TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FHWA/TX-90/1163-3F	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Evaluation of Loop Detector Installation Procedures and Preparation of a Texas Traffic Signal Detector Manual		5. Report Date February 1991; Revised July 1992 6. Performing Organization Code
7. Author(s) Donald L. Woods		8. Performing Organization Report No. Research Report 1163-3F
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843		10. Work Unit No. 11. Contract or Grant No. Study No. 2-18-89/0-1163
12. Sponsoring Agency Name and Address Texas Department of Transportation P.O. Box 5051 Austin, Texas 78701		13. Type of Report and Period Covered Final Report September 1988 - August 1990 14. Sponsoring Agency Code

15. Supplementary Notes

Research performed in cooperation with DOT, FHWA.
Research Study Title: Evaluation of Loop Detector Installation Procedures and Preparation of a Texas Traffic Signal Detector Manual

16. Abstract

The documentary report summarizes the findings of this two year study. Test results, summaries of survey data, laboratory test and evaluation procedures are included. Special emphasis is given to loop shape, sealants and installation procedures. Several innovative loop applications are discussed.

17. Key Words Loop, Detector(s), Sealant(s), Sawing, Installation	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service 5285 Port Royal Road Springfield, Virginia 22161

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 136	22. Price

Form DOT F 1700.7(8-69)

REPORT 1163-3
EVALUATION OF LOOP DETECTOR INSTALLATION PROCEDURES AND PREPARATION OF A TEXAS TRAFFIC SIGNAL DETECTOR MANUAL

FHWA/TX-90/1163-3

FINAL REPORT

by

Donald L. Woods

Sponsored by

The Texas Department of Transportation
Maintenance and Operations Division

in cooperation with

The U.S. Department of Transportation
Federal Highway Administration

July, 1992

Texas Transportation Institute
Texas A&M University
College Station, Texas

ABSTRACT

This report summarizes the results of a broad series of studies dealing with the installation of loop detectors. The studies initially used the older type detectors commonly in use by local governmental units. The later studies used the Texas series detector units which are remarkably more sensitive than their earlier counterparts. This study includes consideration of a wide range of loop detector design factors including design of the loop system, placement of the loop wire, loop shape and loop location relative to the intersection. It also includes installation procedures for saw cutting, sealants and electrical properties of the loop.

A rectangular loop skewed at 45 degrees to the direction of traffic is the most efficient detector shape for detecting the full range of vehicles in the traffic stream. Little difference exists between loops with two turns and those with five turns of the same size. Quadrapole loops have a height of field of about 31 inches while a rectangular loop goes up to 52 inches at first detection. Loops buried up to 20 inches deep in the pavement with two or more turns of wire are equally effective in detecting automobiles as a surface mounted loop. These deep buried loops are slightly less sensitive to a bicycle than the surface mounted loop. Neither is successful in detecting bicycles when using the unskewed rectangular loop.

High-speed dry cutting (15 feet per minute or greater) of loop slots is possible in asphaltic concrete. It requires a properly selected diamond blade and a 65 hp saw. There is a dust problem associated with dry cutting and a reduction in blade life. The reduction in traffic control costs offset these added costs. Wet cutting is appropriate in portland cement concrete.

The 3M Loop Sealant, the Permanent Sealer 974 and the Gold Label Flex 1P are good loop sealants. Others may be useful under certain limited application conditions.

ACKNOWLEDGEMENTS

The assistance of Mr. Stan Swinton, D-18TE, technical representative to this project is gratefully acknowledged. His patience and understanding during the process of this research has been remarkable. The valuable input of Mr. Harvey Beierle, San Antonio District is also gratefully acknowledged. The contribution of Mr. Joe Budyka, Blazer Diamond Products was most significant in the high speed sawing phase of this research. Finally, to the more than one-hundred people contacted in the progress of this research, thank you for your assistance, suggestions and constructive input to this research.

TABLE OF CONTENTS

Page

ABSTRACT i
ACKNOWLEDGEMENTS i
TABLE OF CONTENTS ii
LIST OF TABLES v
LIST OF FIGURES vi

1.0 PROJECT SCOPE 1

2.0 RESEARCH APPROACH 2

3.0 SUMMARY OF THE LITERATURE AND TELEPHONE SURVEYS 3

4.0 LOOP SHAPE INFLUENCES ON VEHICLE DETECTION 10
- 4.1 Inductive System Concepts 10
  - 4.1.1 What happens when the loop is activated? 10
- 4.2 Loop Shapes 12

5.0 WIRE ENCAPSULATION 14
- 5.1 The Need 14
- 5.2 Tests To Substantiate The Need 14
- 5.3 Findings 14

6.0 HIGH SPEED SAWING OF LOOP SLOTS 17
- 6.1 Introduction 17
- 6.2 The Special Needs Of High Speed Sawing 17
- 6.3 Results Of The High Speed Sawing Tests 18

7.0 ALTERNATIVE CORNER TREATMENTS 22
- 7.1 The Basic Problem 22
- 7.2 The Alternative Treatments To Providing The Space . . . 22
- 7.3 Findings 22
- 7.4 Limitations Of The Hammer And Chisel Method 23
- 7.5 Illustration Of The Alternative Corner Treatments 23

TABLE OF CONTENTS (Continued) page

8.0 DEPTH OF PLACEMENT INFLUENCES ON DETECTION EFFICIENCY 24
8.1 The Traditional View 24
8.2 The Test Bed 24
8.3 Results Of The Deep Buried Loop Controlled Studies . . 25
8.4 Findings 25
8.5 Deep Buried Loop Recommendations 25

9.0 TEMPORARY LOOPS 26
9.1 The Need 26
9.2 The Field Installation 26
9.3 The Life Of The Temporary Loop 26
9.4 The Temporary Loop Installation Process 27

10.0 CORRELATION OF MEASURED FIELD STRENGTH WITH DETECTION 33
10.1 The Concept 33
10.2 Statistical Analysis Of Detection Point And Field Strength 33
10.3 Findings 34

11.0 LOOP DETECTOR SEALANTS 35
11.1 Purpose Of Sealing 35
11.2 The Screening Tests 35
11.3 The Laboratory Test Program 36
11.4 Products Included In The Test Program 36
11.5 Results Of The Laboratory Testing 37
11.51 Candidate Sealants Dropped In The Screening Tests 37
11.6 Value Engineering Analysis Approach To Sealant Evaluation 40
11.7 Recommendations On Sealants 45

TABLE OF CONTENTS (Continued) Page

12.0 SUMMARY OF LOOP LEAD LENGTH STUDY DATA 46
- 12.1 Detection 6 x 6, 45-Degree Skewed Loop Presence Mode of Operation - Non Texas Detector Units Used .. 46
  - 12.1.1 Bicycle 46
  - 12.1.2 Full-Sized 1984 Ford 4-Door Sedan 46
- 12.2 Relationship Of Percent Of The Loop Inductance From Leads To Bicycle Detection 46
- 12.3 Texas Series Detector And Lead Length 47
- 12.4 Findings 47

13.0 PREMATURE LOOP FAILURES 49
- 13.1 Reasons For Premature Loop Failure 49
- 13.2 Reasons For Premature Loop Failures In A Properly Installed Loops 49

14.0 FINDINGS OF THE RESEARCH 50

15.0 RECOMMENDATIONS ON FUTURE RESEARCH 52
- 15.1 Introduction 52
- 15.2 Areas Of Further Research 52

APPENDICES 54

REFERENCES 79

LIST OF TABLES

Table Number		Page
3.1	Summary Of Loop Detector Interviews	4
5.1	Data From Loop Detector Vibration Test	15
6.1	Notes From The Final Test Loop Sawing	19
6.2	Wet Cut Saw Cut Rate Data Summary	20
6.3	Summary Of Saw Cut Rate Data	21
7.1	Summary Of The Corner Treatment Preparation Times - Four Loop Corners Treated	22
11.1	Sealant Study - No Track Time Tests	38
11.2	Summary Of Pullout Force Required To Extract The Perforated Plate	39
11.3	Value Engineering Analysis Of Loop Sealants	41
12.1	Relationship Of The Percent Of Inductance From The Leads To Detection Of A Bicycle	47
12.2	Lead Length Study	48

LIST OF FIGURES

Figure Number		Page
4.1	The Bicycle Detection Problem	10
4.2	Sketch Of Capacitors And Inductors In The System	11
4.3	Suggested Detector Layout For Detecting All Design Vehicles	13
5.1	False Call Vibration Sensitivity Of A Loop Detector - Five Turns Of Wire in PVC Conduit	16
7.1	Alternative Corner Treatments	23
8.1	Typical Section - Deep Buried Loop Locations	24
9.1	Temporary Loop Installation Photos	28

1.0 PROJECT SCOPE

The goals of this research were:

1. To investigate techniques (equipment and procedures) to install loops as fast as possible. This assumes that maintenance personnel do the installing and a highly reliable loop detector is the goal. Also, to recommend practical field test methods.

2. To reduce the need for traffic control during loop installation.

3. To test the field strength of various loop detector layouts and to relate field strength to the detection of various vehicles including bicycles. Further, to determine if field strength bears a direct relationship to loop detector presence retention.

4. To suggest and test alternative loop detector shapes.

5. To laboratory and field test various loop sealants.

6. To determine the reasons for premature loop failures and suggest improved procedures for increasing the life of a detector loop.

2.0 RESEARCH APPROACH

The very broad nature of this study necessitated organization of the research effort into nine specific tasks. These are:

1. Determine the influence of loop shape on the detection of the various design vehicles.
2. Determine the relative need for full encapsulation of the loop wire in the slot or in a PVC conduit.
3. Develop a method to allow rapid saw cutting of the loop slot in asphaltic concrete and portland cement concrete.
4. Examine the alternative corner treatments to determine which would be most time efficient for field use.
5. Determine the depth of placement influences on loop detector efficiency.
6. Measure and correlate the strength of the electromagnetic field with the detection of various design vehicles.
7. Laboratory and field test a wide variety of materials for sealing loop detectors. These include commonly used building construction sealants, sealants used in the home market and those sealants in common use to seal loop detectors.
8. Measure the effects of loop lead lengths up to 1000 feet on the efficiency of detecting the various design vehicles.
9. To determine by survey of various agencies and loop detector installation contractors the common reasons for premature loop detector failures.

The initial thrust was a detailed literature survey on the state-of-the-art of loop detector practice. This includes loop shape and saw cutting systems. The last phase of this effort was telephone contact with five (5) loop detector installation firms. The purpose was to determine the most efficient way to install loop detectors. Section 3.0 is a summary of the findings of this phase of the research. Data from only one contractor is included in Table 3.1. The others gave only general guidelines rather than specific details that could be tabulated.

3.0 SUMMARY OF THE LITERATURE AND TELEPHONE SURVEYS

The literature survey revealed little not included in the FHWA Traffic Signal Detector Handbook. It did reveal that the majority of the agencies contacted use rectangular loops. The simple rectangle and the quadrapole were the dominate shapes. Innovative loop shapes include the circular loop, the diamond loop and the octagonal loop. Table 3.1 contains a summary of the telephone survey responses.

Table 3.1 does not provide any clear pattern to the practices of the various states or cities on saw cutting practices. Saw horsepower is in the range from 15 to 35 hp. The loop detector installation contractors offer a completely different perspective. They agree that the most efficient system is one with the largest power unit available and with the best saw blade available. It takes about 10 minutes to change a blade. During that interval, the entire installation crew is nonproductive in installing loops. To increase their profit, they want a saw blade that will last as long as possible. A diamond blade is preferable. Calculations by the study staff support this economic advantage to the state.

The survey did reveal that very few premature loop failures occur when the original installation of the loop is correct. In nearly every case, a premature loop failure is the result of poor installation practices or operating heavy equipment in the loop area. In particular, Roto-Milling frequently causes damage to the loop wire. Commonly this damage occurs near the curb and gutter section where the wire is often closer to the surface. The Roto-Milling depth is also the greatest at this point to reestablish curb drainage. There are methods for reducing the chance of wire lead damage in the curb and gutter area. These include taking the lead wire under the curb and gutter section; and, increasing the saw slot depth across the curb and gutter section.

overall, little new insight on why particular equipment or loop shapes were being used came from the telephone survey. The survey did provide ideas for loop shapes to test and baseline sealant properties that are desirable.

TABLE 3.1
SUMMARY OF LOOP DETECTOR INTERVIEWS

COUNTY OR CITY RESPONDING	PERSON CONTACTED	TELEPHONE NUMBER	LOOPS INST	LOOPS TOTAL	CON-TRACT	IN-HOUSE	LOOP SIZE	LOOP TYPE	REASON FOR TYPE	CORNER	SAW CUT
Ft. Worth	Russ Wiles	817/870-8775	500	3000	0	100	6x6,6x30	Quad	None	Angle	1-1.5"
San Antonio	Dave Bruggeman	299-7765	Unknown	7000	0	100	6x6			None	2 or 5"
Abilene	Ron Hampton	915/676-6374	25-30	Unknown	0	100	6x6,6x20-40		No success w/quad or powerhead	Ang/chip	1-1.5"
Arlingtón	Steve Oliver	817/459-6350	150	1800	0	100	4x60,6x60 w/6x6 header				
Amarillo	Carl Bussler	806/378-3021	30-40	750-800	0	100	6x25,6x8			drilled	3"
Witchita Falls	Terry	817/761-7643	30	800	0	100	5x60-80			Angle	1.5"
Corpus Christi	Poncho Flores	512/880-3500	175	3000	50	50	6x6,6x15,6	Quad		Angle	1.5-2"
Bryan	George Mitchell	409/361-3634					6x6,6x20				
College Station	John Black	409/764-3570					6x6,6x35				
Odessa	Tom Cronic	915/337-5043	25	500	100	0	6x10			Angle	2"
Austin	Stan Cozik	512/479-6037	100 trips	300 ints.	100	0	6x6,6x50			Angle	1-1.5"
Lubbock	Van Cook	806/762-6411	144	759	0	100	6x6			Drilled	3"
Dallas	Jerry DeCamp	214/670-3109	400	5000	50	50	6x40-50 6x18 per head	Quad		Angle	1.5-2"
Houston	M. Hawkins/J. McGrew	713/868-4335	50-100	1000	60	40	6x6,6x50			Angle	1.5"
El Paso	Armondo Chavez	915/594-8622	200-250		0	100	6x6,6x30	Quad		Angle	1.5"
Richardson	G. Grayson/L. McInis	214/238-4070		500-700	0	100	5x5,15,25 Std.,Quadfit in 11′ lane			Angle	2"
Los Angeles	Dave Royer	213/405-3548	800	4139	50	50	6x6	Octagon		None	4"
Phoenix	Bill Bein	602/262-4693	1000	4500	0	100	6x6,5x40-			Drilled	1.5-2.5"
STATES											
Alabama	Charles Alexander	205/261-6121	100's	too many	80	20	6x6,6x50			Angle	
Georgia	John Reid	404/656-7438			50	50	Variable			Angle	2"
California	E. Stooker/L. Welsh	916/445-5163	too many	too many	100	0	6x6			Angle	1" cover
Florida	John Gray	904/488-4284	2000	12000	0	100	6x20	Quad/Std.		Angle	2"
Oklahoma	Paul Stejskal	405/521-2861			100	0	6x6,6x30	Quad		Angle	3"
Mississippi	Bob Maybry	601/354-6050	100	400	70	30	6x6,6x50	Quad		Angle	1.5-2"
Arizona	Ray Johnson	602/255-7376			100	0	6x6,6x50-	Quad		Drilled	1.5-2.5"

TABLE 3.1 (CONTINUED)
SUMMARY OF LOOP DETECTOR INTERVIEWS

TEXAS DOT DISTRICT RESPONDING	PERSON CONTACTED	TELEPHONE NUMBER	LOOPS INSTALLED	LOOPS TOTAL	CONTRACT	IN HOUSE	LOOP SIZE	LOOP TYPE	REASON FOR TYPE	CORNER	SAW CUT
District 1	Tommy Cox	835-9251			100	0	6x6			Angle	1.5"
District 2	Toby Daley	837-6371	150	1500	0	100	6x6-60	Powerhead/ Quadrapole		Angle	1.5"
District 3	Don Dolberry	891-3243	25	100	0	100	6x40-50			Angle	1.5"
District 4	Leon Wood	843-6453		New	Repairs		6x6,6x40			Angle	2-2.5"
District 5	Ted Kopeland	842-4429	12	18	0	100	6x20,16x10,20x10,6x15			Angle	1.5"
District 6	Morris Leach	844-9243	10-15	300	100	0	6x6,6x20-	Quad		Angle	1.5-2"
District 7	Mark Tomlinson	848-5200	25	200	100	0	6x30			Angle	2"
District 8	Robert Holford	841-1202	5	60	60	40	6x18			Angle	1.5-2"
District 9	Ed Jenkins	820-2070	4	60	50	50	6x50			Angle	3"
District 10	John Fowler	836-2220	45	180	100	0	6x30			None	2.5-3"
District 11	Jerry Biggs	730-4433	25	100	0	100	6x6,6x40,60	Quad/Pwr head		Angle	2"
District 12											
District 13	Paul Ferrick			50	0	100	6x12x20 across 2 lanes			Angle	1.5-2"
District 14	Ed Schroder		50	625HEW	Repairs		6x20, 6x60			Angle	1.5"
District 16	Dexter Turner			500	50	50	6x90,20	Quad/pwr head		None	2-2.25"
District 17											
District 18		833-5236	10	500	0	100	6x6,6x10			Angle	1-2"
District 19	Jimmy Roberts	835-1218	60	500	0	100	6x6,6x30-100,6x16 across 2 lanes			Angle	1.5"
District 20	L.C. Rhyers	855-3267			40	60	7x7	Diamond		Drilled	1.5"
District 21											
District 22											
District 23											
District 24											
District 25											
Contractors											
SIR-circular loops	Frank Swain	818/989-1688					6' dia	Circular		Drilled	1.5-6"

TABLE 3.1 (CONTINUED)
SUMMARY OF LOOP DETECTOR INTERVIEWS

COUNTY OR CITY RESPONDING	SEALANT	REASON	WIRE TYPE	REASON	LOOP TYPE	SAW TYPE	SAW SPEED	TYPICAL INSTALL TIME	CREW SIZE	SPLICE @ PULL BOX
Ft. Worth	3M, PRECO no longer used	None	#14 XHHW	None	Assembled	40 hp	2 ft/min	1 hr	3 or 4	Yes
San Antonio	3M	One-part	#14 THHN	None	Prefab	Target		1-1.5 hrs	2 and 2	No
Abilene	3M	Warranty/ Experience	#14 THHN	None	Assembled	Target 16 hp		1-3 hrs	3	If necessary
Arlington	"In house" epoxy	Cost	#14 THHN	None	Assembled	Diesel 60-65 hp		3 hrs	2	Yes
Amarillo	Bondo	Cost	#14	None	Assembled	Gas 18 hp	18 in/min	3 hrs	2	Yes
Witchita Falls	Crack Sealer	Cost/ Convenience	#12 Solid Core	None	Assembled	Target 16 hp	Variable	4 hrs	2 to 5	No
Corpus Christi	3M - will use water base	Convenience	#14 XHHW	None	Assembled	Target 13.5 hp		2-2.5 hrs	3	Yes
Bryan	3M	Convenience	#14 kj10	None	Assembled	Diesel		2-4 hrs	2 and 3	Yes
College Station	PRECO gold label		#14 THHN	None	Assembled	12 hp	1 ft/min	2-4 hrs	2	Yes
Odessa	Latex		#16 THHN	None	Assembled			2 hrs	3	Yes
Austin	3M & 2 System Liquid Patch	Works Better Cost	#14 THHN	None	Assembled	5 hp		1 hr	4 to 6	Yes
Lubbock	3M	Consultants Recommend.	7Comes in .25 inch orange duct, visible when exposed	None	Assembled	Clipper	2 ft/min	2 hrs	3	Yes
Dallas	Epoxy Crack Sealer	Cost	#14	None	Assembled		1 ft/min	2-2.5 hrs	2	Yes
Houston	3M	Works well	#12 XHHW	None	Assembled	Target 65 hp			4	Yes
El Paso	3M	Best Results	#14 THHN	None	Assembled	Target		2-3.5 hrs	6	Yes
Richardson	3M or 1/4" wire in 1/4" slot with no sealant	3M is messy	3M 3-000-3 horserun cable	None	Both	60 hp		2 hrs	2	Yes
Los Angeles	3M	Reliable/easy	#14	None	Assembled	Super 201AG 20 hp		.5 hr	2 and 3	Yes
Phoenix	3M	Stable/works	#14 THHN	None	Assembled	65 hp		2.5 hrs	2	Yes

TABLE 3.1 CONTINUED
SUMMARY OF LOOP DETECTOR INTERVIEWS

STATES RESPONDING	SEALANT	REASON	WIRE TYPE	REASON	LOOP TYPE	SAW TYPE	SAW SPEED	TYPICAL INSTALL TIME	CREW SIZE	SPLICE @ PULL BOX
Alabama	3M	Best Results	#12 RHWUSE	Best Results	Assembled	Target 5 hp		2.5-3 hrs	2 to 3	Yes
Georgia	Epoxy Asphalt				Assembled				4	Yes
California	Elastimeric Sealant - Asphalt Mixture		#7 THHN	None	Both - New Const. in PVC			1 hr	4	Yes
Florida	PRECO, 3M, Uclide 491	Easy	THHN	None	Assembled			2 hrs	3	Yes
Oklahoma	PRECO gold label		THHN & ISMA	None	Assembled			1 hr	3	Yes
Mississippi	3M		#14 XHHW	None	Assembled			6X6 1-2 hrs	3	Yes
Arizona	CRF(emulsion) Craftco - demo Project		#14 THWN in PVC	None	Prefab					Yes
TEXAS DOT										
District 1	3M - in a tube	Few installed	#14 XHHW	None	Assembled	Gas		1 hr	4	Yes
District 2	UPH grade 2 & sand	Availability	#14 XHHW or THWN	None	Assembled	Rented 35 hp		3 hrs	4	Yes
District 3	3M	Easy/works				Target		1-1.25 hrs	3+	Yes
District 4			#14 Beldon	None	Assembled				2+	Yes
District 5	Asphalt w/cotton cord	Cost	#14 THHN	None	Assembled			3 hrs	4	Yes
District 6	3M	Works well	#14 XHHW	None	Assembled	30 hp		2 hrs	3	Yes
District 7			#12 THHN	None	Assembled			0.75 hrs	3	Yes
District 8	3M		#14 Stranded	None	Assembled	Target		2 hrs	4 to 5	Yes
District 9	Asphalt		#14	None	Assembled			3-4 hrs	4	Yes
District 10	3M	Easy/works	#14 XHHW	None	Assembled	Target 35 hp		2.5 hrs	2+ Traffic	Yes
District 11	3M	Works	#14 XHHW	None	Assembled	Cutter 18 hp		1.5-2 hrs	2+ Traffic	Yes
District 12										
District 13	3M	Works	#14	None	Assembled	16 hp		1 hr	3 to 4	Yes
District 14	3M		#14 XHHW	None	Assembled	Clipper 18 hp	4 ft/min	2-2.5 hrs	2	Yes
District 15	3M	Quick set	#14 XHHW	None	Both	18 hp & 12 hp	4.5 ft/min	1-1.5 hrs	3 to 4	Yes
District 17										
District 18	3M	Works best	#14 XHHW	None	Assembled			2 hrs	5	Yes
District 19	Bitumen adhesive	Cost	#14	None	Assmebled			1.5-4 hrs	4	Yes
District 20	3M		#14 XHHW	None	Assembled	60 hp		1.5-2 hrs	2+ Traffic	Yes
SIR-circular loops						Truck Mounted		0.5 hr	2	

TABLE 3.1 (CONTINUED)
SUMMARY OF LOOP DETECTOR INTERVIEWS

COUNTY OR CITY RESPONDING	MUTCD	TC GLASSES	DUST MASK	GLOVES	HARD HAT	INNOVATIVE LOOPS
Ft. Worth	Yes	No	No	No	No	None
San Antonio	Yes	No	No	No	No	None
Abilene	Yes	No	No	No	No	Quad. and Powerhead - No success
Arlington	Yes	No	No	No	No	Fishtail on upstream end - Good
Amarillo	Yes	No	No	No	No	3 foot diamonds - works well
Witchita Falls	Yes	No	No	No	No	None
Corpus Christi	Yes	Yes	Yes	Yes	No	None
Bryan						
College Station						
Odessa	Yes	No	No	No	No	None
Austin	Yes	No	No	No	No	Quad and Diamond - not worth the trouble
Lubbock	Yes	No	No	No	No	None
Dallas	Yes	No	No	No	No	Infrared - daytime is ok, night is tough front and back line at 120 degrees
Houston	Yes	No	No	No	No	Microloops - work well
El Paso	Yes	No	No	No	No	Wire in PVC conduit for new construction
Richardson	Yes	No	No	No	No	Four conductor spliced in series microloops
Los Angeles	Yes	Yes & ear protect.	Yes	Yes	No	Quad was used - too costly Conga scanning detector - eliminates crosstalk
Phoenix	Yes	Yes & ear protect.	No	No	No	None
STATES						
Alabama	Yes	No	No	No	No	None
Georgia	Yes	No	No	No	No	None
California	Yes	No	No	No	No	Round loops - reduces traffic control Never Fail loops
Florida	Yes	No	No	No	No	Prefab loops in conduit - tears up pavement - 1.25 in. slot
Oklahoma	Yes	No	No	No	No	Micro loops and prefab.
Mississippi	Yes	No	No	No	No	None
Arizona	Yes	No	No	No	No	Installing loops under new pavement 10-12"

TABLE 3.1 (CONTINUED)
SUMMARY OF LOOP DETECTOR INTERVIEWS

TEXAS DOT RESPONDING	MUTCD	TC GLASSES	DUST MASK	GLOVES	HARD HAT	INNOVATIVE LOOPS
District 1	Yes	No	No	No	No	None
District 2	Yes	No	No	No	No	Header and Quad
District 3	Yes	Yes	No	No	No	Triangle at front/right of loop picks up right
District 4	Yes	No	No	No	No	None
District 5	Yes	Yes	No	No	No	None
District 6	Yes	Yes	No	Yes	No	Conduit in concrete - special situation
District 7	Yes	Yes	No	No	Yes	None
District 8	Yes	Yes	No	No	Yes	None
District 9	Yes	No	No	No	No	None
District 10	Yes	Yes	Yes	No	No	Headers - didn't work: Ear protection
District 11	Yes	Yes	No	No	Yes	Wire in conduit - tends to float to top
District 12						
District 13	Yes	No	No	No	No	None
District 14	Yes	No	No	Yes	Yes	None
District 15						
District 16	Yes	Yes	Yes	No	No	90 degree turns holds wire down
District 17						
District 18	Yes	Yes	No	No	Yes	Using loop duct (wire in PVC) in asphalt
District 19	Yes	No	No	No	Yes	Do not twist lead in wires - tight slot eliminates wire movement
District 20	Yes	No	No	No	Yes	Prefab in 3/4 inch PVC
District 21						
District 22						
District 23						
District 24						
District 25						
Contractors						
SIR-circular loops						From circle to curb w/flat saw - efficiency comes with quantity

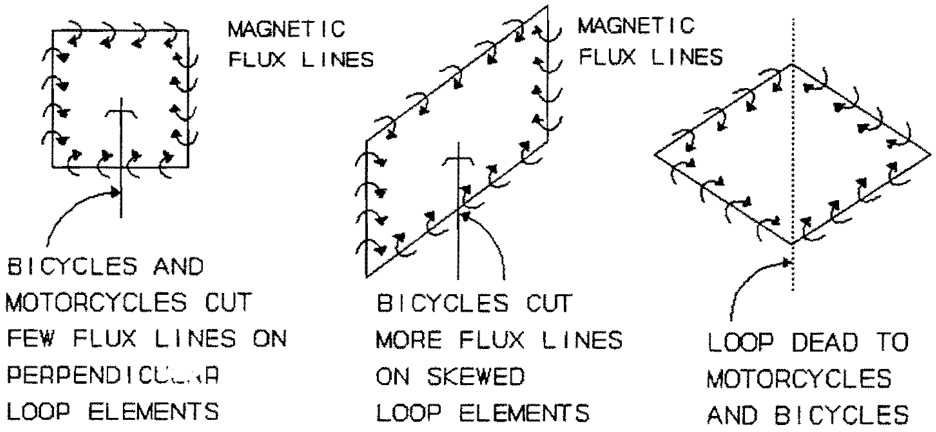
4.0 LOOP SHAPE INFLUENCES ON VEHICLE DETECTION

4.1 Inductive System Concepts

Misunderstanding the principles of inductive loop operation is the primary problem in the lack of consistency in the design and application of loop detectors. Therefore, it is appropriate to begin this section with a basic discussion of inductive loop operations.

4.1.1 What happens when the loop is activated?

A closed-circuit conductive material placed in the detection zone has an induced current flow. However, the flux lines of the electromagnetic field must pass through the material. If the closed-circuit is parallel to the flux lines, the change in the system will be very small. Thus, a bicycle or motorcycle which has the closed-circuit in the vertical plane parallel to the lane line will not result in a detection by a wire element placed perpendicular to the traffic lane. No flux lines pass through the vehicle. Figure 4.1 illustrates this concept.



The Bicycle Detection Problem
Figure 4.1

A second major misunderstanding of loop detection principles is the assumption that a ferrous metal is necessary to activate the detector. Any electrically conductive material in a closed-loop configuration will have a small current flow when a magnetic flux field passes through it. The conductivity of different materials vary, and thus the responses to the magnetic field will vary. On occasion, a conductive material may not produce the level of response needed to activate the detector. The reason is not the material properties but rather the threshold setting used on the detector.

A third area of concern is the relationship of the number of flux lines cut by the vehicle and the strength of the inductive response. It is reasonable to assume that the flux density and the detector systems' response to the presence of a vehicle correlate to a high degree. The more flux lines that pass through a vehicle the greater the level of inductive response to that flux field. The correlation of flux density with detection probability is difficult. The closed-loop electrically conductive circuit in a vehicle can be in any plane in space. Additionally, more than one closed-loop circuit may be instantaneously active. Based on the field strength measurements of six loops, the correlation of detection probability and field strength, if one exists at all, is far too complex a relationship for practical use.

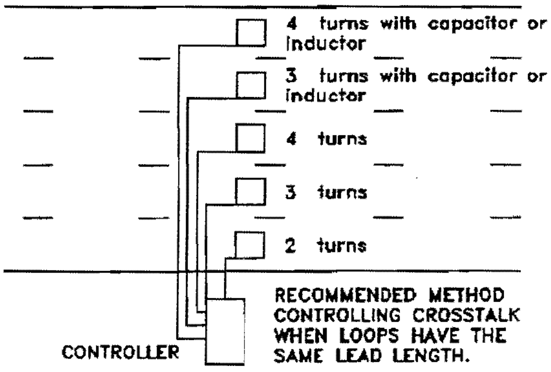
A 700-foot maximum lead length is common in loop detector practice. Much more lead than 700 feet results in the inductance of the system exceeding the capability of the older detector units; this is no longer a limit. There are two primary reasons for this no longer being a constraint on the detector system. First, the Texas series detector is far superior to the older detector units. The available inductance is 20 to 2000 microhenries rather than 75 to 700 microhenries as in the past. The second reason is the extensive use of self tuning detectors. Self tuning detectors allow an inductance set near the bottom of the inductance range. It then can adapt to a wide range of temperatures without exceeding the system limiting value. Experimental measurements with lead lengths of 1000 feet were highly successful. There is no tendency to fail to detect with the 1000-foot lead. Nor is there is a tendency to fail to detect small vehicles with the 1000-foot lead wire.

The Texas series detector improvements also allow the use of fewer wire turns for equal detection reliability. For a 6 x 6, there was essentially no difference in detection reliability in the two to five turns of wire range.

The use of a loop detector in reinforced portland cement concrete has always been a concern since the steel grid forms closed-loop electrically conductive circuits. Field experience shows that modern detector units can successfully operate when the loop, in a PVC conduit, is below the reinforcing steel or on top of it. The reasons cited above are again applicable here. The improved quality of the detection unit is such that a constant energy loss can be tuned out of the circuit. This does not appreciably affect the operation of the loop. The depth of placement does reduce the chance of detecting smaller vehicles (bicycles, MOPEDS and motorcycles). Deep placement may also reduce the detection reliability on high profile trucks due to a reduced height of electromagnetic field. No experimental confirmation of this statement exists. Subsequent field studies performed by Hamm (3) confirmed that high profile truck detection is not a problem with loop buried 15 inches or less.

Crosstalk between loop circuits running in the same conduit is a more significant problem with self tuning detector. Normally, the lead length difference will change the circuit properties sufficiently to reduce the problem to a minimum. However, when large numbers of loop circuits are bundled together, crosstalk is a real possibility. Through judicious use of capacitors and inductors this problem is easily controlled.

Sketch Of Capacitors And Inductors In The System
Figure 4.2



4.2 Loop Shapes

The testing included the following loop shapes:

1. Rectangular short loop (6 x 6)
2. Rectangular Long Loop (6 x 40)
3. Short quadrapole loop (6 x 6)
4. Long quadrapole loop (6 x 40)
5. Hexagonal loop (6 x 6)
6. Octagonal loop (6 x 6)
7. Double 6 x 6 loops offset 2 feet 2-4-4-2 winding
8. Special square bicycle loop
9. Z-bicycle loop
10. 6 x 6 skewed loop w/3:2 skew
11. 6 x 6 skewed loop w/1:1 skew
12. Right triangular loop 6 x 6 x 8.5
13. 6 x 6 skewed loop w/6 x 6 triangular power header 2-4-2 winding
14. Circular loop

While the testing of each shape is not exhaustive, a general pattern did develop for each loop shape. In general, none of the more complex shapes are better than the basic rectangular loop. Any of the layouts that has a wire run perpendicular to the traffic flow has a dead spot for bicycles, mopeds, and motorcycles. This is also true for the circular loop. A design vehicle, easily detected over the longitudinal wire runs will go undetected when the wire run is perpendicular to the vehicle. This explains the improvement of the quadrapole for detecting bicycles and other small vehicles. There are three longitudinal wire runs in the quadrapole layout and only two in the rectangular layout. Two dead spots still exist with the quadrapole between the wire runs. The quadrapole also has a much reduced height of field (from 52" down to 31" measured in the controlled environment testing). This reduces the chance of detecting and holding the call from a high profile truck.

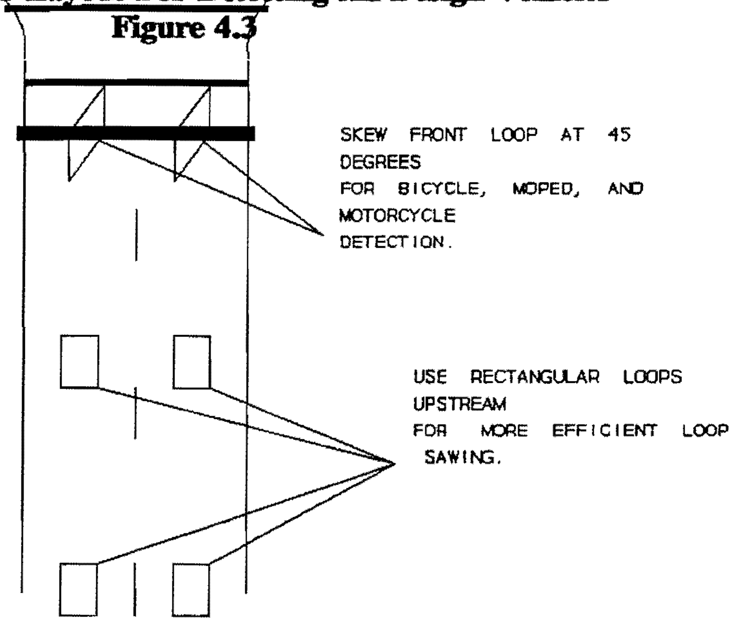
In reviewing loop detector shape detection patterns, it is clear that the 6 x 6 skewed loop at a 1:1 skew is the best single loop shape. It detects the full range of desired vehicles in the traffic stream. The 45-degree wire run crossing of the vehicle path allows sufficient flux lines to pass through the smaller design vehicles (bicycles, MOPEDS, and motorcycles) to detect them with a high degree of reliability. Locate the 1:1 skewed loop in the traffic lane as shown in Figure 4.3. The reader is referred to the unpublished Research Report 163-2 for a more detailed treatment of the loop shape studies.

The primary problem with using the skewed loop is the rather acute corners formed. For short loops 10 feet or less in length, this is not a problem. Enough space remains to allow for expansion and contraction due to temperature change. For long loops, the acute corners are a potential problem. With the use of long loops, the advantage of skewing is lost. The rather large area in the center of the loop that is insensitive to bicycles, MOPEDS and motorcycles. This negates the benefit of skewing the loop ends. Also the skewing of the loop is unnecessary for detectors well upstream from the intersection. Therefore, the acute angle is not a serious drawback to the use of the skewed loop. For practical application the skewed loop is located at the stop bar. The critical detection problem with

the smaller vehicles is at the stop bar. Therefor, it is recommended that rectangular loops be used for the upstream locations. Figure 4.2 presents this conceptual layout.

Suggested Detector Layout For Detecting All Design Vehicles

Figure 4.3



SKEW FRONT LOOP AT 45 DEGREES FOR BICYCLE, MOPED, AND MOTORCYCLE DETECTION.

USE RECTANGULAR LOOPS UPSTREAM FOR MORE EFFICIENT LOOP SAWING.

5.0 WIRE ENCAPSULATION

5.1 The Need

A requirement for complete encapsulation of the loop wire by the sealant is commonly specified and rarely achieved in practice. There are two common reasons for this practice. First, the wires left free to vibrate could change their relative positions to one another and induce a false call. The second reason cited is water could collect between the wires changing the capacitance of the tuned RF circuit. This may alter the loop electrical properties to an undesirable degree for good operation.

5.2 Tests To Substantiate The Need

Two tests help to clarify these issues. A 6 x 6 loop of 2 turns of wire was placed in a 1/2-inch PVC conduit. The dry capacitance and the capacitance when the PVC conduit is full of water wire measured. The second test is a vibratory test of a 6 x 6 foot loop of 4 turns of wire in PVC conduit. This test attempts to replicate the vibration condition of the field. The test is to record detection, with frequency and magnitude of vibration varying over a large range. A detector activation occurs at some vibration combination. The data consists of the "first call" vibration and the "continuous call" vibration magnitudes.

5.3 Findings

The test results of the presence of water around the loop wire was a very small change in the capacitance of the loop. The actual measured change was 7 pf(picofarads) between the dry and wet conditions. This resulted in a resonate frequency change in the RF circuit of 0.10 kHz. This difference is so small that only extremely sensitive equipment could distinguish it. Modern detection equipment can easily tune around such a small change. Therefore, the presence of water between the loop wires is not a significant enough problem to justify any added effort to obtain full wire encapsulation. Testing by Hamm(3) confirmed the laboratory observations regarding the presence of water around the loop wire. Subsequent testing by Cronin (4) of the same loop one year after the water was added indicated that the long term exposure of the loop wire to water is of no consequence.

Table 5.1 presents the vibration test results. Figure 5.1 is a graphical summary of these data. Figure 5.1 superimposes the magnitude of the vibrations in typical pavement section from another research project on the vibration data from this experiment. Figure 5.1 shows that the actual pavement vibration magnitude is far below those required to cause false detection in a heavy duty pavement. For light duty pavements, there is a potential for false calls with the passage of heavy trucks. Since loop detectors are not frequent on light duty roadways (i.e., FM roads) and heavy trucks are rare, full wire encapsulation is a solution to a nonexistent problem. There is no real need for full wire encapsulation, however, full wire encapsulation is still desirable. The primary concerns in selecting a

sealant is to keep the wire down to prevent traffic damage to the insulation. Second, it must remain pliable at low temperatures to prevent wire fracture due to reflected cracks.

Table 5.1
Data From Loop Detector Vibration Test
Data Collected April 10, 1989
Materials Engineering Laboratory
Texas A&M University

Vibrator Operator: Jody Short   Recorder: Don Woods

Detector Type: Detector Systems Model 262B

Loop Sensor Type: One-Half Inch PVC Pipe With Five Turns Of # 14
AWG Stranded Wire.

Test Number	Detector Sensitivity Setting	First False Call Detected	Rheostat Setting @ Average First False Call Detected	Constant Call Detected	Average at Constant Call
1	7	5		8	
2	7	5	4.8	7	7.5
3	7	5		8	
4	7	5		7	
5	6	8		10	
6	5	8	6.5	10	9.8
7	5	8		11	
8	5	4		10	
9	3	62		85	
10	3				
11	3	25		55	
12	3	55		70	
13	2	58		75	
14	2	48	50.3	75	76.8
15	2	50		82	
16	2	45		78	
17	1	NA		NA	
18	1	NA	NA	NA	NA
19	1	NA		NA	
20	1	NA		NA	

Constant Call Amplitude: Amplitude $\approx 0.0108 + 0.00018 *$ Rheostat Setting

First Call Amplitude: Amplitude $\approx 0.0107 + 0.000166 *$ Rheostat Setting

The magnitude of the vibration of a pavement varies from 0.010 inches for a high type surface up to 0.060 inches for low-volume FM Road pavements.

False Call Vibration Sensitivity Of A Loop Detector
Five Turns Of Wire In PVC Conduit
Figure 5.1

6.0 HIGH SPEED SAWING OF LOOP SLOTS

6.1 Introduction

High speed sawing of the loop slots is one of the major goals of this phase of the research. The task is the development of a method (equipment and procedure) to saw cut the pavement slot much more rapidly. Realizing the efficiency that the San Antonio District is achieving using the Tennant Grinder, a goal of 15 feet per minute in the sawing operation in asphaltic concrete seems appropriate. This is essentially what the District personnel are achieving with the grinder.

This telephone survey left the project staff with the impression that a large saw with a diamond blade was the way to do the job. Thus, a large enough saw with a good quality diamond saw blade would fulfill the project need. Telephone discussions with the Tennant Company design staff about the modification of their equipment for easier guidance by a single operator were negative. They saw no economic value in such a modification. By way of summarizing a long conversation, the market for a special design is too small to make the redesign attractive to the Tennant Company.

With the focus on big saws and diamond blades, the project staff began a search for a saw/blade combination to do the job.

6.2 The Special Needs Of High-Speed Sawing

In reviewing the blade type to use, the staff soon discovered that power alone was not the answer to the high speed sawing problem. After several abortive attempts, the staff made contact with Mr. Joe Budka, Vice-President, Blazer Diamond Products. In discussing our needs with him, the concept of diamond blade design became clear.

While the staff concept of larger horsepower saw is correct, a failure to understand diamond blade design lead to overlooking the heat buildup on the blade. This leads to its ultimate destruction. To saw more rapidly without exceeding the blade heat limit meant not only a bigger saw but also a different saw blade binder matrix. Essentially, the diamond chips used in cutting could not be allowed to become as dull. By discarding the chips a little earlier, the sharp chip edges could cut away the material more rapidly with essentially the same heat buildup. Thus, two basic principles of diamond blade design evolved:

1. The high power saw would drive the blade faster during sawing, thus creating a higher heat load, and

2. By releasing the diamond chips before the edges are fully round, the heat load buildup is controlled, but only at the expense of blade life.

Based on these concepts, Mr. Budka designed three test blades for high-speed sawing of asphaltic concrete and portland cement concrete. Testing of these blades took place at the Riverside Campus of Texas A&M University, Bryan, Texas. The testing includes a 20-year old asphaltic overlay and a portland cement concrete runway nearly 45 years old as the test sites. These represented the worse case heat load conditions for the diamond blade.

6.3 Results Of The High Speed Sawing Tests

The blade testing narrowed the three blade alternatives down to one. The Blazer 9107722 blade provided the high-speed cutting capability at an acceptable heat level. It is useful for dry cutting of asphaltic concrete and wet cutting of portland cement concrete pavements. The estimated blade life is about 120,000 inch-feet (1-inch deep x 1-foot long - 1/4-inch wide) in asphaltic concrete. This life is somewhat longer on green p.c. pavements and new asphaltic concrete surfaces. Table 6.1 summarizes the final series of test runs. Note that the speed of cutting is consistently between 20 and 30 inch-feet per minute. For the typical 1-1/2 inch deep slot, the cutting would be 13 to 20 feet per minute. At the 2-inch depth, the rate would be 10 to 15 feet per minute. These values are close to the target cutting rates for this phase of the research. Actually, the limiting condition on speed is unknown. Rates of up to 50 inch-feet per minute are possible. At cutting speeds above 20 inch-feet per minute, control of the depth of cut becomes critical. For high-speed sawing, the depth of cut is controlled by placing a dead weight of 100 pounds directly over the blade drive shaft. This keeps the blade down at full depth.

Using a Blazer blade Model N-22 allows high-speed saw cutting in asphaltic concrete. It also is suitable for wet cutting portland cement concrete. An accurate estimate of blade life when dry cutting asphaltic concrete is not possible. Experience in Washington, D.C., suggests a life of 20,000 inch-feet when dry cutting in asphaltic concrete. Appendix G is the benefit/cost comparison of cheaper blades versus the diamond blades. This appendix shows the diamond blade to be cost effective for both wet and dry cutting. The benefit/cost ratio is 1.2 to 1.4 for dry cutting and 1.7 to 2.0 for wet cutting. The benefit/cost ratios exclude the cost reduction of traffic control associated with high-speed sawing.

Appendix F contains the data which form the basis of the blade life estimates. These are representative blade life estimates. Appendix H is a draft functional specification for diamond blade purchase.

Table 6.1 Notes From The Final Test Loop Sawing

7/25/89 Riverside Campus Terry Perry, Don Woods Blade No. 9107722
45 Degree Skewed Loop Nominal Depth 1.5" Average Depth = 1.41"

Cut Number	Time (Seconds)	Cut Distance (Feet)	Sawing Rate (Ft/Min)	General Notes
	14.00"	NA	NA	Setup To Saw
1	35.61"	6'	10.11'/Min	Cut 1-1/2" Deep
	5.21"	NA	NA	Setup 2nd Parallel
2	25.44"	6'	14.15'/Min	
	5.02"	NA	NA	Turn 45 Degrees & Line Up To Cut
3	34.75"	8.5'	14.68'/Min	Cut Diagonal Side
	41.73"	NA	NA	Setup For Diagonal
4	25.96"	8.5'	19.63'/Min	Cut Diagonal Line
Cut Times =	121.76"	29.0'	20.15 Inch-feet/min	

Double Rectangle Overlapped 2 Feet 6 x 6 Nominal Depth 1.5"
Ave. Depth = 1.34"

1	20.35"	8'	23.60'/Min	Cut One Side
	28.79"	NA	NA	Setup For 2nd Side
2	20.41"	8'	23.53'/Min	Cut One Side
3	19.55"	6'	18.40'/Min	Cut One Cross Line
4	17.14"	6'	21.00'/Min	Cut One Cross Line
	50.38"	NA	NA	Setup For Next Cut
5	15.91"	6'	22.64'/Min	Cut One Cross Line
	30.35"	NA	NA	Setup For Next Cut
6	15.42"	6'	23.35'/Min	Cut One Cross Line
Cut Times =	108.78"	40'	29.56 Inch-feet/min	

Triangle Loop Nominal Depth 1.5" Average Depth = 1.33"

1	16.77"	6'	21.47'/Min	Cut One Side
	24.10"	NA	NA	Turn Through 45 Degrees And Setup
2	24.59"	8.5'	20.74'/Min	Cut Diagonal
	14.95"	NA	NA	Turn 45 Degrees & Setup For Last Cut
3	14.02"	6'	25.64'/Min	Cut One Side
Cut Times=	55.38"	20.5'	24.41 Inch-feet/min	

Table 6.2 Wet Cut Saw Cut Rate Data Summary
Test Data, May 25, 1989
Riverside Campus Test Area

Blazer Blade Number	Average Cut Rate In-Ft/Min	Pavement Type	Cut Rate Adjusted For Depth Inch-Feet Per Minute			
			1.5"	2.0"	2.5"	
9107724	40.3	Asphaltic Concrete	26.9	20.2	16.1	
9107724	37.7	Asphaltic Concrete	25.1	18.9	15.1	
9507722	56.0	Asphaltic Concrete	37.3	28.0	22.4	
9507722	82.3	Asphaltic Concrete	54.9	41.2	32.9	
9107723	6.4	P. C. Concrete	4.3		3.2	2.6
9107723	11.7	P. C. Concrete	7.8		5.9	4.7
9107723	38.2	Asphaltic Concrete	25.5	19.1	15.3	
9107723	43.6	Asphaltic Concrete	29.1	21.8	17.4	

Each reported value represents five cuts of 10 feet in length averaged. The two values for each blade in the AC are 1 inch and 1.5 inch nominal cut depths average values.

Table 6.3 Summary Of Saw Cut Rate Data
Rated HP 65 - Saw Was Under Powered And Had Very Poor Water Distribution

Wet Cut Data 5/16/89

Blazer Blade Number	Average Cutting Rate In-Ft Per Min	Substrate Material	Projected Cut Rate For Various Slot Depths Inch-Feet Per Minute		
			1-1/2"	2"	2-1/2"
9507722	4.0	PC	2.7	2.0	1.6
9507722	14.1	AC	9.4	7.1	5.6
9107723	16.7	AC	11.1	8.4	6.7
9107723	2.9	PC	1.9	1.5	1.2
9107724	11.0	AC	7.3	5.5	4.4

Summary Saw Cut Rate Data
Target Concrete Saw - Quadra/Matic - 65 HP

Dry Cut Data 5/27/89

9507722	39.5	AC	26.3	19.8	15.8
9507722	41.1	AC	27.4	20.6	16.4
9107723	21.0	AC	14.0	10.5	8.4

Wet Cut Data* 5/27/89

9107723	25.0	AC	16.7	12.5	10.0

* Very low water pressure. Essentially a dry cut situation.

Summary Saw Cut Rate Data
Target Concrete Saw - Quadra/Matic - 65 HP

Wet Cut Data 6/10/89

9107724	38.5	AC	25.7	19.3	15.4
9507723	55.9	AC	37.3	28.0	22.4
9507722	82.2	AC	54.9	41.2	32.9
9507722	82.4	AC	54.9	41.2	33.0
9107723	6.3	PC	4.2	3.2	2.1
9507722	11.7	PC	7.8	5.9	4.7

7.0 ALTERNATIVE CORNER TREATMENTS

7.1 The Basic Problem

The run of wire in the loop must have enough slack to allow for normal movements of the pavement. The tendency toward using smaller loops reduces this problem since the contraction and expansion of the pavement and wire are kept to minimum. Also, wire runs over cracks are less frequent and the relative movements within the pavement are small. There is still a need for some minimal space at the intersection of the two saw cuts.

This need arises in installing the wire. It is difficult to hold the wire at the bottom of the slot and concurrently turn 90 degrees to place it in the next saw cut. The installation task is easier if sufficient space exists to place the fingers down in the opening.

7.2 The Alternative Treatments To Providing The Space

There are three alternative approaches to providing this space. These are: 1) the traditional diagonal corner cut; 2) a 1.5-inch drilled hole; and, 3) a hammer and chisel diagonal cut. The primary measure of effectiveness is the time required to prepare the corner. Table 7.1 below summarizes the observations of these studies.

Table 7.1 Summary Of The Corner Treatment Preparation Times
Four Loop Corners Treated

Alternative	Preparation Time	Implementing Time/Corner	Total Time	Time In Roadway
Diagonal Saw Cut	30-40"	30"	2-3 mins	2-3 mins
1.5 Inch Drilled Hole	5-6 mins	20"	6-7 mins	1 min
Hammer and Chisel	2 mins	10"	2-3 mins	< 1 min

7.3 Findings

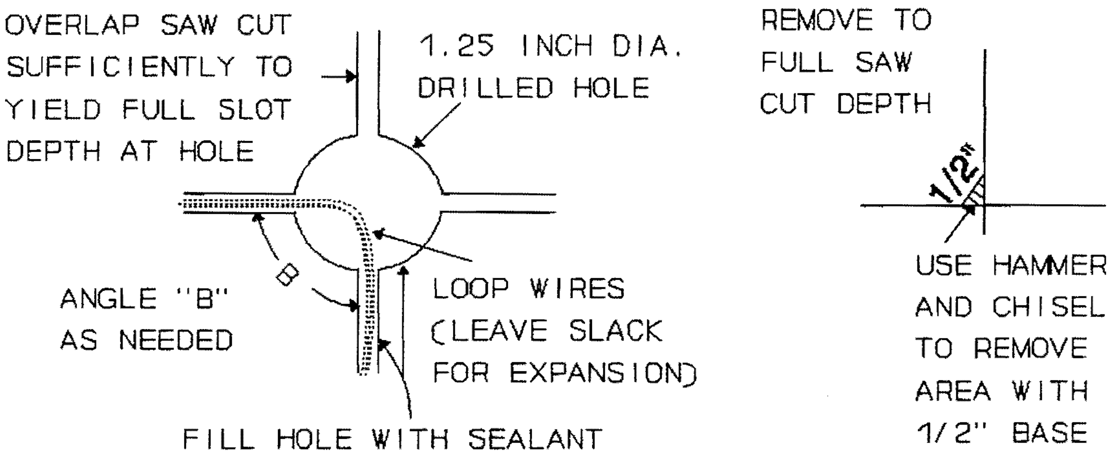
Table 7.1 illustrates that the in-the-roadway time of the drilled hole and the hammer and chisel method are comparable. The total time required for the drilled hole corner treatment is much larger that for the hammer and chisel method. Also, the drilled hole method requires a much higher level of physical work due to the size and weight of the equipment. The hammer and chisel method of corner treatment proved is very simple and effective. It provides the necessary space where the wire runs change direction.

7.4 Limitations Of The Hammer And Chisel Method

The hammer and chisel method is not practical for loops greater than 10 feet in length. The expansion/contraction characteristics of the pavement and wire result in a need for more slack than is easily provided by this method. With the decision to use a long loop, concurrent diagonal corner cut design should be selected to provide the slack necessary to insure good performance.

7.5 Illustration Of The Alternative Corner Treatments

Figure 7.1 illustrates the three basic loop corner treatment methods.



DRILLED HOLE CHISELED HOLE

Alternative Corner Treatments
Figure 7.1

8.0 DEPTH OF PLACEMENT INFLUENCE ON DETECTION EFFICIENCY

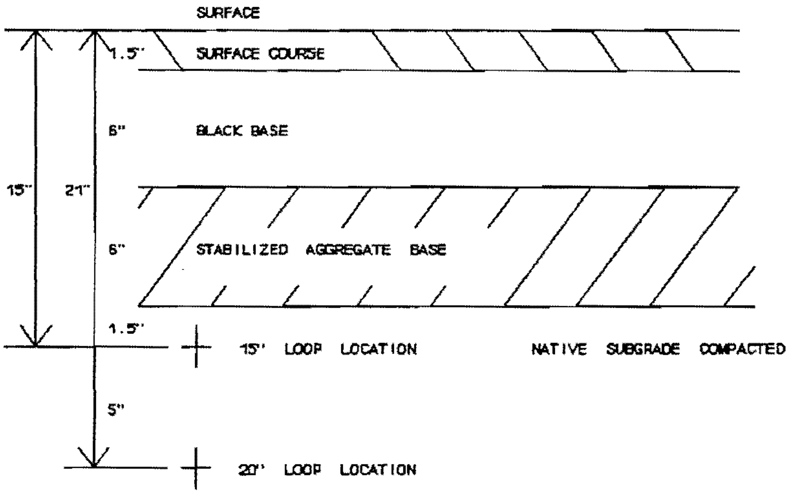
8.1 The Traditional View

The 1985 FHWA Detector Manual (1) was a widely distributed and referenced document. It implies that a three-inch depth of wire below the pavement surface is about the maximum for practical field use. While the latest edition of the FHWA Detector Manual notes that depths greater than 3 inches, the three inch maximum depth is often used in engineering practice. Many unpublished sources suggest that this traditional view is not totally valid. For example, several agencies place the loop wire in PVC conduit, and lay it on top of the reinforcing steel in a P.C. pavement with success. This results in the wire being four to five inches below the surface. Still other agencies place the wire in PVC conduit in the subgrade below the pavement section. This practice placed the wire six to nine inches below the surface. In these cases, satisfactory detection of automobile traffic results according to the agency personnel. Personal observation by the research staff confirm this fact.

The difference could be the modern loop detector unit. This detector is remarkably more flexible than the older units. It is also entirely possible that the three-inch limitation is so wide spread that the profession simply went along without exploring the potential application of deep buried loops. The industry perception is fundamentally incorrect. There was need to quantify the depth effects on detection of various design vehicles.

8.2 The Test Bed

University Drive in College Station, Texas, was undergoing reconstruction about the time this research effort got underway. This was an opportunity to examine the depth effects in detail at modest cost to the State of Texas. A test bed consisting of two, five-turn loops in PVC conduit is set in the compacted subgrade. The design depths are 15 inches and 20 inches below the pavement surface. The sketch on below presents the typical section.



Typical Section - Deep Buried Loop Locations
Figure 8.1

Before the placement of the surface lift, while the lane was still closed to traffic, controlled studies of the detection system were possible. The design depths in these studies were 13-1/2 inches and 18-1/2 inches, respectively.

8.3 Results Of The Deep Buried Loop Controlled Studies

Appendix I contains the detailed data for the controlled deep buried loop studies. The system did detect passenger cars at all sensitivity settings at the 18-1/2 inch depth. Bicycle detection occurs only at the high sensitivity setting. Also, bicycle detection only occurs when it is over the longitudinal wire run on the loop sides. Bicycle detection is independent of number of turns between two turns and five turns. Motorcycle detection at 18-1/2 in loop depth is achievable with high and medium sensitivity settings within the boundaries of the loop. No detection of the motorcycle occurs at the low sensitivity setting. The reader should consider that these findings may not be valid for the Texas series detectors.

8.4 Findings

Appendix I presents the data presented from this phase of the research. There is little doubt that the implication in the Federal Detector Manual that a 3-inch depth was the maximum practical depth for loop is incorrect. Depending upon the design vehicle, the practical working depth varies from zero to at least 20 inches. There is little difference in the detection efficiency of bicycles between the surface loop and the 18-1/2 inch deep buried loop. This strongly suggests loop shape rather that depth of placement is the key factor in detection of bicycles.

Subsequent testing under normal traffic operations with the Texas series detectors results in comparable data to that presented in Appendix I. However, the added sensitivity of the Texas series detector opened the range to include all working sensitive ranges.

8.5 Deep Buried Loop Recommendations

Three situations are clearly conducive to using deep buried loops. These are: 1) Light duty pavements where loop installation severely damage the pavement surface; 2) where the pavement surface is cracked or shoving is apparent; and, 3) where using a substantial overlay. Consideration of installing the loop detectors in the subgrade when reworking the intersection approach is appropriate. For thick overlays, use of the temporary loop system described in Section 9.0 can be very cost effective.

9.0 TEMPORARY LOOPS

9.1 The Need

When a loop becomes nonfunctional or when short-term traffic data is desirable at a location, a temporary loop is a very attractive alternative. This allows full restoration of service until completing the permanent repair or for the needed duration of the data collection. Also, loop configurations can be field tested without committing to an expensive installation of questionable success. Finally, when scheduling an overlay and there is need to replace the existing detectors, a temporary detector is a very cost-effective way to achieve a functional loop which is easily overlaid.

Work for the City of Houston strongly suggests the use of bituminous crack patching material to install a loop directly onto the surface of an existing roadway. Temporary loops using duct tape are common in research. Duct tape has a life of a few days. The use of bituminous crack patching material to attach the loop to the surface of the pavement offers a longer life alternative that can be directly overlaid.

9.2 The Field Installation

A 6 x 6 loop consisting of four turns of number 14 wire went into service on March 10, 1990. The location is on University Drive in College Station, Texas, just east of Avenue A. Bituphene crack sealing material seals the loop wire. Using a six-inch wide section of Bituphene for the installation results in a cost for a 6 x 6 loop of about $10.

9.3 The Life Of The Temporary Loop

The ability of the surface mounted loop to perform normally was never in question. The real question this experiment addressed was the life of the loop under moderate to heavy traffic on an arterial roadway. Appendix K is the service record of the temporary loop.

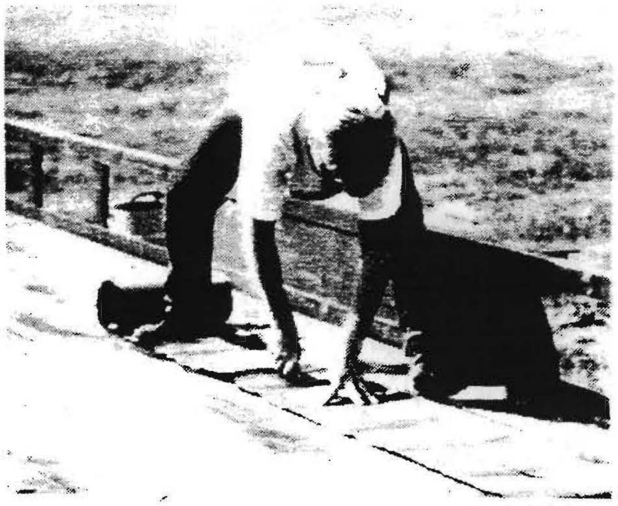
From the data in Appendix K, the life of the temporary installation is six to eight months under moderate to heavy traffic loads. During the observation period, there is evidence of several vehicles skidding on the loop. Skid testing was also conducted at the Texas A&M University Riverside Campus. A Plymouth Reliant test vehicle skidded several times across a surface loop using the Bituphene as the sealer. No noticeable damage to the loop was found. A minimum life appears to be six months and possibly as much as nine months is reasonable.

9.4 The Temporary Loop Installation Process

Figure 9.1 illustrates the installation procedure for the temporary loop using the bituminous crack sealing material. The procedure in Figure 9.1 requires a considerable amount of time in the traffic lane. An alternative is to lay out the crack sealing material in the shop and place the wire on it. Replacing the wax paper protective sheet after the wire is in place for transport to the field. Installation in the field then requires less than 2 minutes and only one person excluding traffic control. This procedure is easy to use and was found to be very practical.

The latter installation procedure also allows the maintenance personnel to carry a temporary loop on the maintenance truck. When a loop is defective, an immediate replacement is possible by a single technician. The life of six to eight months allows scheduling the permanent loop installation at a convenient time from the maintenance crew and traffic demand points of view.

Figure 9.1 Temporary Loop Installation Photos



STEP 1

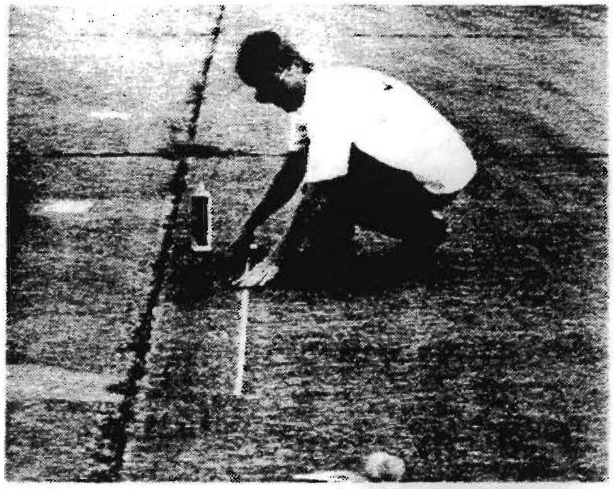
Pavement crack sealing comes in 12, 24, and 48 inch widths as well as 12 foot rolls. For temporary traffic loops, the material must be cut to six inch width.

A sharp pocket knife or a carpet knife work well for cutting the material to size.

STEP 2

The pavement must be free of loose material and oil.

Figure 9.1 Temporary Loop Installation Photos (Continued)



STEP 3

Locate the loop and mark the corners.

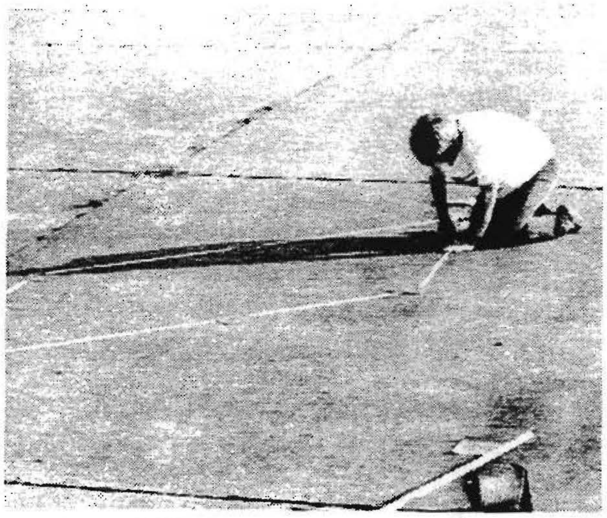
Upside down paint works well for this task.

A small dot is usually sufficient.

Figure 9.1 Temporary Loop Installation Photos (Continued)

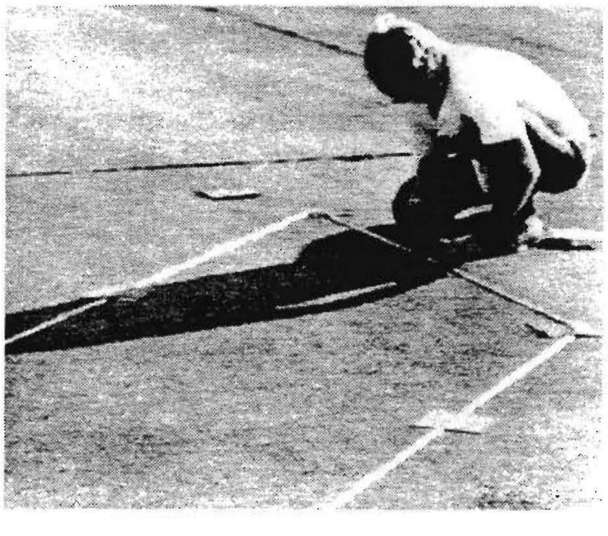
STEP 4

Place 6" x 6" tack strips at each corner and at the midpoints along long runs. Press one side down with the foot but leave the other side loose for the wire to go under.



STEP 5

Note tack strips at corners and middle of each side. Place wire by lifting the corner of the tack strip.



Be certain that the wire remains tight.

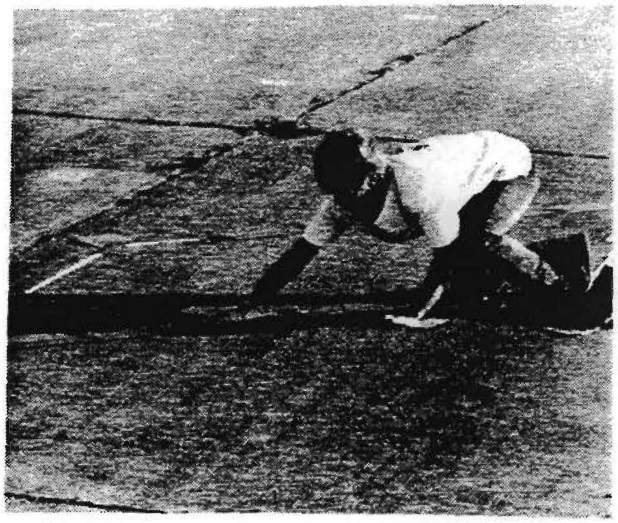
Figure 9.1 Temporary Loop Installation Photos (Continued)

STEP 6

Place hold down fabric over wire and seal with 2" wide crack sealing material strip.

STEP 7

Place 6" wide strip of crack sealing material over the loop wire - hold down - crack sealing material combination.

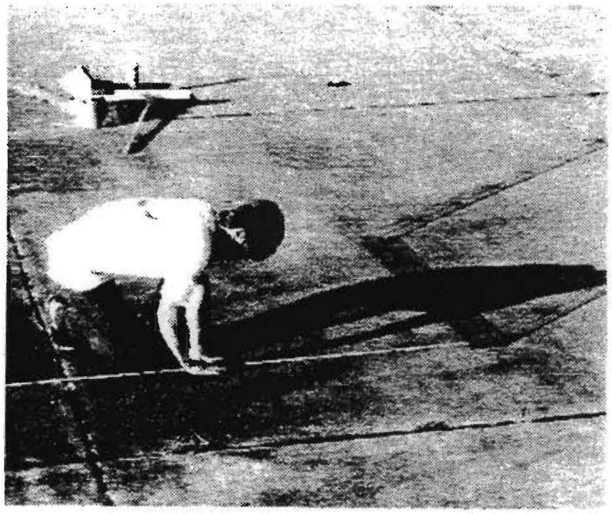


Press down to adhere crack sealing material to the pavement.

Figure 9.1 Temporary Loop Installation Photos (Continued)

STEP 8

Seal by tamping with the foot or driving a vehicle over it.



STEP 9

Take lead wire over to, up, and over the curb. Seal with 6 " wide crack sealing material strip to the back of the curb.

STEP 10

Place run of wire in rigid conduit to controller cabinet.

10.0 CORRELATION OF MEASURED FIELD STRENGTH WITH DETECTION

10.1 The Concept

The frequency of the tuned RF circuit changes with the passage of a closed loop conductive unit through the flux field. Further, it was expected that the magnitude of the frequency change was proportional to the magnetic flux intensity passing through the conductive closed loop unit in the field. There should be some correlation between the detection of a vehicle and the magnetic field strength intensity. The lack of such correlation in the past is important. Possible explanations are the failure to account for the various planes in which the closed conductive circuit exist in the vehicle. Another possible reason is measurement of total field strength and attempting to correlate that value with detection.

After assembling the necessary equipment, field strength measurements on a three dimensional basis at each grid point of the test loop were made. Measurements in a horizontal plane parallel to the pavement, a plane parallel to traffic flow and a plane perpendicular to traffic flow complete the data set. Correlation of these data with the point of detection of the vehicle produces no meaningful correlation. Appendix E contains a sample of these detection data.

10.2 Statistical Analysis Of Detection Point And Field Strength

Contrasts of the total field strength with the detection when a passenger car is the design vehicle were test statistically. The component of the flux field in a vertical plane perpendicular to traffic direction became the logical variable in correlating field strength with detection for motorcycles and bicycles. The flux intensity values at the observation point of detection are the data of interest. The appropriate flux field density at the point of the grid before the detection point and at the detection point for various vehicle paths became the independent variables. These field strength data were correlated with a detection/no detection coded binary variable.

Regression analysis to predict detection given the flux field intensity results in an R^2 of about 0.25 without using any transformed variables. That is, of the variation about the mean value, the model accounts for only 25 percent. An 80 percent level is commonly necessary for predictive purposes. An R^2 this low means there in practically no chance of obtaining a regression model suitable for prediction from these data.

There are two possible sources of error in the variance of this analysis: 1) The approach speed was low but not accurately controlled. Thus, a small variation in the speed may alter the point at which a detection occurs, and 2) the complex closed loop conductive circuits formed in the test vehicle. This is particularly true with the automobile and possible for the motorcycle. However, the bicycle which has all the closed loop conductive circuits located in a vertical plane parallel to traffic had a similar trend. The correlation with the component of the flux field in the vertical plane perpendicular to the flow of traffic is the field strength variable. The test speed of the bicycle was consistently four to five feet per second throughout the testing. Therefore these two possible sources of error in the data probably cannot offer significant hope for a successful regression model even through carefully controlling speed in future experimentation.

10.3 Findings

The results of these experiments are discouraging. There is little point in pursuing this area further. The equipment used in this research is very sensitive. Also a high level of data consistency did occur in repeated measurements at the same point. Field strength data are at a height of six inches and twelve inches to assure inclusion of any height of field effect in the measurement and, therefore, in the modelling process.

For these reasons, the conclusion in this phase of the research is that prediction of detection based on field strength is not possible from the three dimensional flux field strength data.

11.0 LOOP DETECTOR SEALANTS

11.1 Purpose Of Sealing

The purpose of sealing the loop detector wire into the saw cut is often misunderstood. Sealing to keep the water away from the wire is not important. The tests of water in the PVC enclosed loop confirm this fact. These tests show that water around the loop wire changes the loop characteristics so slightly that it is difficult to measure. A second myth is that the sealant must hold the wire in the various turns at a fixed spacial separation. The idea is that a relative movement between the wire will cause false actuation. While this behavior is repeatable in the laboratory, it is difficult to accomplish. A motion amplitude of more than 0.05 inches repetitively is necessary. Measured pavement deflections are much less than this magnitude in a heavy duty pavement. A loop in PVC conduit without a filler of any kind located on an urban arterial street is performing flawlessly. The time period includes periods of heavy rainfall and very hot dry weather. While these tests are not absolutely conclusive, they suggest that motion between the loop wires is a relatively minor problem.

Thus, the basic question remains. Why is it necessary to seal a loop wire into the pavement? Some conclude that sealing of the loop is not necessary. Richardson, Texas, places hold downs at selected points to keep the wire down and backfills the saw cut with sand. No adverse effects on loop life or performance is evident at this time. **The purpose of sealing the loop is to hold the loop wire down to prevent traffic damage to the wire insulation.** Accomplishing this by any alternative treatment, there is little reason to believe an adverse effect on operation of the loop will occur.

Since the purpose of the sealing is hold the wire down, bond to the saw cut is a primary need. The sealant must also remain pliable enough to be sure that pavement cracks at low temperature crossing the loop sides will not shear the wire. A very fluid sealant can permit the wire to migrate to the surface. A sealant that fails to bond the saw cut provides no resistance to vertical wire movement.

11.2 The Screening Tests

The test program requirements include a review of the potential of sealants commonly used in building construction. Also, those in common use in home caulking are possible candidates for sealing loop detectors. The sheer number of sealant alternative lead to a two-stage test program: 1) A screening stage, and 2) a detailed laboratory materials properties stage.

The screening stage testing includes the ASTM patty bond test, the surface no track time test and the low temperature bending test. Only the low temperature bending test was a pass/no pass test. Pass/fail evaluation of the patty bond test was a part of the planning.

No sealant bonded to the finished surface of the concrete. Most of the sealants commonly used in building construction or home caulking were rejected due the low temperature performance.

11.3 The Laboratory Test Program

The laboratory test program involved the following tests:

1. Ability of encapsulate the loop wire.
2. Solubility of the sealant in gasoline or oil.
3. Ability of the sealant to cure at low temperature.
4. Brookfield viscosity at 75 degree F and 33 degree F.
5. Pullout test of 2-1/2 inch wide serrated plate.
6. Toxicity analysis of the sealant and its solvents.

Testing using ASTM standard test procedures when applicable was the general guideline to the laboratory technician. However, the majority of the test procedures were especially devised to meet the needs of this research.

11.4 Products Included In The Test Program

Tests were conducted on the following products:

1. 3M Detector Loop Sealant,
2. Sealex Loop Sealant,
3. Griggs Sealant,
4. Dow Silicone Home Caulk,
5. GE Silicone 1200,
6. Dow Silicone 888,
7. Dow Silicone 890,
8. Dow Silicone 889SL,
9. Dow Silicone 888SL,
10. Preco Gold Label Flex 1P,
11. 974 Permanent Sealer,
12. McLanburg-Duncan Asphalt Cement,
13. McLanburg-Duncan Rubbery Sealant,
14. McLanburg-Duncan Silicone Sealer, and
15. Dow Silicone Rubber.

11.5 Results Of The Laboratory Test Program

11.5.1 Candidate sealants dropped in the screening tests

The Dow Silicone Home Caulk, the GE Silicone 1200 and the McLanburg-Duncan Silicone Sealer failed to bond to the asphalt or the portland cement concrete, eliminating them from further consideration. The McLanburg-Duncan Asphalt Cement did not cure at all. The McLanburg-Duncan Rubber Sealer and the Dow Silicone Rubber sealer did not cure for an extended period and handling properties lead the laboratory technician to recommend discontinuing the testing of these products. The Dow Silicone 888 and 890 products failed to provide even a reasonable coverage of the wire (usually just covering the air space above the wire) without an extensive effort to force the sealant down into the sawed slot. These are not practical for use as a loop detector sealant. The full laboratory test series applies to the remainder of the products.

The results of the laboratory testing are included in Table 11.1. Appendix L is the typed laboratory notes of the technician. Appendix M are the notes of the sealant solubility test in gasoline. Table 11.1 also contains the results of the no track time test and manufacturer's recommendation for use of the product.

Evaluation of the bond strength of the sealant to asphaltic concrete and portland cement concrete are based on the patty test. As shown in the fifth and sixth columns of Table 11.1, the patty test failed to reveal any significant degree of bond with many of the products that had been successful in field use. For this reason, an alternative method of directly measuring the minimum bond that exists is needed.

A perforated metal plate 2-1/2 inches wide set in the freshly place sealant and allowed to cure for three days became the basic test sample. Pulling the perforated plate out in pure tension results in direct test of bond strength. A plot of force and time results. Observation of the plate after extraction reveals the nature of the failure. The force to pull the plate out is the minimum force required to overcome the bond force. For the interface bond failure, it is indicative of the actual bond strength. For failure in the sealant, it is indicative of something less than the actual bond strength.

Table 11.2 provides a summary of the pullout test results. A copy of the actual force vs. time plot is included in Appendix N.

Table 11.1 Sealant Study
No Track Time Tests

Producer	Type of Sealant	Elastic Temperature Range	Placement Temperature	Crack Condition	Cleaning Agent	Track Free Time	Crack Depth
McLanburg Duncan	Rubbery Sealant	-40 F To +220 F	+ 40 F	Free of dirt and oil	Mineral spirits turpentine and kerosene		0.5 W 0.5 D
General* Electric	Silicone 1200	All Temperatures	All Temps	Clean and dry		1 Hr	Up Crack over 3/8"
McLanburg Duncan	Asphalt Cement	Not Specified	NA	NA	Mineral spirits	NA	NA
McLanburg Duncan	Silicone Sealer	Unknown	- 35 F	Free of dirt and oil	Unknown	5 - 10 Hours	NA
McLanburg Duncan	Glazing Compound	Unknown	+ 40 F	Free of dust, dirt, and oil	Soap and water	Unk	NA
DOW*	Silicone Rubber	-60 F to +400 F	NA	Clean and dry	NA	5 min touch 24 hrs	NA
DOW 888	Silicone Rubber	Unknown	--->	Testing	Discontinued		
DOW 888SL	Silicone Rubber	Not Specified	Wide Temp. Range	Clean and dry		Unk	NA
PRECO	Polyurethane Sealant	Not Specified	40 - 130 F	Clean and dry	Unk	Unk	Not Meas
DOW 890	Silicone Rubber	Not Specified	Unknown	Clean and dry	XYLOL	NA	Not Meas

* Not set in 36 hours.

Table 11.2 Summary Of The Pullout Force Required To Extract The Perforated Plate

Material	Pavement Type	Test Temperature	Rate Of Load Application	Pullout Force
DOW 888	A. C.	120 F	2"/Min	49 #
DOW 888	A. C.	120 F	2"/Min	50 #
DOW 888	A. C.	120 F	2"/Min	46 #
DOW 888	A. C.	75 F	2"/Min	65 #
DOW 888	A. C.	75 F	2"/Min	60 #
DOW 888	A. C.	75 F	2"/6 Seconds	83 #
DOW 888	A. C.	33 F	2"/Min	5 #
DOW 888	A. C.	33 F	2"/Min	8.5 #
DOW 888	A. C.	33 F	2"/Min	4 #
DOW 888SL	P. C.	77 F	2"/Min	6 #
DOW 888SL	P. C.	77 F	2"/Min	6.5 #
DOW 888SL	P. C.	77 F	2"/Min	34 #
DOW 888SL	P. C.	120 F	2"/Min	44 #
DOW 888SL	P. C.	120 F	2"/Min	27 #
DOW 888SL	P. C.	120 F	2"/Min	31 #
DOW 888SL	A. C.	55 F	2"/Min	14 #
DOW 888SL	A. C.	55 F	2"/Min	25 #
Preco	A. C.	120 F	2"/Min	57 #
Preco	A. C.	120 F	2"/Min	50 #
Preco	A. C.	55 F	2"/Min	37 #
Preco	A. C.	55 F	2"/Min	29 #
Preco	A. C.	75 F	2"/Min	95 #
Preco	A. C.	75 F	2"/Min	85 #
Preco	A. C.	75 F	2"/Min	95 #
Sealex	A. C.	77 F	2"/Min	125 #
Sealex	A. C.	77 F	2"/Min	130 #
Sealex	A. C.	77 F	2"/Min	100 #
Sealex	A. C.	120 F	2"/Min	5 #
Sealex	A. C.	120 F	2"/Min	16 #
Sealex	A. C.	35 F	2"/Min	170 #
Sealex	A. C.	35 F	2"/Min	20 #
Sealex	A. C.	35 F	2"/Min	95 #
Griggs	A. C.	120 F	2"/Min	3 #
Griggs	A. C.	120 F	2"/Min	2 #
Griggs	A. C.	120 F	2"/Min	4 #
DOW 890SL	A. C.	120 F	2"/Min	12 #
DOW 890SL	A. C.	120 F	2"/Min	17 #

Table 11.2 Summary Of The Pullout Force Required To Extract The Perforated Plate (Continued)

DOW 890SL	A. C.	120 F	2"/MIN	13 #
DOW 890SL	A. C.	33 F	2"/MIN	9 #
DOW 890SL	A. C.	33 F	2"/MIN	10 #
DOW 890SL	A. C.	33 F	2"/MIN	8 #
DOW 890SL	A. C.	77 F	2"/MIN	25 #
DOW 890SL	A. C.	77 F	2"/MIN	21 #
DOW 890SL	A. C.	77 F	2"/MIN	22 #
DOW 890SL	A. C.	55 F	2"/MIN	10 #
DOW 890SL	A. C.	55 F	2"/MIN	14 #
3M	A. C.	75 F	2"/MIN	190 #
3M	A. C.	75 F	2"/MIN	150 #
3M	A. C.	75 F	2"/MIN	195 #
3M	A. C.	120 F	2"/MIN	33 #
3M	A. C.	120 F	2"/MIN	13 #
3M	A. C.	120 F	2"/MIN	19 #
3M	A. C.	55 F	2"/MIN	24 #
3M	A. C.	55 F	2"/MIN	18 #
FOSROC	P. C.	77 F	2"/MIN	54 #
FOSROC	P. C.	77 F	2"/MIN	58 #
974 PERM.	P. C.(DRY)	77 F	2"/MIN	80 #
974 PERM.	P. C.(DRY)	77 F	2"/MIN	64 #
974 PERM.	P. C.(WET)	77 F	2"/MIN	60 #
974 PERM.	P. C.(WET)	77 F	2"/MIN	58 #
3M NO PRIMER	P. C.	77 F	2"/MIN	350 #
3M NO PRIMER	P. C.	77 F	2"/MIN	250 #
3M PRIMER #1	P. C.	77 F	2"/MIN	225 #
3M PRIMER #1	P. C.	77 F	2"/MIN	250 #
3M PRIMER #1	P. C.	77 F	2"/MIN	

11.6 Value Engineering Analysis Approach To Sealant Evaluation

The selection of a loop detector sealant involves a wide range of factors. These factors depend upon the product's mechanical properties, the experience with the product and the cost of the product. Since the range of values is very large and individual characteristics impact on performance vary, a value engineering approach is the most objective method of considering both the measurable and subjective variables. Table 11.3 contains the value engineering analysis of the eight products which appeared from the laboratory testing to have merit as a loop sealant.

TABLE 11.3
VALUE ENGINEERING ANALYSIS OF LOOP SEALANTS

LEVEL 1 - 70% OF WEIGHT

				IDEAL MATERIAL	WORSE MATERIAL	3M LOOP SEALANT	SEALEX	GRIGGS SEALANT
A.	EASE OF PLACEMENT	EASY	23	23		23	23	23
		MODERATE	12					
		HARD	0		0			
B.	PLIABILITY	PASSED BENDING TEST	23	23		23	23	
		MARGINAL ON BENDING	12					12
		FAILED BENDING TEST	0		0			
C.	REACTION TO PETROLEUM PRODUCTS	YES	-23		-23			
		MAYBE	-12				-12	
		NO	0	0		0		0
D.	QUALITY OF THE BOND	GOOD	24	24			24	
		ONLY AC OR LOW	13			13		
		POOR	0		0			0

LEVEL 2 - 20% 0F WEIGHT

A.	TOXICITY OF MATERIAL	NON-TOXIC	0	0				
		LOW TOXICITY	-3			-3	-3	-3
		TOXIC	-7		-7			
B.	TOXICITY OF SOLVENT	NON-TOXIC	0	0				0
		LOW TOXICITY	-3					
		TOXIC	-7		-7	-7	-7	
C.	REACTION TO GASOLINE	NONE	0	0		0		0
		MAYBE	-3				-3	
		YES	-7		-7			
D.	ONE OR TWO PART COMPOUND	1 PART	6	6		6		6
		2 PART	-6		-6		-6	
E.	TRACK FREE TIME	< 10 MINUTES	7	7				
		10-30 MINUTES	0			0	0	
		> 30 MINUTES	-7		-7			-7
F.	DUCTILITY	HIGH	7	7				
		MODERATE	3					3
		LOW	0		0	0	0	

TABLE 11.3 (Continued)

LEVEL 3 - 10% OF WEIGHT				IDEAL MATERIAL	WORSE MATERIAL	3M LOOP SEALANT	SEALEX	GRIGGS SEALANT
A.	COMPETITIVE BIDDING	YES	1	1		1	1	1
		NO	0		0			
B.	BROOKFIELD VISCOSITY							
	75° F	LOW	0		0		0	0
		MODERATE	1			1		
		HIGH	2	2				
	35° F	LOW	2	2		2	2	2
		MODERATE	1					
		HIGH	0		0			
C.	SHELF LIFE	< 30 DAYS	-2		-2			
		30-90 DAYS	-1					
		90 DAYS - 6 MONTHS	0				0	0
		6 MONTHS - 1 YEAR	1			1		
		> 1 YEAR	2	2				
D.	FIELD TRACK RECORD	YES	1	1		1	1	
		LIMITED	0					
		NEW PRODUCT	-1		-1			-1
E.	EASE OF STORAGE	EASY	1	1		1	1	1
		DIFFICULT	0		0			
F.	EASE OF REUSE	EASY	1	1				1
		DIFFICULT	0			0		
		NOT POSSIBLE	-1		-1		-1	
G.	SPECIAL EQUIP. REQUIRED	YES	0		0		0	0
		NO	1	1		1		

SUMMARY MATRIX

TOTAL VALUE POINTS ACCUMULATED	101	-61	63	43	38
COST PER QUART IN 1990 DOLLARS ***			9.95	4.35	5.20
DOLLARS PER VALUE POINT PROVIDED			0.157	0.101	0.136
COST PER VALUE POINT RANK			4	1	2*

* NOTE: The Griggs Sealant should be limited to the non-pavement freezing areas of the State. The area South of I-10 from the Louisiana State line to San Antonio and I-35 from San Antonio to Mexico is suggested.

*** Includes a 10% surcharge on products supplied only in one or five gallon containers and where special application equipment is required.

TABLE 11.3 (Continued)

LEVEL 1 - 70% OF WEIGHT

			DOW 888	DOW 888SL	DOW 890SL	PRECO	974 SEALER
A.	EASE OF PLACEMENT	EASY		23	23	23	23
		MODERATE					
		HARD	0				
B.	PLIABILITY	PASSED BENDING TEST	23	23	23	23	
		MARGINAL ON BENDING					12
		FAILED BENDING TEST					
C.	REACTION TO PETROLEUM PRODUCTS	YES					
		MAYBE		-12	-12		-12
		NO	0			0	
D.	QUALITY OF THE BOND	GOOD					24
		ONLY AC OR LOW		13	13	13	
		POOR	0				

LEVEL 2 - 20% OF WEIGHT

			DOW 888	DOW 888SL	DOW 890SL	PRECO	974 SEALER
A.	TOXICITY OF MATERIAL	NON-TOXIC					
		LOW TOXICITY	-3				-3
		TOXIC		-7	-7	-7	
B.	TOXICITY OF SOLVENT	NON-TOXIC					
		LOW TOXICITY					
		TOXIC	-7	-7	-7	-7	-7
C.	REACTION TO GASOLINE	NONE	0			0	0
		MAYBE		-3	-3		
		YES					
D.	ONE OR TWO PART COMPOUND	1 PART	6	6	6	6	6
		2 PART					
E.	TRACK FREE TIME	< 10 MINUTES					7
		10-30 MINUTES	0	0	0		
		> 30 MINUTES				-7	
F.	DUCTILITY	HIGH			7		7
		MODERATE	3				
		HIGH		0		0	

TABLE 11.3 (Continued)

LEVEL 3 - 10% OF WEIGHT			888	888SL	890SL	PRECO	974 SEALER
A.	COMPETITIVE BIDDING POSSIBLE	YES	1	1	1	1	1
		NO					
B.	BROOKFIELD VISCOSITY						
	75° F	LOW				0	
		MODERATE					1
		HIGH	2	2	2		
	35° F	LOW					
		MODERATE				2	
		HIGH	0	0	0		1
C.	SHELF LIFE	< 30 DAYS					
		30-90 DAYS					
		90 DAYS- 6 MONS. 6	0	0	0		
		MONTHS - 1 YR.					1
		1 YEAR OR MORE				2	
D.	FIELD TRACK RECORD	YES		1		1	1
		LIMITED					
		NEW PRODUCT	-1		-1		
E.	EASE OF STORAGE	EASY	1	1	1	1	1
		DIFFICULT					
F.	EASE OF REUSE	EASY					
		DIFFICULT	0	0	0	0	0
		NOT POSSIBLE					
G.	SPECIAL EQUIP. REQUIRED	YES					
		NO	1	1	1	1	1

SUMMARY MATRIX

TOTAL VALUE POINTS	26	42	47	52	65
COST/QUART IN DOLLARS ***	14.75	16.33	16.33	10.50	9.40
DOLLARS PER VALUE POINT PROVIDED	0.567	0.389	0.347	0.201	0.149
COST PER VALUE POINT RANK	8	7	6	5	3

*** Includes a 10% surcharge on products supplied in one or five gallon containers or for which special equipment is required.

The ranking at the bottom of the table is instructive only in light of the limitations of each product. The Sealex is the least costly product, but because it is very fluid is not useable on a grade. The Griggs Paint Company Sealant failed the low temperature bending test and is not useable in areas subject to freezing temperatures. The 3M Sealant and the Permanent Sealer 974 are for all practical purposes equivalent products in performance and cost. The Preco Gold Label Flex 1P has a moderate performance rating and a somewhat higher cost. A breakeven cost of $6.30 per quart in one quart container would make Preco equivalent in value to the 3M Sealant and the Permanent Sealer 974. The three silicone based products had low to moderate performance ratings and high cost. This combination results in a cost per value point more than twice that for the 3M Sealant and the Permanent Sealer 974.

11.7 Recommendations On Sealants

Considering the laboratory testing, the limited field trials with the various sealants and the cost of the product in one-quart containers the following priority list is recommended:

Top Value:
- 3M Sealant
- Permanent Sealer 974

Acceptable:
- Preco Gold Label Flex 1P - Comparable at $6.40/quart

Acceptable with Restrictions:
- Sealex - Limited to Near Level Terrain
- Griggs Paint Sealant - Limited to Nonfreezing Areas

Probably Unacceptable:

DOW 888 DOW 888SL	The high cost and lack of encapsulation limit these products as a loop sealant. A DOW 890SL price reduction of 60% would make them comparable to the top value group.

Subsequent field experience with the Permanent Sealer 974 suggests that it may not be a desirable as the laboratory data indicates.

12.0 SUMMARY OF LOOP LEAD LENGTH STUDY DATA

12.1 Detection 6 x 6, 45-Degree Skewed Loop Presence Mode Of Operation - Non-Texas Detector Units Used

12.1.1 Bicycle

Satisfactory detection of the bicycle in the presence mode results at medium and high sensitivity settings with lead lengths up to 300 feet. Bicycle detection on the low sensitivity setting occurs. The detection call chattered at both zero and 100 foot lead lengths.

Using a lead of 300 feet or less with the 6 x 6, 45-degree skewed loop or the 6 x 6 right triangular loop does detect and hold a bicycle occupying the loop area. Four turns of wire are necessary and the detector setting of either medium or high sensitivity.

12.1.2 Full-Sized 1984 Ford 4-Door Sedan

Effective detection of a full-sized passenger car is possible. The call was held for all lead lengths up to and including 500 feet with little noticeable difference in detection efficiency. The use of up to 700 feet of lead is reasonable for the 6 x 6, 45-degree skewed loop and the 6 x 6 right triangular loop with four turns of wire. This assumes the non-Texas series detectors.

High-speed operation at 30, 40 and 50 miles per hour results in no detection problems with 500 feet of lead wire for the 6 x 6, 45-degree skewed loop or the 6 x 6 right triangular loop. Each loop has four turns of wire.

Stopping the vehicle in the loop area revealed that the detector does hold the call until the vehicle clears the detection area. The call then drops immediately. The results reveal no static or dynamic operational problems with the full-sized passenger car. The condition of the observation are the 6 x 6, 45-degree skewed loop or the 6 x 6 right triangular loop using four turns of wire for lead lengths of 500 feet or less and probably none for up to 700 feet. Table 12.1 summarizes the observations of this study.

12.2 Relationship Of Percent Of Loop Inductance From Leads To Bicycle Detection

The lead length inductance data are useful in determining the maximum contribution to the inductance of the loop system that can come from the leads and still have satisfactory bicycle detection. Table 12.1 summarizes these data.

Table 12.1 Relationship Of The Percent Of Inductance From The Leads To Detection Of A Bicycle

Lead Length (feet)	Loop System Inductance (mu h)	Inductance From The Lead Wire (mu h)	Percent Of "L" From Leads (%)	Sensitivity Levels At Which Bicycle Detection Occurred
0	107.74	0	0%	High Or Medium
100	137.97	30.23	21.0%	High Or Medium
200	155.40	47.66	30.6%	High Or Medium
300	312.07	205.28	65.8%	High Or Medium
400	535.60	427.86	79.9%	High Only - Some Chatter

NOTE: The detectors used in this study were not the Texas standard detector.

From these data, a percentage of system inductance of 65 percent or less allows for good bicycle detection. Thus if the lead length is greater than 300 feet and bicycle detection is an important consideration, the loop inductance must increase relative to the system inductance. The lead to loop inductance ratio was less than 65 percent.

Similar data exists for a full-sized passenger car. There was no noticeable change in detection performance for leads up to 500 feet. In general, the 65 percent guideline mentioned above is equally valid, but less critical, for passenger cars. This statement applies for the non-Texas specification detector units only.

12.3 The Texas Series Detector and Lead Length

The Texas standard detector (Texas Series Detector) is far more sensitive than the detectors used in this phase of the study. In subsequent field studies, very good detection occurs when 70 percent of the total inductance came the lead wire. These later studies did not include the bicycle test vehicle. Using lead lengths up to 1000 feet results in no noticeable impact on the loop performance from two to five turns of wire.

12.4 Findings

Based on the controlled studies of lead length, the following recommendations are appropriate:

For Non-Texas Series Detectors (Older Units)

Lead lengths for these detectors are relatively short to insure effective performance.

For the bicycle design vehicle, a maximum lead length is about 300 feet. The maximum lead length for the automobile design vehicle was not determined. However, a 700-foot maximum value is in the right order of magnitude based on experience with these units.

For Texas Series Detectors

Lead length of 1,000 feet are acceptable with this detector. It is likely that the maximum length for the bicycle design vehicle is somewhat less. However, this will not normally be a constraint since only the stop bar detector will normally detect bicycles and MOPEDS.

Table 12.2 Lead Length Study
Detection Reference Line For Activation And Call Drop

Detector			Lead Length											
Test Vehicle	SENS	FREQ	0 Feet On	0 Feet Off	200 Feet On	200 Feet Off	400 Feet On	400 Feet Off	600 Feet On	600 Feet Off	800 Feet On	800 Feet Off	1000 Feet On	1000 Feet Off
Bicycle	L	L	5	3	5	4	ND	ND	ND	ND	ND	ND	ND	ND
	M	L	4	13	5	13	5	13	5	13	ND	ND	ND	ND
	H	L	4	13	4	14	4	14	4	13	5	13	ND	ND
1984 4-Door Ford Sedan	L	L	5	14					7	13			6	12
	M	L	3	17					6	15			7	14
	H	L	2	15					4	15			5	15

			30 mph	**40 mph**	**50 mph**
High Speed Tests 400' of Lead Wire	**L**	**L**	**Good detection each of three runs.**	**Good Detection each of three runs.**	**Good detection each of three runs.**
	H	**L**	**Good detection each of three runs.**	**Good detection each of three runs.**	**Good detection each of three runs.**
Stopped In Loop Area Ability To Hold A Call	**L**	**L**	**Held call and cleared immediately after the vehicle left the loop area on each of three trials of one minute duration each.**		

*** ND - Not detected**

*** Blank - No test with this combination**

*** Numbers in table are the grid line numbers where detection occurs and where the call is dropped.**

13.0 PREMATURE LOOP FAILURES

13.1 Reasons For Premature Loop Failure

The survey of agencies and contractors revealed that well installed loops had a very long service life. Many sources reported the following situations to avoid. When these situations exist, there is a high chance of premature loop failure.

1. Pavements showing signs of shoving.
2. Pavements showing signs of excessive wheel path rutting.
3. Pavements showing a highly developed crack pattern. Alligator cracking is also a common name for this crack pattern.
4. Joints or large cracks in an existing pavement.
5. Using sharp edged tools in loop wire installation.
6. Inadequate wire slack to accommodate thermal expansion.

A well installed loop is seldom a problem in the field due to a loop wire failure in absence of some external damage.

13.2 Reasons For Premature Failures In A Properly Installed Loop

Most loop replacements with properly installed loops come from damage resulting from construction or maintenance equipment operation in the loop area. Roto-Milling the pavement to reestablish the drainage path is a relatively common practice. The area adjacent to the curb is the target of the milling operation and this frequently damages the loop leads. There is no method of totally preventing this from occurring. However, being certain lead wire is at its full depth until it leaves the paved surface reduces this damage to a minimum.

Utility work in the area, water, sewer, electrical etc., often damages the lead wire or actually removes a section of the loop. Close coordination with utility contractors and maintenance personnel can keep this damage to minimum.

14.0 FINDINGS OF THE RESEARCH

- Premature loop failures are usually the result of poor installation.
- Contractor or maintenance crew equipment working in the area is the dominate reason for loop wire/lead failures.
- Bicycles, MOPEDS, and motorcycles are not easily detected by wire runs perpendicular to the vehicle path.
- Individual lane detection at a point for counting purposes must be carefully designed to avoid crosstalk.
- The 45 degree skewed loop was the most efficient loop shape for detecting bicycles, MOPEDS, and motorcycles.
- The quadrapole loop field height is relatively low (about 32 inches) compared to a rectangular loop (about 51 inches). Thus, a high profile truck may be over the loop, but if the axle is not in the loop area, the truck may not be detected. This is a common problem reported by the truckers.
- Full loop wire encapsulation, while desirable, is not critical to the successful detection of vehicles.
- High speed sawing of loop slots is practical with a large saw and a properly designed diamond saw blade.
- High speed sawing requires added weight on the saw blade to control the slot depth. One hundred pounds placed directly over the drive axle is recommended.
- Diagonal corner cuts for short loops (10 feet or less in length) is not essential. A faster alternate is hammer and chisel technique.
- Loops placed as deep as 20 inches below the surface resulted in 100 percent detection of automobile traffic in the lane. Loop depth below the surface is not a critical design issue.
- There is not identifiable correlation between the field strength measured along three mutually orthogonal planes and the detection of vehicles. This is probably due to the complex nature of the closed loop circuits formed in the vehicle which create the change in the system.

- The standard ASTM patty test to determine the bond to Portland Cement Concrete failed to correlate to any measurable degree with the measured bond strength in the saw cut. This is probably due to the difference in the finished concrete surface as compared to the very polished saw cut face.

- Many commonly available loop sealants failed to have sufficient pliability at low temperature. A brittle sealant will reflect pavement cracks and damage to the loop wire.

- Lead length with loop detector can be up to 1,000 feet with automobile traffic and about 500 feet (300 preferred) with bicycles without significant problems. A good rule-of-thumb is to keep the lead inductance to less that two-thirds of the total system inductance.

- The modern Texas Standard Detector (TX Detector) is remarkably better than the older detector units. The performance difference is significant enough to justify discontinuing the use the older detector units and replacing the older units in the field at the first opportunity.

15.0 RECOMMENDATIONS FOR FURTHER RESEARCH

15.1 Introduction

In the conduct of any research, some questions are answered and others are left to be examined by others. This section describes those areas which, in the authors opinion, deserve further investigation.

15.2 Areas Of Future Research

- Design Of Loop Depth

The three inch maximum loop wire depth recommended in the Federal Detector Manual (1) is clearly not compatible with modern detection equipment. Loops were placed up to 20 inches below the surface which operated very well. It is appropriate for future research to define the magnetic field height above the pavement. Then suggest the design depths to be compatible with a desired design vehicle.

- Application Of Loop Detector On Bridges

The use of deep buried loops, especially those below reinforced concrete pavements, lead to examination of using loop under the bridge deck. A tentative test revealed that for prestressed concrete girders and a reinforced concrete deck, the use of loop under the deck the detector detected traffic on the bridge above. The question of the influence of steel girders and the problem of locating the loop in the center of the lane were not addressed. The general application of loop detectors beneath the bridge deck with a special emphasis on left-in-place steel forms, steel girders, and placement of the loop relative to the traffic lane need to be explored.

- Alternate To Loop Sealing

The practice of one Texas city of using wire hold downs and backfilling the slot with loose sand deserves further examination. Sealing the loop is time consuming, expensive, and messy. If the sand packed loop has the life of a well sealed loop, this alternative to sealing is highly desirable. The relationship of wire size to slot width, and the type of hold down to use need to be examined.

- Control Of Dust During High Speed Sawing

The dust problem created during dry, high-speed sawing of asphaltic is a major problem. Ways to reduce the impact of the dust cloud need to be found. This might include filtering the dust out using a trap similar to those used on lawn mower grass catchers. A scoop might be placed behind the blade to direct the dust into the filter.

* Methods Of Increasing The Life Of Surface Loops

The temporary surface loop installation used in this research had a functional life of six to nine months. The measured life was determined by exposure of the wire through the insulation. Obviously, if the wire is still intact, another covering of the crack sealing material should provide another seven months of useful life. Metro, in Houston, is testing a surface loop with a fabric to hold the wire down in the crack sealing material. A life of one and one half to two years is expected from the loop on the Transitway. After one year and three months the loops still fully functional. Subsequent testing on the HOV Lane in Houston indicate a one and one-half year life from surface mounted loops is reasonable.

The advantage of the surface loop is the speed of installation. It can be preformed in the shop and field installation is then accomplished in a few minutes actually in the traffic lane. The ability of the cracking sealing material to protect the wire insulation during an overlay, the most appropriate way to maintain the cracking sealing material over the wire and the shelf life of the preformed loop are but some of the basic questions that must be addressed.

* Loops Placed Around Metal Objects

Occasionally, a metal object, such as a man hole cover, falls within a proposed loop. The usual procedure is to redesign the loop layout to avoid the metal object. The results obtained in this research casts doubt on the need for precaution when using modern detection equipment. The relative efficiency of a loop detector when a metal object is located within it needs to be explored and documented.

Subsequent testing by Hamm(3) demonstrated that a man hole cover in the loop area of a 6' x 6' loop did not effect the ability of the TX detector to detect passing automobile traffic.

Appendix A
Data From Loop Detector Vibration Test
Data Collected April 10, 1989
Materials Engineering Laboratory
Texas A&M University

Vibrator Operator: Jody Short **Recorder: Don Woods**

Detector Type: Detector Systems Model 262B

Loop Sensor Type: One-Half Inch PVC Pipe With Five Turns Of # 14 AWG Stranded Wire.

Test Number	Detector Sensitivity Setting	First False Call Detected	Average First False Call Detected	Rheostat Setting @ Constant Call Detected	Average at Constant Call
1	7	5		8	
2	7	5	4.8	7	7.5
3	7	5		8	
4	7	5		7	
5	6	8		10	
6	5	8	6.5	10	9.8
7	5	8		11	
8	5	4		10	
9	3	62		85	
10	3				
11	3	25		55	
12	3	55		70	
13	2	58		75	
14	2	48	50.3	75	76.8
15	2	50		82	
16	2	45		78	
17	1	NA		NA	
18	1	NA	NA	NA	NA
19	1	NA		NA	
20	1	NA		NA	

Constant Call Amplitude: Amplitude ≈ 0.0108 + 0.00018 * Rheostat Setting

First Call Amplitude: Amplitude ≈ 0.0107 + 0.000166 * Rheostat Setting

The magnitude of the vibration of a pavement varies from 0.010 inches for a high type surface up to 0.060 inches for low-volume FM Road pavements.

Appendix B
Measured Effect Of Water On Loop Capacitance
April 25, 1989

Water between the loop wires causes a shift in the resonant frequency as water adds stray capacitances in the loop. Therefore, a false detection is received. Water does not have much of an effect in changing inductance of the loop. The CRC Manual lists the susceptibility of water. From those data, the magnetic permeability (relative) of water was calculated. It is very close to free space permeability. That means that the addition of water does not have a significant effect on the magnetic flux lines. Water is diamagnetic matter.

So certainly it is the capacitance that is changed as water is added to space between the loop wires. This certainly changes the LC circuit characteristics by changing the resonant frequency. The experiment did show an increase in capacitance between two loop wires with the addition of water. The data are presented below:

 # 14 THHW WIRE Belden
2 - turns
Dry Condition - 60 pf
Wet Condition - 67 pf Change = 7 pf

Given a 6 x 6 loop with 2 turns of wire and 300 feet of lead:

$$L = \frac{5(24)(4)}{10+2} = 40 \text{ muH} \quad C_{dry} = 24(25)2 + 300(25) = 8700 \text{ pf}$$

$$C_{wet} = 8707 \text{ pf}$$

Therefore; Loop Dry Loop Wet

$$f = \frac{1x10^6}{2\,\pi\sqrt{(LC)}} = 269.792 \text{ kHz} \qquad 269.684 \text{ kHz}$$

Where: L is the inductance in microhenries
C is the capacitance in picofarrads

This change in the frequency is so small that only very sensitive equipment could detect the difference.

Appendix C
Loop Detector Field Strength Height Summary
July 1989

Loop Type	Sensor Location	Height At 1st Change	Height At 10 Hz Change	Height At 20 Hz Change
45 Skew	Over End Wire-12	42"	42"	29 1/4"
W/2-4-2	Centered 4-Wire-12	34"	34"	16 1/4"
Wire Turns	Loop Center-9	8 1/4"	6"	4 1/2"
	Over Side Wire-6	14 1/4"	14 1/4"	8 1/2"
	Over End Wire-9	45"	44"	32 1/2"
	Over Side Wire-12	20 3/4"	7 1/4"	8 3/4"
	Over End Wire-6	31 1/2"	23 3/4"	14 3/4"
	Over End Wire-12	34 1/2"	34 1/2"	NA
Diamond-4 Turns	Center Of Loop	47"	45"	35 3/4"
Octagonal-4 Turns	Center Of Loop	52 1/2"	52"	38 3/4"
6 X 6 Skew 2/3 4-Turns	Center Of Loop	54"	53-3/4"	43-1/2"
Chevron-4 Turns	Center Of Loop	49-1/2"	49-1/4"	45"
6 X 6 Skew 1/1 4-Turns	Center Of Loop	50-1/2"	38"	31-1/4"

Frequency Shift In RF Tuned Circuit With The Simulator At Various Heights Above The Pavement

Loop Type	Sensor Location	Base Frequency	Frequency At 2 Feet	Frequency At 1 Foot	Frequency On PVT.
Skew +	Over End Wire	84,912	85,807	85,796	85,793
Header	Center Of Loop	85,733	85,708	85,710	85,839
4 Turns	Center Of Loop	85,691	85,658	85,659	85,747
	Over Side Wire	85,673	85,696	85,706	85,822
	Center 4-Wires	85,705	85,737	85,814	85,252
	Over Side Wire	85,730	85,729	85,729	85,806
	Over Side Wire	85,670	85,658	85,660	85,757
	Center Of Loop	85,680	85,674	85,678	85,751
	Over End Wires	85,701	85,673	85,669	85,673
	Over End Wires	85,685	85,693	85,693	85,693
	Center Of Loop	85,652	85,680	85,752	85,158

Appendix C (Continued)
Frequency Shift In RF Tuned Circuit With The Simulator At Various Heights Above The Pavement

Loop Type	Sensor Location	Base Frequency	Frequency At 2 Feet	Frequency At 1 Foot	Frequency On PVT.
Diamond 6 x 6	Center Of Loop	71,520	71,602	72,016	74,648
Octagonal 6 x 6	Center Of Loop	61,698	61,821	62,092	62,915
6 x 6 Skew 2/3	Center Of Loop	47,705	47,803	47,951	48,248
6 x 6 Skew 1/1	Center Of Loop	46,167	46,223	46,355	46,736
Chevron	Center Of Loop	50,304	50,403	50,634	51,633

Appendix D
Frequency Shift In RF Turned Circuit With The Simulator At Various Heights Above The Pavement

			Location Of Steel Plate		
Loop Type	**Sensor Location**	**Base Frequency**	**Frequency At 2 Feet**	**Frequency At 1 Foot**	**Frequency On PVT.**
Skew + Header 2-4-2	Over End Wire	84,912	85,807	85,796	85,793
	Center Of Loop	85,733	85,708	85,710	85,839
	Center Of Loop	85,691	85,658	85,659	85,747
	Over Side Wire	85,673	85,696	85,706	85,822
	Center 4-Wires	85,705	85,737	85,814	85,252
	Over Side Wire	85,730	85,729	85,729	85,806
	Over Side Wire	85,670	85,658	85,660	85,757
	Center Of Loop	85,680	85,674	85,678	85,751
	Over End Wires	85,701	85,673	85,669	85,673
	Over End Wires	85,685	85,693	85,693	85,693
	Center Of Loop	85,652	85,680	85,752	85,158
Diamond 6 x 6	Center Of Loop	71,520	71,602	72,016	74,648
Octagonal 6 x 6	Center Of Loop	61,698	61,821	62,092	62,915
6 x 6 Skew 2/3	Center Of Loop	47,705	47,803	47,951	48,248
6 x 6 Skew 1/1	Center Of Loop	46,167	46,223	46,355	46,736
Chevron	Center Of Loop	50,304	50,403	50,634	51,633

Appendix E
Analysis Of Field Strength Vs. Detection Of A MOPED
6 Foot x 6 Foot Triangular Loop With
Four Turns Of Number 14 THHN Wire

Correlation Analysis

The correlation analysis indicates the detection total field strength is negatively correlated to detector frequency setting (r=-0.214) and the path of the vehicle (r=-0.176). A weak negative correlation exists with the detector sensitivity setting (r=-0.099).

Multiple Regression Analysis

The multiple regression analysis of the total magnetic field strength at detection of the MOPED with independent variables detector sensitivity setting, detector frequency setting, and vehicle path revealed no significant degree of interaction among these variables. The Beta coefficients (coefficients of the regression independent variables) were found not to be different from zero. This means that the average observation is the best estimate of the effect, if there is an effect. The total regression model was also found to be insignificant ($R^2=0.09$ and p for the regression model is 0.4853).

Plots Of The Independent Variables With Detection Total Field Strength

Plots of detector frequency settings and total field strength at detection of the MOPED; detector frequency setting with total field strength at detection of the MOPED; and vehicle path with total field strength at detection of the MOPED reveal essentially a random pattern of total field strength at detection of the MOPED in each case.

Finding

There is apparently no correlation between the detection total magnetic field strength and any of the independent variables studies. This finding is limited to the MOPED detection on the 6' x 6' triangular loop with four turns of number 14 THHN wire. However, similar trends have been identified with the other design vehicles and other loop shapes.

Appendix F
NOTES ON BLADE LIFE
MAY 30, 1987
JOE BUDYKA, BLAZER DIAMOND SAW CORPORATION
TIME 10:09 am

Based on the work in Washington, D.C., it appears that a life of 30,000 to 35,000 inch-feet per diamond blade should be expected in asphaltic concrete when wet cutting. Dry cutting would be somewhat less, Joe estimated about one-third. I select a 20,000 to 25,000 inch-feet life to estimate the relative cast when dry cutting.

In Portland Cement Concrete, it will be in the general range of 10,000 to 15,000 inch-feet. Dry cutting in P.C. concrete should not be allowed. This was confirmed in our controlled field testing. The blade bound up and the cutting elements were disloged from the metal matrix.

Said (DTM Program) reported that the contractor working with him on the weight-in-motion site installations often uses up a graphite blade in 6 to 8 loop installations (about 48 feet of 1.5 inch cutting per loop). This expands to 432 to 576 inch-feet per blade as the life in asphaltic concrete.I choose to use a life of 500 inch-feet per graphite blade in AC. The use of graphite blades was discontined by the DTM weigh-in-motion installation crews due to the danger of fragments from the blade following dissentagration of the blade.

DEFINITION: An inch-foot is the base measure of blade life capability. One inch-foot is a one foot long cut one inch deep. The top cut would be some fourteen inches longer due to the necessity to cut to the center of the blade. Footage is measured only in that portion that is the full desired cut depth.

Appendix G

BENEFIT COST RATIO OF DIAMOND SAW BLADES VS. GRAPHITE CONCRETE SAW BLADES

ASSUMPTIONS

1. GRAPHITE BLADE LIFE
   - AC - 500 inch-feet
   - PC - Graphite blades should not be used in Portland Cement Concrete

2. DIAMOND BLADE LIFE
   - AC - 30,000 TO 35,000 inch-feet Wet Cutting
   - AC - 20,000 TO 25,000 inch-feet Dry Cutting
   - PC - 10,000 TO 15,000 inch-feet Wet Cutting

3. TIME TO REPLACE BLADE 5 minutes (time to stop cut to start cut)

4. CREW SIZE 3 persons at $10 per hour (i.e., $6.50 per hour personnel)

ASPHALTIC CONCRETE WET CUTTING BENEFIT/COST RATIO

Blade replacements for graphite blades per diamond blade 60 - 70
Cost of graphite blades $13
Cost of Diamond blades $550
Lower Bound Salary Savings = (60(5)/60)$30 = $150
Upper Bound Salary Savings = (70(5)/60)$30 = $175
Cost of Graphite Blades = 60($13) = $780 Lower bound
Cost of Graphite Blades = 70($13) = $910 Upper bound

B/C Ratio in A. C. = $930/$550 = 1.69 Lower bound
B/C Ratio in A. C. = $1,085/$550 = 1.97 Upper bound

ASPHALTIC CONCRETE DRY CUTTING

Blade replacements for graphite blades per diamond blade 40 - 50

Cost of graphite blade $13
Cost of Diamond blade $550
Lower Bound Salary Savings = (40(5)/60)$30 = $100
Upper Bound Salary Savings = (50(5)/60)$30 = $125
Cost of Graphite Blades = 40($13) = $520 Lower bound
Cost of Graphite Blades = 50($13) = $650 Upper bound

Appendix G (Continued)
BENEFIT COST RATIO OF DIAMOND SAW BLADES VS. GRAPHITE CONCRETE SAW BLADES

B/C Ratio in A. C. = \$620/\$550 = 1.18 Lower bound
B/C Ratio in A. C. = \$775/\$550 = 1.41 Upper bound

FINDING: The added labor cost of blade change out more than off sets the higher cost of the diamond blade. The savings in traffic control costs associated with a higher cutting speed have not been included in this analysis. Therefore, it is concluded that the diamond blade is the least costly on a life cycle cost comparison.

Appendix H
Specification For The Purchase Of A Circular Blade For High Speed Dry Cutting Asphaltic Concrete

1.0 Blade Size and Width

Blades purchased under this specification are to have a nominal diameter of fourteen 14 inches. Blades shall consist of a steel core and a minimum of 17 diamond/matrix cutting edges laser welded to the core. A minimum air gap of 0.3 inches between the cutting elements and 0.1 inches in the core shall be provided. The combined air gap shall be a minimum of one inch deep below the cutting element surface upon delivery. The blade width shall be as specified in the bid document. Normally the blade width is one-quarter inch.

2.0 Diamond Cutting Element Minimum Thickness

The diamond impregnated cutting surface elements shall be a minimum of 300 mils in thickness. This shall be measured from the surface of the cutting elements to the core below cutting elements. Measurements are to be made at each of the air gaps. The resulting measurements, measured to the nearest 1/100 inch, will be averaged. An average cutting element thickness of less than 300 mils (0.3 inches) will be rejected.

3.0 Diamond Cutting Element Quality

The diamond chips and binder matrix shall be of a type and density suitable for high speed dry cutting of asphaltic concrete. The asphaltic concrete is to be made of crushed limestone and sand in accordance with SDHPT Standard Method XX-XX-XX. High speed, for the purposes of this specification, is defined as a minimum dry cutting speed in asphaltic concrete of 15 feet per minute one inch deep at a nominal width of one-quarter inch using a 65 horsepower concrete saw. The depth shall be measured at each end and at each one foot interval between the ends of a nine foot test slot cut. This test is to be conducted using a 100 pound dad weight placed directly over the drive shaft of the blade. The resulting 10 depth measurements will be averaged and the variance determined. A minimum average depth of 1.0 inch and a variance of the depth measurements not exceeding 0.002 inches squared are required to meet this specification. No measurable wear or loss of any portion of the cutting elements is allowed.

A cutting rate below 15 inch-feet per minute, an average depth below 1.0 inch, a variance of slot depth exceeding 0.002 inches squared and/or a measurable wear or loss of the cutting elements will result in the designation of the blade as not conforming the requirements of this specification. The testing will be repeated one time to insure that no acceptable blade has been rejected due to test measurement error.

Appendix H (Continued)
Specification For The Purchase Of A Circular Blade For High Speed Dry Cutting Asphaltic Concrete

4.0 Expected Blade Life

Blades purchased under this specification are required to have a useful cutting life in dry cutting asphaltic concrete in excess of 20,000 inch-feet of one-quarter inch wide slot (nominal 30,000 inch-feet wet cut). An inch-foot is defined as a one inch deep slot one foot long. Based on the agency's experience, blades that fail to have a cutting life in excess of 20,000 inch-feet will result in that Company's blades being disqualified in future purchases until the company can produce evidence that the 20,000 inch-feet life can be achieved with their blade.

5.0 Restriction on Future Biding

Any manufactures blade(s) that fail to pass the basic quality control tests or the expected life guideline described above will not be eligible to submit a bid on furnishing diamond saw blades for a period of one calendar year beginning the day the defective blade(s) are identified by the SDHPT. Following one calendar year the manufacturer may submit a blade or blades to be tested, however, the quality and quantity of diamond chips and/or the binder matrix in these blades must be demonstrated to be different from those submitted previously and rejected. A minimum of three test blades must be submitted for complete field testing at the expense of the supplier following an initial failure to conform to this specification.

6.0 Blade Identification

Each blade shall be clearly identified by a unique number embossed directly on the core. The number shall be placed near the center of the core well below the normal maximum slot cut depth of two and one-half inches.

The label placed on the blade and on the box in which the blade is shipped shall clearly state that the blade is suitable for wet or dry cutting in asphaltic concrete surfaces. Documentation paperwork accompanying the blade(s) on delivery shall indicate the quality and number of diamond chips used in the manufacture of the blades to meet this specification. An accepted industry quality grading system shall be used in meeting this requirement.

Appendix I
Bicycle Detection By A Deep Buried Loop
Loop In PVC Conduit At 18.5 Inches Below The Surface
Number Of Turns Of Wire In Loop As Noted

PATH CODE	6X6 SURFACE LOOP		MICROSENSE DETECTOR		SARASOTA DETECTOR		DETECTOR SETTINGS		TURNS OF WIRE IN LOOP
	ON	OFF	ON	OFF	ON	OFF	FREQ	SENS	
F	—	—	—	—	—	—	LOW	MED	2
F	—	—	—	—	—	—	LOW	HIGH	2
C	11	6	—	—	—	—	LOW	MED	2
C	10	6	8	4	8.5	5	LOW	HIGH	2
C	11	6	11	5	8.5	6	LOW	HIGH	2
F	—	—	—	—	—	—	LOW	MED	3
F	—	—	—	—	—	—	LOW	HIGH	3
C			—	—	—	—	LOW	MED	3
C			9	3	8	7	LOW	HIGH	3
C			11	5	9	6	LOW	HIGH	3
F			—	—	—	—	LOW	MED	4
F			—	—	—	—	LOW	HIGH	4
C			—	—	—	—	LOW	MED	4
C			8	4	8	9	LOW	HIGH	4
C			10	5	10	6	LOW	HIGH	4
F			—	—	—	—	LOW	MED	5
F			—	—	—	—	LOW	MED	5
C			—	—	—	—	LOW	MED	5
C			8.5	4	8.5	6	LOW	HIGH	5
C			10	6	7	5	LOW	HIGH	5

Note: No entry means no data were collected. A — entry means no detection in test. ON is the longitudinal line where the front axle was located at initiation of the detection. OFF is the line number of the rear axle when the bicycle call was dropped. A one foot by one foot grid was used. Path codes were A through M and line number codes ran from 1 to 55.

Findings:

1. There is no practical difference in bicycle detection by deep buried loops using the MICROSENSE and SARASOTA detectors.
2. At a depth of 18 1/2 inches, the bicycle detection by a 6' x 6' placed in a one-half inch PVC conduit is only slightly less efficient than a surface mounted 6' x 6' loop. The difference occurs at the medium sensitivity setting. The surface loop detected the bicycle on path C at a medium sensitivity setting while the deep buried loop did not.
3. The rectangular 6' x 6' loop did not detect the bicycle in the center portion of the loop mounted on the surface or at 13.5 and 18.5 inches below the pavement surface. This is regardless of the detector sensitivity setting. The obvious conclusion is a rectangular loop is a very poor shape for detecting smaller design vehicles.

Appendix I (Continued)
Large Car Detection Deep Buried Loop
Loop 18 1/1 Inches Below The Pavement Surface
Five Turns Of Wire In One-Half Inch PVC With No Filler

	Microsense		Sarasota		Detector Settings	
Path	On	Off	On	Off	Freq	Sens
D	3	13			Low	High
B	2	13			Low	High
D	4	13			Low	Med
C	4	12			Low	Med
D	6	11			Low	Low
C	6	12			Low	Low
D	6	11			Low	Low
C	6	11			Low	Low
B	6	11			Low	Low
D	4	12			Low	Med
C	5	12			Low	Med
B	5	12			Low	Med
D	3	13			Low	High
C	3	13			Low	High
B	3	13			Low	High
D	2.5	13			Low	High
D	4	12			Low	Med
D	6	11			Low	Low

On -	The line number of front bumper of the car when detector activated.
Off -	The number of the line of the rear bumper when the detection is dropped.
Path -	The letter code of the line followed by the right edge of car in traversing the detection area.

A one foot by one foot grid pattern was used. "D" is the outer edge of the loop on the right side. "J" is the outer edge of the loop on the left side. "C" is one foot outside the loop on the right side. "B" is two feet outside the loop on the right side.

Appendix I (Continued)
Motorcycle Detection By Deep Buried Loops
Loop Located 18 1/2 Inches Below The Pavement Surface
Five Turns Of Number 14 THHN Wire In One-Half Inch PVC
6 x 6 Loop

Path	Sarasota Detector On	 Off	Detector Settings Freq	 Sens
K	----	----	Low	High
J	8	5.5	Low	High
I	9	5	Low	High
H	8.5	3.5	Low	High
G	9	4.5	Low	High
F	9	3.5	Low	High
E	8.5	4	Low	High
D	9	4	Low	High
C	9	4.5	Low	High
B	8	7	Low	High
A	----	----	Low	High
K	----	----	Low	Med
J	----	----	Low	Med
I	Chattered		Low	Med
H	6.5	4.5	Low	Med
G	7	4.5	Low	Med
F	7	4	Low	Med
E	6.5	4.5	Low	Med
D	6.5	5	Low	Med
C	6.5	5.5	Low	Med
B	----	----	Low	Med
A	----	----	Low	Med
	Microsense Detector			
K	7	5	Low	High
J	9	3	Low	High
I	9.5	3	Low	High
H	10	2	Low	High
G	10	2	Low	High
F	9.5	3	Low	High
E	9.5	3	Low	High
D	9.5	3	Low	High
C	9	4	Low	High
B	8.5	5	Low	High
A	----	----	Low	High

---- Indicates measurement taken but not detection resulted.

Appendix I (Continued)
Motorcycle Detection By Deep Buried Loops
Loop Located 18 1/2 Inches Below The Pavement Surface
Five Turns Of Number 14 THHN Wire In One-Half Inch PVC
6 x 6 Loop

Path Code - The letter of the line followed by the motorcycle wheels. "D" and "J" are the edges of the loop. "A", "B", and "C" are three, two and one foot outside the edge of the respectively.

On - The number of the line where the front axle is located at the time of detector activation.

Off - Line number of rear axle position when call is dropped.

Finding:

The loop located 18 1/2 inches below the pavement surface detected the motorcycle successfully when five turns were used on medium and high sensitivity. The low frequency, low sensitivity settings were used. No detection resulted with the low sensitivity settings.

Appendix J
Contrast Of Deep Buried Loop Sensitivity To Three Design Vehicles

TEST VEHICLE	DETECTOR SETTINGS		DEPTH OF LOOP	% OF LOOP WIDTH DEAD - MICROSENSE	% OF LOOP WIDTH DEAD - SARASOTA
BICYCLE	HIGH	LOW	13.5"	100	100
	HIGH	MED	13.5"	33	100
	HIGH	HIGH	13.5"	0	83
	MED	LOW	13.5"	100	100
	MED	MED	13.5"	0	100
	MED	HIGH	13.5"	0	0
	LOW	LOW	13.5"	100	100
	LOW	MED	13.5"	0	100
	LOW	HIGH	13.5"	0	0
BICYCLE	HIGH	LOW	18.5"	0	100
	HIGH	MED	18.5"	0	100
	HIGH	HIGH	18.5"	50	100
	MED	LOW	18.5"	100	100
	MED	MED	18.5"	0	100
	MED	HIGH	18.5"	0	
	LOW	LOW	18.5"	100	
	LOW	MED	18.5"	0	
	LOW	HIGH	18.5"	50	
MOTOR-CYCLE	HIGH	LOW	18.5"		
	HIGH	MED	18.5"		
	HIGH	HIGH	18.5"		
	MED	LOW	18.5"		
	MED	MED	18.5"		
	MED	HIGH	18.5"		
	LOW	LOW	18.5"		100
	LOW	MED	18.5"		0
	LOW	HIGH	18.5"		0
STATION -WAGON	HIGH	LOW	18.5"		
	HIGH	MED	18.5"		
	HIGH	HIGH	18.5"		
	MED	LOW	18.5"		
	MED	MED	18.5"		
	MED	HIGH	18.5"		
	LOW	LOW	18.5"	0	0
	LOW	MED	18.5"	0	0
	LOW	HIGH	18.5"	0	0

Appendix K
SERVICE RECORD ON BITUPHENE AS A COVER FOR A TEMPORARY LOOP INSTALLATION

LOCATION: University Drive @ Avenue "A", College Station, Texas

DESCRIPTION: Surface loop 6' x 6' set under 6" wide Bituphene crack sealing cold laid material. Installed March 10, 1990. The pavement is a new A.C. Pavement, however similar adhesive properties were observed in test installations at the Riverside Campus on older P.C. pavements.

May 18, 1990 - Two Months in Service

Observation of the loop revealed that the loop wire had worked up through the Bituphene to the surface at several points around the loop. The wire appeared to be undamaged and the loop performed perfectly under normal operating conditions. However, the wire was exposed to further damage by traffic. The damage is concentrated in the longitudinal loop wire runs and at the corners.

Also, there is evidence of a vehicle skidding across the loop. There was no movement of the loop wire and no damage to the Bituphene. The skid marks just ran across the surface mounted loop. The skid mark is located in the center of the transverse wire runs.

July 6, 1990 - Four Months in Service

Observation of the surface loop revealed that wire previously exposed was now covered by the Bituphene. It had apparently been softed by the summer heat. The loop was connected to three different detector units and performed without a flaw. The surface has now been in place 4 months and subject to moderate to heavy traffic.

November 14, 1990 - Eight Months in Service

The loop wire was exposed on a section about one-half inch long on the down stream transverse edge of the loop in the wheel path. Also, a bolt was observed embedded in the Bituphene. This apparently did not effect the function of the loop. The loop would still function but the quality of service is questionable. Therefore, it appears that the functional life of the temporary loop placed on the surface using Bituphene crack sealing tape is 7 to 8 months under moderate to heavy traffic loads.

Appendix L
LOOP WIRE TEST LABORATORY NOTES

3M LOOP SEALANT

3/28/89 Placed 3M Loop Sealant in bending test mold. Skimmed over in about 30 minutes at room temperature (75 degrees F). It still was not set in the bottom of the mold after 4 days.

4/14/89 Placed wire in 1/4 inch slot and filled with 3M Sealant. Material does not flow into slot easily. Wire not fully encapsulated.

Pull-out test did not pull away from slot edges or stick to test paddle. About 200 pounds of load required to pull out paddle.

SEALEX

4/12/89 Mixed and placed Sealex in 32:1 ratio at 10:00 am. Track free in 20 to 25 minutes. Bar sample removed form the form at 4:30 pm the same day.

4/14/89 Mixed and placed Sealex in 1/4 inch slot with 14 gage wire. Sealex is very fluid and flows easily into the slot. The wires were completely encapsulated. The wire in the center appeared to float up. This may have been due to the sealing of the end of the slot to prevent sealant from running out (wire ends may have been pushed down). Test to be rerun to to be certain.

4/27/89 Retest of Sealex using 14 gage wire with heavy insulation. Wire was cut short of the ends of the test slot. Wire placed in slot and slot filled with Sealex. The wire did not float to the top as was suspected in first test. Wires stayed on the bottom of the slot and were fully encapsulated.

DOW 888

4/19/89 Placed Dow 888 for bending sample. No track time was about 20 minutes. The DOW 888 is easily placed.

5/1/89 DOW 888 pull test sample prepared. Material did not flow well into the 1/4 inch slot.

Appendix L (Continued)
LOOP WIRE TEST LABORATORY NOTES

DOW 890SL

4/28/89 Material still wet in bottom of mold. Unable to remove from the mold.

5/1/89 Removed bending test sample from mold. It still was not easily handled and tended to deform.

5/2/89 Place DOW 890SL in 1/4 inch slot with two 14 gage THHN wires. Material flows into slot freely. Wires completely covered.

DOW 888SL

4/24/89 Placed DOW 890SL in 1/2 x 1/2 x 6 inch bending sample mold. The material flows freely. No track time was observed to be about 30 minutes. On 4/28/89 material was still wet at the bottom and could not be removed from the form.

5/1/89 Bending sample removed from 1/2 x 1/2 x 6 inch mold. It tended to deform when handling.

5/2/89 Placed DOW 888SL in 1/4 inch slot with 2 14 gage THHN wires. The material flows freely and completely covers the wires.

PRECO

5/2/89 Placed PRECO into 1/4 inch slot with 2-14 gage THHN wires. The material flowed freely and completely covered the wire.

5/9/89 Placed PRECO in 1/2 x1/2x 6 inch mold. No track time was about 3 hours.

5/16/89 Removed sample from mold. It was still not completely cured.

5/16/89 Wire encapsulation test cuts made. Complete coverage of both the heavy insulated and normally insulated wire was observed.

GRIGGS

3/28/89 Placed Griggs Loop Sealant in 1/2 x 1/2 x 6 inch bending test mold. On 4/3/89 it still could not be removed from the mold. Also noted shrinkage away from the form sides not seen with other materials. The shrinkage may be excessive high.

6/19/89 Placed Griggs loop sealant into 1/4 inch slot with 2-14 gage THHN wires. Material flows freely and wire completed covered.

Placed Griggs loop sealant in 1/2 x 1/2 x 6 inch form.

6/22/89 Bending test formed bar still not cured in the bottom of the slot.

GE SILICONE 1200

3/22/89 Placed GE Silicone 1200 sealant in 1/2 x 1/2 x 6 inch mold. Material still not set after 60 hours in a 75 degree F environment.

5/16/89 Wire encapsulation test sample sawed into three parts. The silicone did flow down into the slot easily. Indeed, the wires were never touched by the silicone.

DOW SILICONE RUBBER SEALANT

3/22/89 Placed DOW Silicone Rubber Sealant in 1/2 x 1/2 x 6 inch mold. Material not completely cured on 3/27/89.

McLanburg-Duncan Rubber Sealant

3/22/89 Attempted to place McLanburg-Duncan Rubber Sealant into mold. It did go into the 1/2 x 1/2 x 6 inch mold easily. Did not set after five days. It does not appear that this material is a good candidate for further study.

McLanburg-Duncan Asphalt Cement

3/22/89 Attempted to place M-D Asphalt Cement into bending sample mold. It would not go in without being forced. This material is not a candidate for further study. It does not cure out to a rubbery state.

Appendix M
PROJECT 1163 - LOOP DETECTOR SEALANT SOLUBILITY TEST LAB NOTES

TEST PROCEDURE

A piece 1/2 x 1/2 x 2 inches was placed in a container of gasoline for a period of about one minute. The test piece was then removed and visually examined for indications of the effects of being submerged in gasoline.

3M SEALANT

4/27/89 No effect of gasoline was apparent.

DOW SILICONE

4/27/89 No effect of gasoline was visually apparent.

DOW 890SL

4/29/89 Surface appeared to wrinkle but when gasoline evaporated, the surface appeared to be normal. No loose of material was noted. The test did not appear to deteriorate the sample.

DOW 888

4/29/89 No effect of gasoline was visually apparent.

GE SILICONE 1200

4/29/89 No effect of gasoline was apparent.

DOW 888SL

4/29/89 Surface appeared to wrinkle due to exposure to gasoline. The sample returned normal after the gasoline evaporated.

SEALEX

4/29/89 Caused slight discoloration of gasoline. Did not apparently did not effect the sample.

Appendix N
Sealant Pull Out Test Data

Appendix O
Test Vehicles

Appendix P
Total Field Strength In Microvolts
6 x 6 Triangular Loop With Four Turns Of THHN #14 Wire

Detector Settings: Frequency LOW Sensitivity HIGH

		Loop		Loop			
Line	A	C	Edge E	G	I	Edge K	M
1	0	0	0	0.07	0.17	0.07	0.12
3	0	0	0.31	1.04	2.30	2.77	0.16
5	0	0.25	1.36	7.23	32.27	8.93	0.25
7	0	0.83	5.20	35.30	27.57	7.96	0.91
9	0.05	1.66	34.19	27.78	31.07	1.63	0.81
11	0	0.77	5.97	9.07	5.97	0.24	0.35
13	0	0.06	0.47	0.79	0.52	0.25	0

References

1. Traffic Detector Handbook, Implementation Package FHWA-IP-85-2, April 1985, U.S. Department of Transportation, Federal Highway Administration.

2. Scullin, Tom, Robert C. Briggs and Robert L. Lytton, "Using the Multidepth Deflectometer to Verify Backcalculation Procedures," Proceedings of the ASTM Conference on NDT (Non Destructive Testing) of Pavements and Backcalculation of Muduli, Baltimore, Maryland, May 1988.

3. Hamm, Robert, "Analysis of Inductance Loop Detector Sensitivities", Southwest Regional Transportation Center Summer Intern Report, Texas A&M University, College Station, TX., August 1991

4. Cronin, Brian, "Loop Detector Inductance Change Confidence Limits By Vehicle Type," Southwest Regional Transportation Center Summer Intern Report, Texas A&M University, College Station, TX, August 1992