2, respectively. Average speeds through Work Zone 1 were consistently higher than those through Work Zone 2.

TABLE 3.14 SPEEDS AT WORK ZONE 1

Location	Mean Speed	Remarks	Percentage reduction
Sensor 1	58.4 mph	Exit of Work Zone (free flow) approaching town limit	-
Sensor 6	60 mph	At Work Zone	2.4 percent
Sensor 3	61.5 mph	Entrance of Work Zone (free flow)	-

Note: 1 mph=1.61 km/h (see Fig 2.4)

TABLE 3.15 SPEEDS AT WORK ZONE 2

Location	Mean Speed	Remarks	Percentage reduction
Sensor 4	56 mph	Entrance to Work Zone (free flow)	-
Sensor 5	50 mph	At Work Zone	12.3 percent
Sensor 2	57 mph	Exit of Work Zone (free flow)	-

Note: 1 mph=1.61 km/h (see Fig 2.5)

TABLE 3.16 RESULTS OF SPEED STUDY AT WORK ZONE 1

Speed Class (mph)	4/17/92 (Friday)	4/18/92 (Saturday)	4/19/92 (Sunday)	4/20/92 (Monday)
<45	381	1553	1152	1037
45-49	91	79	33	60
50-54	375	221	143	157
55-59	670	661	420	456
60-64	934	1259	994	929
65-69	708	1738	1836	1484
>70	198	1485	1746	1241
Total veh.	3357	6996	6324	5364
Calculated avg. speed (mph)	59	60.2	61.9	61
50th percentile speed (mph)	62	62	67	67
85th percentile speed (mph)	67	70	70	70
Max. speed (mph)	74	74	74	74

Note: 1 mph=1.61 km/h (continued)

TABLE 3.16 RESULTS OF SPEED STUDY AT WORK ZONE 1

(continuation)

Speed Class (mph)	4/21/92 (Tuesday)	4/22/92 (Wednesday)	4/23/92 (Thursday)	4/24/92 (Friday)
<45	1808	1259	1880	922
45-49	39	50	106	13
50-54	140	169	254	67
55-59	394	474	717	128
60-64	930	926	1690	307
65-69	1440	1733	2764	664
>70	1180	1536	2468	698
Total veh.	5931	6147	9879	2799
Calculated avg. speed (mph)	58.9	61.1	61.3	59
50th percentile speed (mph)	62	67	67	62
85th percentile speed (mph)	70	70	70	70
Max. speed (mph)	74	74	74	74

Note: 1 mph=1.61 km/h

TABLE 3.17 RESULTS OF SPEED STUDY AT WORK ZONE 2

Speed Class (mph)	6/22/92 (Monday)	6/23/92 (Tuesday)	6/24/92 (Wednesday)	6/25/92 (Thursday)
<45	606	1456	1471	329
45-49	819	1974	1856	357
50-54	950	1965	1881	298
55-59	355	695	738	162
60-64	70	109	129	35
65-69	5	17	17	6
>70	0	4	1	1
Total veh.	2805	6220	6093	1188
Calculated avg. speed (mph)	49.9	49.6	49.6	49.6
50th percentile speed (mph)	47	47	47	47
85th percentile speed (mph)	57	52	52	57
Max. speed (mph)	69	73	74	72

Note: 1 mph=1.61 km/h

TRUCK PERCENTAGE AND VEHICLE SPEED

The observed relationship between truck percentage and average vehicle speed for each hour on Thursday 4/23/92 at Work Zone 1 is shown graphically in Fig 3.14. During the late-night and early-morning hours, truck percentage increased from 15 to about 65 percent, and average speed fluctuated around 97-km/h (60-mi/h). After daylight when proportionately more cars began traveling, truck percentage declined sharply, and average speed increased about 3-km/h (2-mi/h) to around 100-km/h (62-mi/h).

A similar relationship was seen at Work Zone 2 where the pattern of truck percentage was about the same with respect to time of day, but where the magnitude of average hourly speed during the hours of darkness was only 77-km/h (48-mi/h). Average speed during the daytime also increased about 3-km/h (2-mi/h) to 80-km/h (50-mi/h) at this site. Truck percentages and speed values recorded hourly on Tuesday 6/23/92 at Work Zone 2 are shown graphically in Fig 3.15.

It is not appropriate to attribute the relatively-small observed average speed difference solely to concurrent variations in truck percentages. The day/night driving conditions that drivers experienced when traveling through the work zones surely had an effect on their chosen speed.

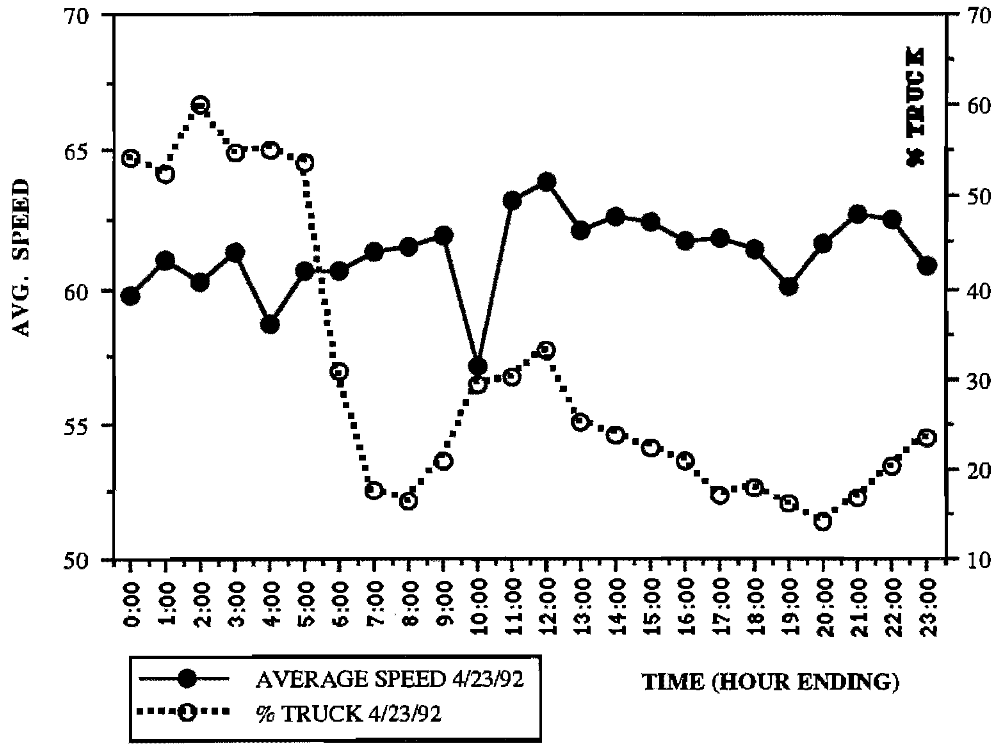


Fig 3.14 Truck percentage and speed (in mi/h) at Work Zone 1. Date: 4/23/92 (Thursday) (1 mph=1.61 km/h).

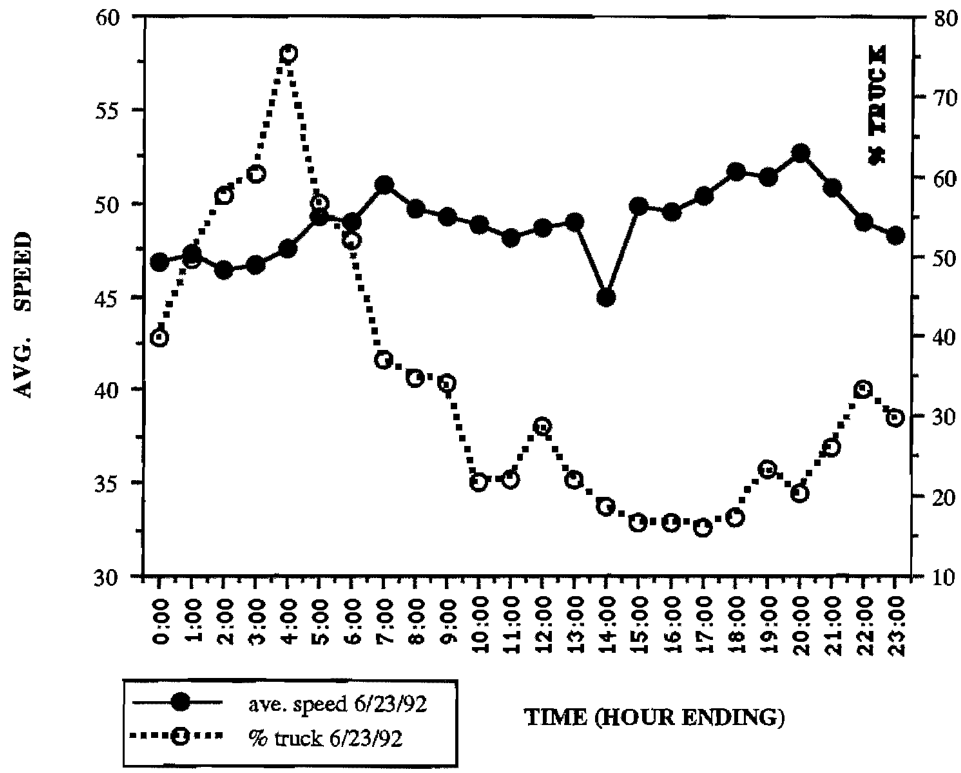


Fig 3.15 Truck percentage and speed (in mi/h) at Work Zone 1. Date: 6/23/92 (Tuesday) (1 mph=1.61 km/h).

SUMMARY

The thrust of this chapter has been to present an analysis of data concerning traffic volume and speed measurements made with infrared light-beam sensors at, and near, two work-zone sites on US 59 where pavement test sections were being constructed. A different traffic detour strategy was utilized for each work zone.

Both northbound and southbound traffic volume through the respective work zones averaged between 6,000 and 7,000 vehicles per day. Similar one-way, southbound average daily volumes were observed during a post-construction period when data were obtained from special weigh-in-motion systems that were installed to monitor traffic parameters continuously for approximately three years at each of the two pavement test sites, which are about 8-km (5-mi) apart.

Hourly traffic volumes at the two work zones exhibited similar patterns of variability throughout the day. Volumes increased steadily after about 7:00 A.M., remained high through the day, and declined after about 8:00 P.M. to a low value around 3:00 A.M. Northbound volume exceeded 5 or 6 percent of daily traffic volume continually between 8:00 A.M. and 8:00 P.M., but southbound volumes exceeded 5 percent of daily volume after 10:00 A.M. and until about 6:00 P.M.

Except during the early-morning hours, about 60 to 85 percent of all northbound vehicles were the 2-axle type. The 5-axle tractor-semitrailer type vehicle accounted for 10 to 30 percent of all vehicles on weekdays between 7:00 A.M. and midnight, and up to 60 percent of all vehicles during the early-morning hours. On weekends, truck volume was lower, and the 5-axle type comprised only about 10 percent of all vehicles between 6:00 A.M. and midnight. This type represented between 10 and 40 percent of all vehicles on weekends during the early morning hours. Of all trucks, about 60 to 65 percent were the 5-axle type.

Lane distribution of traffic outside the work zones was found to comprise an overall 75:25 ratio of vehicles in the right-hand and left-hand lanes, respectively. This ratio for single-tire vehicles was 73:27 and for dual-tire vehicles, it was 81:19.

In Work Zone 1, where traffic ran for about 1.6-km (1-mi) beside a concrete traffic barrier, the average free speed of approaching traffic (in advance of the zone) of 99-km/h (61.5-mi/h) decreased to 97-km/h (60-mi/h), a reduction of only 2-km/h. However, in Work Zone 2 where plastic barrels were beside the work zone lane for about 30-m (1,000-ft), the free approach speed changed from 90 km/h (56-mi/h) to 80-km/h (50-mi/h), a reduction of 10-km/h.

In both work zones, a 3-km/h (2-mi/h) speed reduction was observed during the late-night and early-morning hours of darkness when the truck-traffic proportion increased from 15 to about 65 percent. This speed reduction cannot, however, be attributed to the change in truck percentage alone. The darkness certainly affected the speed chosen by drivers, also.

CHAPTER 4. TRAFFIC SIGNS AND OPERATIONS

INTRODUCTION

Traffic control within work zones involves the use of the following techniques and operations: (1) diversions, (2) detours, (3) contra-flows (crossovers), (4) lane alterations, and (5) lane closures.

DIVERSION AND DETOURS

While diverting traffic to another facility is the most effective way of enhancing work zone safety, this technique can usually be used only on highways with low traffic volumes. Detours result in longer driving time, and they create more delays and higher operating costs that result in lower levels of service. Alternative routes should have the capacity to handle the additional traffic from the detours, but many alternative routes do not have the necessary capacity. In the detour area, driver information is vital so as to ensure an efficient and safe flow of traffic.

CONTRA-FLOWS

Where a work zone occupies one roadway of a divided highway, traffic on the remaining roadway is channeled by means of a contra-flow system—that is, vehicles cross the median; Work Zone 1 in this study is representative of a contra-flow system.

LANE CLOSURES

Lane closures, which hinder normal traffic flow, are introduced where work on existing routes encroaches on running lanes and shoulders. A reduction in the number of operational lanes reduces capacity and level of service, and results in speed reduction and delay—which this study has demonstrated.

TRAFFIC CONTROL DEVICES

Traffic control devices are placed in work zones to ensure safe traffic movement. Such devices warn road users that a constricted roadway lies ahead. Another purpose of traffic control is to guide vehicles around work zone obstructions. And while traffic controls are governed by the *Manual on Uniform Traffic Control Devices* (MUTCD) (Ref 13), this text fails to address fully traffic controls through work zones. At the time of this writing, revisions were underway to review Part VI of the MUTCD to define more clearly the various work zone areas and traffic control device applications. The traffic controls used in the work zones for this study follow the guidelines of the *Texas Manual on Uniform Traffic Control Devices* (Ref 18). Part VI of this manual describes extensively the principal guidelines and standards for use of control devices in construction and maintenance areas, including descriptions of design, application, installation, and maintenance standards of various types of required traffic controls. In addition, rules and guidelines are provided for the use of signs, signals, lighting devices, markings, barricades, traffic channeling, and hand signal devices. A sketch is given below of the layout of some of the traffic signs that were observed at the work zone areas.

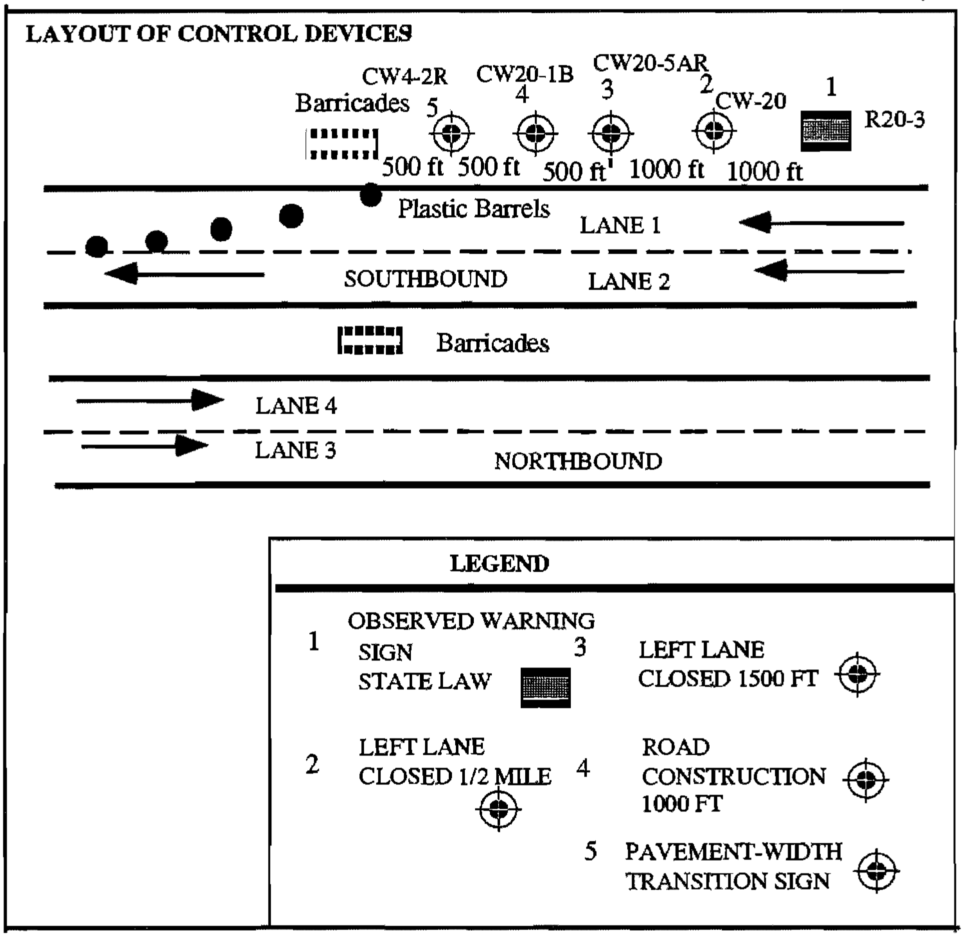


Fig 4.1 Layout of traffic signs (1 ft=0.304 m).

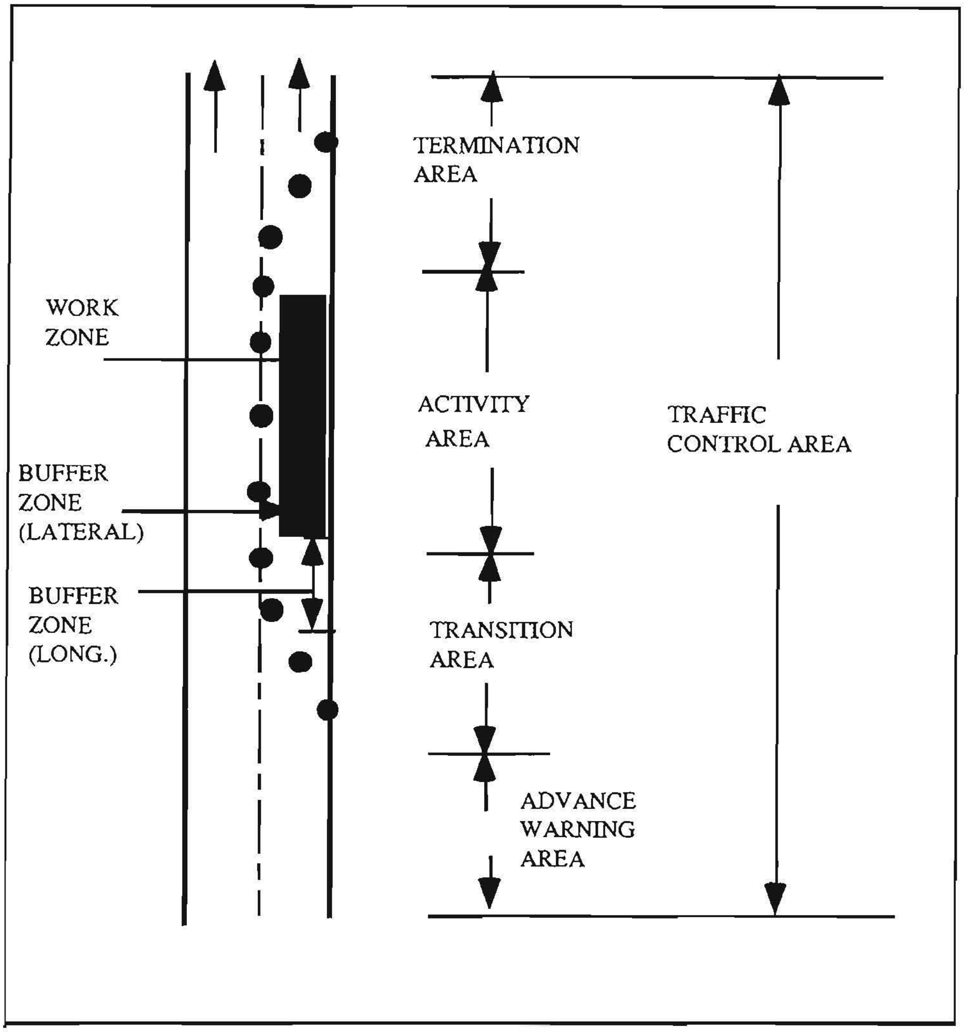


Fig 4.2 Areas established for work zone traffic control.

TRAFFIC CONTROL AREA

With reference to Fig 4.2, traffic control in work zones is comprised of four main areas: (1) advance warning area, (2) transition area, (3) activity area, and (4) termination area.

ADVANCE WARNING AREA

This area warns drivers of obstructions ahead. It gives drivers the opportunity to react and to make the appropriate adjustment. In the advance warning area, traffic signs—made of retro-reflective sheetings to ensure visibility and conspicuousness during the day, at night, and under all weather conditions—convey warnings to drivers of unexpected dangers. They are intended to advise, to warn, and to instruct motorists on how to drive through the work zones. As mentioned in the *Manual On Uniform Traffic Control Devices* (MUTCD) (Ref 13), there are three major categories of signs—regulatory, warning, and guide.

Design and application of traffic control devices in work zones should conform to existing standards and guidelines. Traffic signs are also designed to attract motorists' attention and are enhanced by large letter sizes and good background contrast. Increasing the distance at which signs are detected and recognized provides the drivers with sufficient time to react. A sample of the traffic signs that were observed at the work zones are shown in the photographs of Figs 4.3 through 4.7.

Fig 4.3. Traffic signs for Work Zone 1 on the northbound lane (4/9/92).

Fig 4.4. Traffic signs for Work Zone 1 on northbound lane (4/9/92).

Fig 4.5. Traffic signs for Work Zone 1 on northbound lane (4/9/92).

Fig 4.6. Traffic signs for Work Zone 1 on northbound lane (4/9/92).

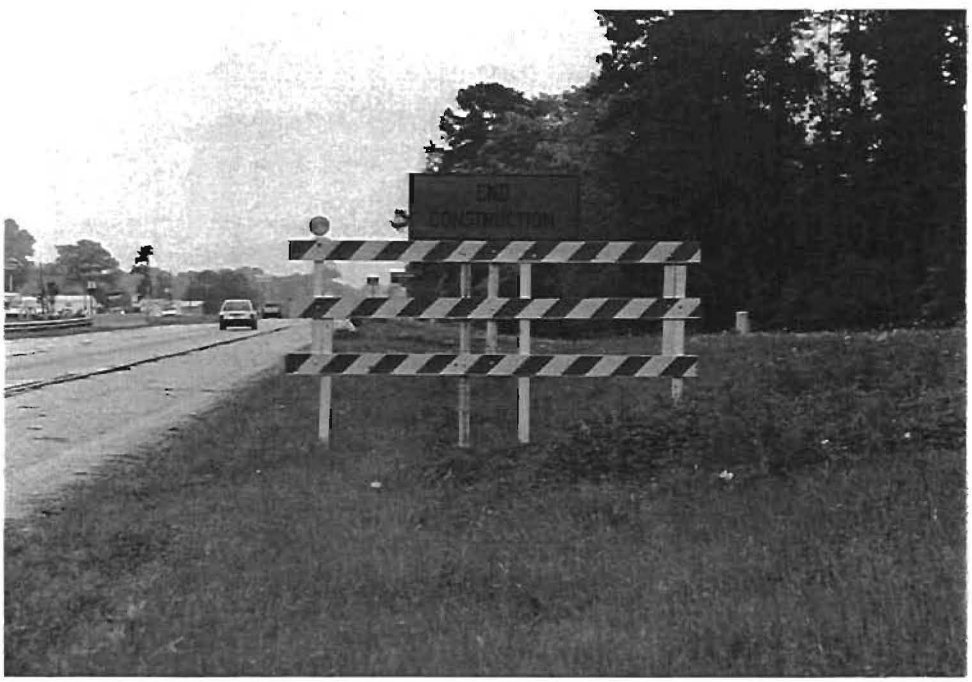


Fig 4.7. Traffic signs for Work Zone 1 on northbound lane (4/9/92).

TRANSITION

The transition area is where traffic slowly merges from a two-lane to a one-lane highway. This practice is carried out whenever lane closures are necessary in road construction and maintenance. Table 4.1 gives the typical transition lengths which are provided in the *Texas Manual on Uniform Traffic Control Devices* (Ref 18). The manual also suggests that the 85th percentile speed be used on roads where traffic normally exceeds the posted speed limits.

TABLE 4.1 TYPICAL TRANSITION LENGTHS

Posted speed (mph)	Formula	Min. desirable length (10' offsets)	Min. desirable length (11' offsets)	Min. desirable length (12' offsets)
30		150 ft.	165 ft.	180 ft.
35	L=(W * S^2)/60	205 ft.	225 ft.	245 ft.
40		265 ft.	295 ft.	320 ft.
45		450 ft.	495 ft.	540 ft.
50		500 ft.	550 ft.	600 ft.
55	L=W * S	550 ft.	605 ft.	660 ft.
60		600 ft.	660 ft.	720 ft.
65		650 ft.	715 ft.	780 ft.

Source: *Texas Manual On Uniform Traffic Control Devices* (Ref 18).
Note: 1 mph=1.61 km/h; 1 ft=0.304 m

In the transition area of the work zone, two types of channeling devices were used for traffic control. The first type involves the use of traffic barriers in the form of portable precast units. Each unit is 7.6-m (25-ft) in length and is designed for safe handling and easy installation. Concrete traffic barriers provide workers excellent protection from moving vehicles. Reflectors were installed on the barriers at intervals of 12-m (40-ft). Fig 4.8 illustrates the use of concrete barriers in a work zone (i.e., during construction of the detour at Work Zone 1).

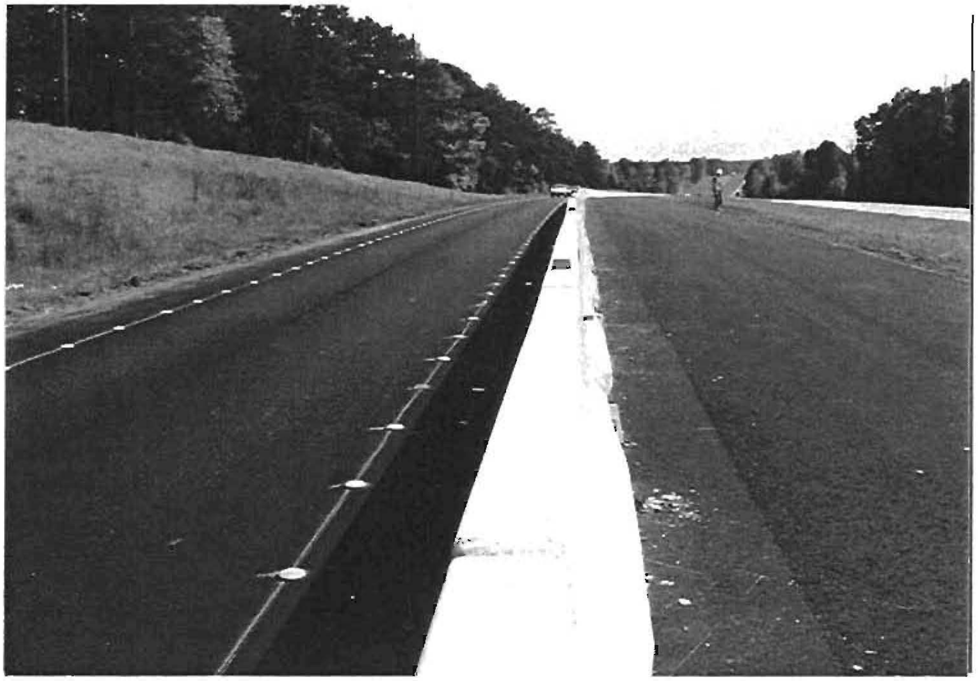


Fig 4.8 Concrete traffic barrier.

The second type of traffic channeling device involved the use of plastic barrels. The placement and spacing of the barrels (given in Table 4.2) in the transition zone in the traffic control area conform to the standards of the *Texas Manual On Uniform Traffic Control Devices*. The plastic drums are 1-m (3-ft) in height and are usually 0.5- to 0.6-m (1.5- to 2-ft.) in diameter. Each unit is either designed as a two-piece or a one-piece unit. The two-piece plastic drums are base mounted with a closed top. Each unit weighs a minimum of 13.6-kg (30-lb) (the maximum is 34-kg [75-lb] when sand-filled). A one-piece plastic drum weighs a maximum of 22.65-kg (50-lb) with the sand-filled base. Horizontal circumferential markings of reflectorized orange and reflectorized white stripes of 10.2-cm to 20.3-cm (4- to 8-in) wide were placed on the plastic drums, with the first reflectorized strip placed at least 10.16-cm (4-in) from the top. Chevrons were also used to channel traffic. The color of these delineators conformed to the Texas MUTCD requirements (Ref 18). Fig 4.9 illustrates the use and layout of this channeling device.

TABLE 4.2 SPACING OF PLASTIC BARRELS

Posted speed mph	Formula	Max. spacing of device (on a taper)	Max. spacing of device (on a tangent)
30		30 ft.	60 - 75 ft.
35	L = (W * S) / 60	35 ft.	70 - 90 ft.
40		40 ft.	80 - 100 ft.
45		45 ft.	90 - 110 ft.
50		50 ft.	100 - 125 ft.
55	L = W * S	55 ft.	110 - 140 ft.
60		60 ft.	120 - 150 ft.
65		65 ft.	130 - 175 ft.

Source: *Texas Manual On Uniform Traffic Control Devices* (Ref 18)
Note: 1 mph=1.61 km/h; 1 ft=0.304 m

Fig 4.9 Plastic barrels as channeling devices at Work Zone 2.

ACTIVITY

The activity zone of the traffic control area is where most of the construction activities are carried out. As indicated in Fig 4.2, the activity area also includes the effective working area, with a lateral and longitudinal buffer zone to keep workers and equipment at a safe distance from oncoming traffic in the adjacent lane. Plastic barrels were used as temporary lane barricades to divert traffic from the construction area.

TERMINATION AREA

The termination area is at the end of the construction zone and, thus, involves the use of control devices to merge traffic from the constricted lane to normal highway operations. The length and spacing of control devices of the taper for the termination area follows that of the transition area.

LIGHTING DEVICES AND WARNING BEACONS

Lighting devices were used in the work zone to supplement signs, barriers, and channeling devices. The arrow panels and the high intensity lights were effective in getting the attention of drivers. Flashing arrow panels have become prominent features in many work zones since being introduced in the early 1970's (Ref 14, pp 63). The arrow panel has all the desirable features of a good traffic control device because of its conspicuousness and its long-distance visibility. It is simple in design, and its message is easily understood. The arrow panels placed at the start of the lane-closure taper, to supplement the existing traffic control features in the work zones, were effective, since they promoted early merging into the open lane. The application and operation of such devices at the taper of the work zone traffic control area can be seen in Fig 4.10.

Warning beacons are also common in work zone areas: They are used to indicate hazards and to delineate safe vehicle travel paths. The warning beacons are portable, generally mounted on signs or barriers, and are effective only at night. These high-intensity beacons are usually placed on advance warning boards, signs, and road-blocking boards.

Fig 4.10 Arrow panels at Work Zone 2 on the southbound lane (6/23/92).

SUMMARY

This chapter has summarized the management and operational aspects of traffic control in providing signs and appropriate devices that are imperative for the safe and efficient travel of vehicles through work zones. The 1980 *Texas Manual on Uniform Traffic Control Devices* describes extensively the use and applications of these devices. Rules and guidelines for various work zone situations are contained in the manual. The principal guidelines are twofold. The guidelines are aimed at (1) directing traffic safety so as to minimize potential accident risks among vehicles and motorists, and (2) ensuring the safety of workers in the construction areas.

The work zones studied in this research used traffic control techniques that complied with the recommended practice. Several photographs illustrate the deployment of various official traffic control devices at the work sites.

CHAPTER 5. CONCLUSION

The effects of traffic detours on a 4-lane divided rural highway were investigated in this research project. The principal features of the detours which were thought to affect traffic behavior were lane geometry and traffic control devices. Two types of work zone detours were studied. One type involved reducing traffic to one lane flow in each direction, providing median-crossing transitions at each end of a mile-long work zone, and separating the adjacent, directional lanes with a concrete traffic barrier. The other type involved the sequential construction of a series of short pavement sections one-lane-at-a-time while detouring traffic into the other lane with temporary barrel-type barricades and other traffic control devices. Observed traffic volume, composition, and speed were used to characterize and evaluate traffic operations within and adjacent to the work zones. conventional traffic control practices were utilized to effect the detours.

Several sets of special traffic data acquisition (TDA) equipment were used to make traffic measurements during a five-month period. Infrared light-beam sensors directed across the traffic lane detected the passage of each vehicle (or axle) with respect to time and made it possible to record the lane of operation, the speed, the class (via number of axles), and the volume of traffic at selected locations. When compared to a manual traffic count, the difference in the TDA count ranged between 0.4 and -1.5 percent; thus, the accuracy of the TDA count was deemed to be quite adequate for this research.

Both northbound and southbound traffic volume through the work zones averaged between 6,000 and 7,000 vehicles per day. Hourly volumes generally increased steadily after about 7:00 A.M., remained high through the day, and declined after about 8:00 P.M. to a low value around 3:00 A.M. Northbound hourly volume exceeded 5 or 6 percent of daily volume continually between 8:00 A.M. and 8:00 P.M., but southbound volume stayed above 5 percent of daily traffic only between 10:00 A.M. and 6:00 A.M.

Except during the early-morning hours, about 60 to 85 percent of all northbound vehicles were the 2-axle type. From 10 to 30 percent of all vehicles on weekdays between 7:00 A.M. and midnight were 5-axle tractor-semitrailers, and comprised up to 60 percent of all vehicles during the early-morning hours. Truck volume was lower on weekends. Of all trucks, about 60 to 65 percent were 5-axle tractor-semitrailers.

Outside the work zones, on average, about 75 percent of all vehicles traveled in the right-hand lane. About 73 percent of the single-tire vehicles, and 81 percent of the dual-tire vehicles used the right-hand lane.

The average free speed of traffic approaching the 1.6-km (1-mi) section of concrete traffic barrier was 99-km/h (61.5-mi/h). This speed decreased to 97-km/h (60-mi/h) when traveling beside the barrier - a speed reduction of only 2-km/h. Where plastic barrels and other traffic control devices were used to close one lane to create a 30-m (1,000-ft) one-lane work zone, the average free approach speed of 90-km/h (56-mi/h) decreased to 80-km/h (50-mi/h)—a reduction of 10-km/h. In both work zones during late-night and early-morning hours of darkness, observed average speeds were 3-km/h (2-mi/h) lower than at other times. Truck traffic, expressed as a percentage of all traffic ranged up to 65 percent during the hours of darkness when fewer cars were traveling and comprised about 15 percent during other times of day. The small average speed reduction cannot be attributed solely to either a high percent of trucks or to the effect of darkness on perceived safe speed.

Traffic control guidelines contained in the 1980 Texas Manual on Uniform Traffic Control Devices were applied throughout the project described herein. Traffic responded smoothly to the guidance provided and moved efficiently and safely through the work zones. These guidelines appear to be adequate for work zone traffic control on rural highways of the type studied.

The observed traffic behavior described in this report provides a basis for assessing the potential effects of two types of work-zone detours on traffic operations on high-speed, moderate-volume rural highways.

The two types of lane geometry and traffic control that were deployed during the study produced relatively small average speed reductions (2 to 10-km/h) through the work zones. The longer section of positive guidance afforded by the concrete traffic barrier caused the smaller speed reduction. It also provided maximum work zone safety, but it was much more expensive to implement.

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