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16. Abstract

Recent national developments will have a potentially significant impact on the traffic monitoring program conducted by Texas and the other States. The most important of these are the implementation of the Federal Highway Administration (FHWA) Traffic Monitoring (TM) Guide and the traffic data portions of the experimental designs prepared for use in the Long Term Pavement Performance (LTPP) monitoring element of the Strategic Highway Research Program (SHRP). The objectives of this study were: (1) To assess the potential impacts of the FHWA TM Guide and the SHRP Long Term Pavement Performance monitoring requirements upon the Department's traffic monitoring programs, (2) To develop alternatives for meeting these requirements, (3) To develop a plan for implementing the alternative or combination of alternatives selected by the Department, (4) To determine if changes are needed in the guidelines presented by the Traffic Monitoring Guide; if so, to submit recommendations for those changes to the FHWA.

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ANALYSIS OF TEXAS TRAFFIC MONITORING PROGRAM

by

Wiley D. Cunagin

and

Habib S. Nassiri

Research Report 1142-1F
Research Study 2-10-86-1142
Analysis of Texas Traffic Monitoring Program

Sponsored by

Texas State Department of Highways and Public Transportation

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas

January 1989

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
in²	square inches	645.2	millimetres squared	mm²
ft²	square feet	0.0929	metres squared	m²
yd²	square yards	0.836	metres squared	m²
mi²	square miles	2.59	kilometres squared	km²
ac	acres	0.395	hectares	ha

MASS (weight)

Symbol	When You Know	Multiply By	To Find	Symbol
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg

VOLUME

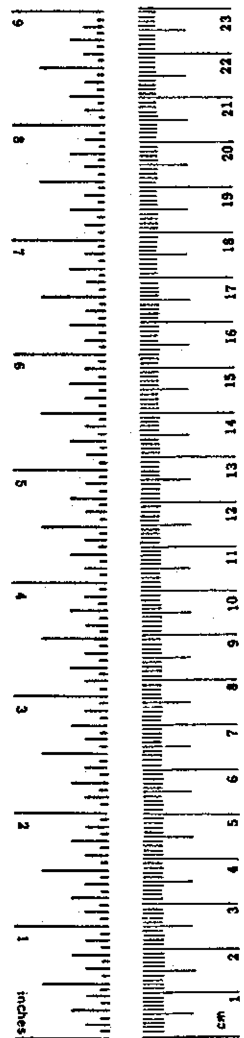
Symbol	When You Know	Multiply By	To Find	Symbol
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft³	cubic feet	0.0328	metres cubed	m³
yd³	cubic yards	0.0765	metres cubed	m³

NOTE: Volumes greater than 1000 L shall be shown in m³.

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* SI is the symbol for the International System of Measurements



APPROXIMATE CONVERSIONS TO SI UNITS

LENGTH

Symbol	When You Know	Multiply By	To Find	Symbol
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi

AREA

Symbol	When You Know	Multiply By	To Find	Symbol
mm²	millimetres squared	0.0016	square inches	in²
m²	metres squared	10.764	square feet	ft²
km²	kilometres squared	0.39	square miles	mi²
ha	hectores (10 000 m²)	2.53	acres	ac

MASS (weight)

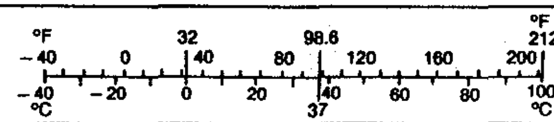
Symbol	When You Know	Multiply By	To Find	Symbol
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T

VOLUME

Symbol	When You Know	Multiply By	To Find	Symbol
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m³	metres cubed	35.315	cubic feet	ft³
m³	metres cubed	1.308	cubic yards	yd³

TEMPERATURE (exact)

Symbol	When You Know	Multiply By	To Find	Symbol
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

ABSTRACT

Recent national developments will have a potentially significant impact on the traffic monitoring program conducted by Texas and the other States. The most important of these are the implementation of the Federal Highway Administration (FHWA) Traffic Monitoring (TM) Guide and the traffic data portions of the experimental designs prepared for use in the Long Term Pavement Performance (LTPP) monitoring element of the Strategic Highway Research Program (SHRP). The objectives of this study were: (1) To assess the potential impacts of the FHWA TM Guide and the SHRP Long Term Pavement Performance monitoring requirements upon the Department's traffic monitoring programs, (2) To develop alternatives for meeting these requirements, (3) To develop a plan for implementing the alternative or combination of alternatives selected by the Department, (4) To determine if changes are needed in the guidelines presented by the Traffic Monitoring Guide; if so, to submit recommendations for those changes to the FHWA.

ACKNOWLEDGMENT

This research was sponsored by the Texas State Department of Highways and Public Transportation (TSDHPT). Dr. Wiley Cunagin was the Study Supervisor and Mr. Jon Underwood was the SDHPT Study Contact Representative.

IMPLEMENTATION

An interim report was submitted comparing the current Texas traffic monitoring programs with the recommended TM Guide programs. A technical memorandum was prepared describing alternatives for meeting both the TM Guide and SHRP requirements. A second technical memorandum was submitted which presented a plan for implementing the alternative or combination of alternatives selected by the Department. This study final report describes the methodology, analyses, results, conclusions, and recommendations of the study.

DISCLAIMER

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CHAPTER 1. INTRODUCTION

Recent national developments will have a potentially significant impact on the traffic monitoring program conducted by Texas and the other states. The most important of these are the Federal Highway Administration (FHWA) Traffic Monitoring (TM) Guide and the traffic data portions of the experimental designs prepared for use in the Long Term Pavement Performance (LTPP) monitoring element of the Strategic Highway Research Program (SHRP).

TM GUIDE

The TM Guide was issued by FHWA to provide the states with recommended minimum traffic data collection programs for meeting statistically acceptable levels of accuracy and precision. These programs include traffic volume, vehicle classification, and truck weight data collection activities. The TM Guide provides specific guidelines for devising and conducting these efforts. Federal regulations require that the Department take the TM Guide recommendations into account in carrying out its traffic monitoring responsibilities.

The FHWA TM Guide is one of the most significant transportation documents of this decade. By clearly defining the relationships among traffic counting, vehicle classification, and truck weighing in systematic terms, FHWA has provided the states with a tool which will enable them to improve both the assessment of current traffic conditions and the projection of future traffic on their highways. The states will also be able to design their traffic monitoring programs with a reasonable expectation of the quality of data which will be obtained from a given level of effort.

The questions of how many samples of traffic volume, vehicle classification, and truck weights should be made, how often they should be taken, and how to obtain these samples are addressed in the TM Guide by presenting procedures which are based upon the following concepts:

1. Statistical variability is directly related to the variability of the quantity being measured.

2. Variability may be reduced by careful stratification.

3. The sample size required to achieve a given level of confidence is reduced by decreasing the variability of the quantity being measured.

Based on a statistical analysis of data files acquired by the states in the biennial Truck Weight Study, FHWA concluded that during each year the following minimum (default) values for data collection programs should be established: one-third (1/3) of the Highway Performance Monitoring System (HPMS) sample sections should be counted for at least 48 continuous hours; 100 vehicle classification locations should be selected from the HPMS counting locations and monitored for 48 continuous hours, with a different 100 sites being monitored each of the following 2 years; 30 truck weighing sessions of 48 hours duration are needed each year in each state, with a different 30 sites being monitored each of the following 2 years. The result of these traffic monitoring efforts is that all HPMS sample locations, 300 vehicle classification sites, and 90 truck weighing locations will be monitored during a 3-year cycle. States which do not wish to use FHWA default values for the number and distribution of data collection stations are provided with statistical procedures for designing their own programs based upon their own data files.

The traffic volume counting and vehicle classification recommendations are not inconsistent with current practice in Texas in terms of the number of sites. However, the 48-hour duration suggested by FHWA will have serious impacts upon both programs. The traffic counting will be substantially more costly and the acquisition method now used (manual counts) for vehicle classification will be absolutely impractical.

The 50 States, by following FHWA minimum recommendations, would have a total of 1500 48-hour truck weighing sessions annually. This number is in contrast to the current level of 600 Truck Weight Study sessions annually, most of which are for less than 24 hours of weighing. The FHWA has recognized that a change of this magnitude in the truck weighing programs will require the use of weigh-in-motion (WIM) equipment to automate the process. However, although Texas has had a longstanding commitment to WIM research and usage, it was not, at the time the FHWA TM Guide was issued, in conformance with that document. This is due to the apparent requirement for 30 unique WIM locations each year. This condition has since been remedied.

SHRP LTPP

The LTPP monitoring element within SHRP is very dependent upon accurate estimates of equivalent single axle loads (ESALs) in order to develop relationships between pavement deterioration and the traffic loading and environmental conditions which cause it. The traffic monitoring components of this effort are the responsibility of the participating States.

Current plans are to have approximately 1500 SHRP Long Term Pavement Monitoring sites nationally. Approximately 150 (10%) of the total are projected for establishment in Texas. Traffic counting, vehicle classification, and truck weighing data will be needed (probably quarterly) for each of these locations. The resulting demands upon the Department's data collection personnel will therefore be at least equal to the TM Guide needs. Unfortunately, only limited funds were available from SHRP for this effort. It was important that the Department prepare to address this new requirement.

OBJECTIVES OF STUDY

The objectives of this study are:

1. To assess the potential impacts of FHWA TM Guide and the SHRP Long Term Pavement Performance Monitoring requirements upon the Department's traffic monitoring programs,

2. To develop alternatives for meeting these requirements,

3. To develop a plan for implementing the alternative or combination of alternatives selected by the Department, and

4. To determine if changes are needed in the guidelines presented by the Traffic Monitoring Guide; if so, to submit recommendations for those changes to the FHWA.

REPORT ORGANIZATION

Chapter 2 describes the work conducted and results obtained in comparing the FHWA Traffic Monitoring (TM) Guide with the current Texas traffic monitoring program. This effort included both statistical and engineering evaluations of the traffic counting, vehicle classification, and truck weighing activities. Texas data files for each of these types of information were statistically analyzed. Recommendations were prepared for modifications to the Texas program and to the TM Guide as needed.

Chapter 3 discusses the manner in which traffic data processing functions are conducted within the Department and provides recommendations about how they should be carried out in the future to meet the Department's needs.

Chapter 4 presents the work carried out to evaluate the needs of the SHRP traffic monitoring activities in Texas. Analyses were prepared to determine the degree to which activities to meet the SHRP requirements can be integrated into the regular Texas traffic monitoring programs.

Chapter 5 describes an implementation plan for the incorporation of the alternative traffic monitoring strategy or combination of alternative strategies identified and/or developed in this study and selected by the Department. The plan includes scheduling, equipment, and computer software aspects. It also describes a Traffic Information System (TIS) intended to bring together the various elements of traffic data collection and processing activities.

CHAPTER 2. COMPARISON OF TRAFFIC MONITORING GUIDE WITH THE TEXAS TRAFFIC MONITORING PROGRAM

The following sections present the results of the comparison of the TM Guide requirements with the current traffic monitoring program in the context of the traffic volume, vehicle classification, and truck weighing activities.

TRAFFIC VOLUME MONITORING

Section 3 of the TM Guide presents the FHWA recommendations for traffic volume counting, including both continuous (ATR) and temporary activities. The following paragraphs discuss the Department's ATR program in the context of the TM Guide stipulations, followed by a similar section for the temporary traffic counting program.

Continuous Count Element

The TM Guide asserts "that the development of seasonal factors to expand short-term counts to annual average daily traffic (AADT) is the most important objective of the continuous ATR program and the one that should guide the establishment of sample size." The following steps are identified in the TM Guide for developing the ATR element:

1. Conduct seasonality analysis of existing continuous ATR data

2. Develop seasonality procedures based on functional class

3. Establish seasonal pattern groups

4. Determine appropriate number of continuous ATR locations.

5. Modify existing continuous ATR locations

6. Compute monthly factors

7. Develop/acquire hardware and software for data management and analyses

These steps were carried out in this study and are discussed in the following paragraphs.

Seasonality Analysis of Existing Continuous ATR Data

Current Texas ATR procedures include the development of seasonal (i.e., monthly) adjustment factors for expanding short-term counts to produce AADT values. As indicated in the TM Guide, a substantial FHWA-mandated effort was carried out in the states during the mid-1970's to develop procedures for identifying seasonal patterns in the monthly ADT values. This was done so that ATR's with similar patterns could be grouped to produce reasonably stable monthly ADT factors that could be applied to short-term counts. In meeting this FHWA requirement, SDHPT carried out the prescribed analyses and developed the following seven groups of ATR locations.

1. Large Urban
2. North Zone - Rural
3. Midstate Group - Rural
4. Southern Group - Rural
5. Recreational (Seasonal)
6. Recreational (Intercity)
7. Rio Grande Valley - Urban

These ATR groups were not based on functional classification, as required in the TM Guide. The TM Guide recommends the following ATR groups as a minimum:

RECOMMENDED GROUP	HPMS FUNCTIONAL CLASS
1. Interstate Rural (I/R)	1
2. Other Rural (O/R)	2, 6, 7, 8
3. Interstate Urban (I/U)	11
4. Other Urban (O/U)	12, 14, 16, 17
5. Recreational (REC)	ANY

The TM Guide also indicates that between five and eight locations are needed for each of the ATR groups. Table 1 shows the general correspondence between the distribution of current Texas ATR groups, further subdivided according to functional class.

Table 1. Distribution of Texas ATR Sites by Texas Groups and Functional Class

TEXAS ATR GROUP	TOTAL	I/R	O/R	I/U	O/U
1. Large Urban	39	-	-	26	13
2. North Zone - Rural	13	1	11	1	-
3. Midstate Group - Rural	70	11	53	5	1
4. Southern Group - Rural	13	4	9	-	-
5. Recreational (Seasonal)	1	-	1	-	-
6. Recreational (Intercity)	5	5	-	-	-
7. Rio Grande Valley - Urban	8	-	4	-	4
TOTAL	149	21	78	32	18

Clearly the current Texas ATR program far exceeds the range of five to eight ATR locations per functional class category recommended in the TM Guide. It was not obvious, however, whether the ATR sites were adequately distributed within each ATR class according to volume group. This was investigated by determining the number of HPMS sections, vehicle miles of travel, expanded system mileage, and number of ATR sites by area type, functional classification, and HPMS volume group as indicated in Exhibit 4-2-1 of the TM Guide. The results are shown in Table 2 for Rural highways and Table 3 for Urban highways.

The following abbreviations are used in Table 2 and 3.

INT - Interstate
OPA - Other principal arterial
MA - Major arterial
Data Type:
- A - Number of HPMS sections
- B - DVMT (expanded) in thousands
- C - Mileage (expanded)
- D - Number of ATR sites

Seasonality Procedures Based on Functional Class

The cluster analysis described in the TM Guide was carried out to assess the degree of seasonal (monthly) variation existing in Texas as detected from the existing ATR program and to examine the validity of the current grouping procedure. This analysis consisted of an evaluation of the monthly variation of traffic volume at the existing ATR locations, together with a procedure to group the locations into common patterns of variation.

The first step in the analysis was to compute the monthly factor (i.e., the ratio of the AADT to the monthly average daily traffic, MADT) at each Texas ATR location in each of the past 10 years for which complete data were available. These were calculated according to the following equation:

$$MF_{ijk} = \frac{AADT_{ik}}{MADT_{ijk}}$$

where MF_{ijk} is the monthly factor for ATR site i for month j and year k
$AADT_{ik}$ is the nondirectional Annual Average Daily Traffic for ATR site i and year k
$MADT_{ijk}$ is the nondirectional Monthly Average Daily Traffic for ATR site i and month j and year k

MADT factors were then computed for each of the seven groups currently in use by the Department. The following equation was used for this purpose:

$$MF_{jkl} = \frac{MF_{ijk}}{N_{kl}}$$

where MF_{jkl} is the monthly factor for ATR group l for month j and year k
MF_{ijk} is the monthly factor for ATR site i and year k
N_{kl} is the number of ATR sites in group l for year k

The same calculations were carried out for the five default functional classification groups recommended in the TM Guide.

Table 2. Distribution of HPMS Samples, Vehicle-Miles of Travel, Mileage, and ATR Sites by Functional Classification and HPMS Volume Group for Rural Highways.

HPMS VOLUME GROUP	TYPE	INT	OPA	MA	MAJOR COLLECTOR	MINOR COLLECTOR
1	A	89	270	107	135	136
	B	6511.6	12337.9	5536.2	17803.4	4582.0
	C	1055.4	4834.4	4433.3	31422.0	16968.1
	D	4	14	5	7	1
2	A	54	127	43	22	12
	B	11249.1	14863.4	6614.7	7966.7	681.0
	C	794.7	2276.2	1925.2	2309.1	520.1
	D	4	5	-	2	1
3	A	26	40	24	20	5
	B	7741.3	6475.8	3585.4	4829.4	145.1
	C	325.2	521.6	504.0	761.7	69.3
	D	-	2	4	2	-
4	A	4	13	7	9	7
	B	1394.9	3368.5	962.2	2892.5	209.6
	C	40.2	192.8	63.2	184.7	60.5
	D	1	2	-	1	-
5	A	5	8	1	3	1
	B	820.9	1479.0	104.1	403.5	22.2
	C	17.8	57.7	4.9	18.3	4.0
	D	1	1	-	-	-
6	A	2	6	1	1	-
	B	326.2	1072.6	20.8	41.8	-
	C	5.9	30.0	0.59	1.3	-
	D	-	-	-	-	-
7	A	2	-	-	-	-
	B	998.7	-	-	-	-
	C	14.9	-	-	-	-
	D	-	-	-	-	-
8	A	-	1	-	1	-
	B	-	416.4	-	31.8	-
	C	-	7.0	-	0.58	-
	D	-	-	-	-	-

Table 2 (continued). Distribution of HPMS Samples, Vehicle-Miles of Travel, Mileage, and ATR Sites by Functional classification and HPMS Volume Group for Rural Highways.

13	A	-	1	-	-	-
	B	-	196.8	-	-	-
	C	-	1.6	-	-	-
	D	-	-	-	-	-

LEGEND

A = Number of HPMS Section
B = DVMT (Expanded) in Thousands
C = Mileage (Expanded)
D = Fixed Existing Sites

Table 3. Distribution of HPMS Samples, Vehicle-Miles of Travel, Mileage, and ATR Sites by Functional Classification and HPMS Volume Group for Rural Highways.

HPMS VOLUME GROUP	TYPE	INT	OFW	OPA	MINOR ARTERIAL	COLLECTOR
1	A	31	67	106	52	6
	B	1672.1	3487.8	926.3	708.9	32.8
	C	113.5	247.7	267.8	480.9	89.7
	D	1	-	-	1	-
2	A	57	65	123	50	3
	B	8479.0	7019.3	3446.1	1474.5	26.50
	C	247.1	210.5	533.8	389.0	16.7
	D	8	1	1	-	-
3	A	28	24	150	54	7
	B	9236.2	5583.3	5535.3	4280.7	157.8
	C	170.8	97.6	572.3	602.4	41.1
	D	5	-	-	1	-
4	A	28	18	136	22	2
	B	13436.5	4197.7	6707.1	1545.9	54.5
	C	165.4	57.6	500.7	126.6	6.2
	D	2	1	2	1	-
5	A	17	12	92	19	6
	B	7505.4	3467.7	6154.5	1130.0	75.0
	C	78.3	31.0	340.6	65.2	5.6
	D	1	-	-	-	-
6	A	17	9	62	6	1
	B	7236.2	3454.3	5879.4	501.5	16.3
	C	59.7	29.3	255.0	23.0	1.0
	D	3	1	-	-	-
7	A	14	3	60	4	-
	B	6319.7	3590.5	6244.2	110.1	-
	C	40.7	21.6	208.7	4.1	-
	D	-	1	-	-	-
8	A	8	1	14	3	-
	B	5119.9	156.4	2183.8	148.2	-
	C	29.6	0.85	51.8	4.2	-
	D	-	-	-	-	-

Table 3 (continued). Distribution of HPMS Samples, Vehicle-Miles of Travel, Mileage, and ATR Sites by Functional Classification and HPMS Volume Group for Rural Highways.

9	A	6	-	6	2	-
	B	2636.1	-	685.6	358.7	-
	C	15.5	-	13.9	0.78	-
	D	-	-	-	-	-
10	A	-	-	3	-	-
	B	-	-	493.1	-	-
	C	-	-	8.1	-	-
	D	-	-	-	-	-
11	A	-	-	4	-	-
	B	-	-	630.3	-	-
	C	-	-	8.0	-	-
	D	-	-	-	-	-
13	A	-	-	3	-	-
	B	-	-	309.5	-	-
	C	-	-	1.9	-	-
	D	-	-	1	-	-

LEGEND

A = Number of HPMS Section
B = DVMT (Expanded) in Thousands
C = Mileage (Expanded)
D = Fixed Existing Sites

The variation in the monthly factors for the ATR locations among the current Texas groups and the groups recommended by the TM Guide were compared. The basis for comparison was the coefficient of variation that resulted for the monthly factors in each group for each month. The coefficient of variation is the ratio of the percent standard deviation of the monthly factors to their means. Table 4 shows the results for the current Texas groups. Table 5 shows the results for the FHWA minimum groups.

Seasonal Pattern Groups

Examination of Tables 4 and 5 shows that the groups based on functional classification produce results that are as good as (but not better than) those obtained using the current Texas procedure. However, since the definition of seasonal patterns based on functional classification provides a consistent national framework for comparisons between States and also provides a simple procedure for allocating coverage counts to the factor groups for estimating AADT, it was recommended that the Department adopt this approach.

Determination of Appropriate Number of Continuous ATR Locations

The determination of the appropriate number of continuous ATR locations was based on the reliability calculations specified in the TM Guide. That is, the confidence intervals were determined from the following formula:

$$B = X \pm T_{1-d/2,n-1} \frac{S}{\sqrt{n}}$$

where B = upper and lower boundaries of the confidence interval for the mean monthly factor

X = mean monthly factor for the group

T = value of Student's t distribution with 1-d/2 level of confidence and n-1 degrees of freedom

n = number of ATR sites in the group

d = significance level

S = standard deviation of the factors

The precision interval was calculated from the following equation:

$$D = T_{1-d/2,n-1} \frac{S}{\sqrt{n}}$$

where D = absolute precision interval
S = standard deviation of the factors

Table 4. Statistical Analysis of Monthly Factors Using Current Texas Groupings

Texas yr = 86 SDHPT w/o outliers

SAS 10:05 FRIDAY, DECEMBER 9, 1988 1

VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE	C.V.
GROUP=LARGE URBAN AREAS									
F1	40	1.03948750	0.05158386	0.89765000	1.17706000	0.00815612	41.57950000	0.00266089	4.962
F2	40	1.12546175	0.06911984	0.93620000	1.24601000	0.01092881	45.01847000	0.00477755	6.141
F3	40	0.96826875	0.04025247	0.86391000	1.06356000	0.00636447	38.73075000	0.00162026	4.157
F4	40	0.98976475	0.03743733	0.85726000	1.06421000	0.00591936	39.59059000	0.00140155	3.782
F5	40	0.96338450	0.02843901	0.84895000	1.01667000	0.00449660	38.53538000	0.00080878	2.952
F6	40	1.02272775	0.19311933	0.88524000	2.18682000	0.03053485	40.90911000	0.03729508	18.883
F7	40	0.98457750	0.23243056	0.78704000	2.37643000	0.03675050	39.38310000	0.05402396	23.607
F8	40	0.95742000	0.04558609	0.84284000	1.10998000	0.00720779	38.29680000	0.00207809	4.761
F9	40	1.01913175	0.03479492	0.90115000	1.11996000	0.00550156	40.76527000	0.00121069	3.414
F10	40	0.97318000	0.03606993	0.86810000	1.09222000	0.00570316	38.92720000	0.00130104	3.706
F11	40	1.04516425	0.04789826	0.92423000	1.22049000	0.00757338	41.80657000	0.00229424	4.583
F12	40	0.99762550	0.05053061	0.90576000	1.18661000	0.00798959	39.90502000	0.00255334	5.065
GROUP=NORTH ZONE									
F1	10	1.09102000	0.08602299	0.95366000	1.26743000	0.02720286	10.91020000	0.00739996	7.885
F2	10	1.31814900	0.13282901	1.15861000	1.61774000	0.04200422	13.18149000	0.01764355	10.077
F3	10	0.99081800	0.03665417	0.94115000	1.06556000	0.01159107	9.90818000	0.00134353	3.699
F4	10	1.04568200	0.06195673	0.95113000	1.14610000	0.01959244	10.45682000	0.00383864	5.925
F5	10	0.95869800	0.02677171	0.91216000	1.00446000	0.00846596	9.58698000	0.00071672	2.793
F6	10	0.93083900	0.07235914	0.80608000	1.04461000	0.02288197	9.30839000	0.00523585	7.774
F7	10	0.89315500	0.06863014	0.81694000	1.00769000	0.02170275	8.93155000	0.00471010	7.684
F8	10	0.88315400	0.07295666	0.78968000	0.99024000	0.02307092	8.83154000	0.00532267	8.261
F9	10	1.01241300	0.03207580	0.95807000	1.06310000	0.01014326	10.12413000	0.00102886	3.168
F10	10	1.00052700	0.04513032	0.92992000	1.08282000	0.01427146	10.00527000	0.00203675	4.511
F11	10	1.02843200	0.04664454	0.96485000	1.10287000	0.01475030	10.28432000	0.00217571	4.536
F12	10	1.01257300	0.05462733	0.95346000	1.12878000	0.01727468	10.12573000	0.00298415	5.395
GROUP=SOUTH ZONE									
F1	12	1.09915333	0.09917281	0.90513000	1.26367000	0.02862872	13.18984000	0.00983525	9.023
F2	12	1.19248917	0.07531074	1.06607000	1.31086000	0.02174034	14.30987000	0.00567171	6.315
F3	12	0.91836750	0.07686424	0.76763000	0.99778000	0.02218879	11.02041000	0.00590811	8.370
F4	12	1.05954083	0.04243609	0.99650000	1.15510000	0.01225024	12.71449000	0.00180082	4.005
F5	12	0.98840750	0.05070155	0.92063000	1.11440000	0.01463628	11.86089000	0.00257065	5.130
F6	12	0.97674167	0.06257767	0.88484000	1.11969000	0.01806462	11.72090000	0.00391596	6.407
F7	12	0.90331833	0.08379297	0.75439000	1.05586000	0.02418895	10.83982000	0.00702126	9.276
F8	12	0.90565917	0.06901794	0.78566000	1.01781000	0.01992376	10.86791000	0.00476348	7.621
F9	12	1.08080667	0.06096232	1.01855000	1.19752000	0.01759831	12.96968000	0.00371640	5.640
F10	12	1.03893833	0.06947880	0.95715000	1.16521000	0.02005680	12.46726000	0.00482730	6.687
F11	12	0.99762167	0.08916130	0.80062000	1.13411000	0.02573865	11.97146000	0.00794974	8.937
F12	12	0.98305083	0.10172314	0.80359000	1.17714000	0.02936494	11.79661000	0.01034760	10.348

Table 4 (continued). Statistical Analysis of Monthly Factors Using Current Texas Groupings

Texas yr = 86 SDHPT w/o outliers

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VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE	C.V.
GROUP=VALLEY URBAN									
F1	3	1.08082667	0.10071192	1.00185000	1.19424000	0.05814605	3.24248000	0.01014289	9.318
F2	3	1.08441667	0.04438696	1.04554000	1.13278000	0.02562682	3.25325000	0.00197020	4.093
F3	3	0.83470000	0.06618057	0.77134000	0.90338000	0.03820937	2.50410000	0.00437987	7.929
F4	3	1.04123667	0.04128651	1.00304000	1.08504000	0.02383678	3.12371000	0.00170458	3.965
F5	3	0.98335667	0.04453307	0.93272000	1.01643000	0.02571118	2.95007000	0.00198319	4.529
F6	3	1.00451333	0.10024499	0.92590000	1.11740000	0.05787647	3.01354000	0.01004906	9.979
F7	3	0.93778000	0.14845093	0.81146000	1.10129000	0.08570819	2.81334000	0.02203768	15.830
F8	3	0.92448667	0.11172539	0.81792000	1.04074000	0.06450468	2.77346000	0.01248256	12.085
F9	3	1.05703667	0.02686239	1.03848000	1.08784000	0.01550901	3.17111000	0.00072159	2.541
F10	3	1.03429667	0.05798121	0.96842000	1.07758000	0.03347547	3.10289000	0.00336182	5.606
F11	3	1.11831333	0.13050245	0.98284000	1.24320000	0.07534563	3.35494000	0.01703089	11.670
F12	3	1.04473000	0.13473819	0.91053000	1.18000000	0.07779113	3.13419000	0.01815438	12.897
GROUP=REMAINING AREAS									
F1	64	1.09367172	0.06210915	0.94502000	1.21849000	0.00776364	69.99499000	0.00385755	5.679
F2	64	1.20020156	0.07606226	1.01133000	1.36495000	0.00950778	76.81290000	0.00578547	6.337
F3	64	0.96007406	0.03278633	0.81788000	1.03761000	0.00409829	61.44474000	0.00107494	3.415
F4	64	1.02906562	0.04416664	0.94168000	1.12728000	0.00552083	65.86020000	0.00195069	4.292
F5	64	0.95774922	0.03275697	0.87979000	1.04953000	0.00409462	61.29595000	0.00107302	3.420
F6	64	0.96425797	0.03731901	0.88054000	1.04728000	0.00466488	61.71251000	0.00139271	3.870
F7	64	0.92259266	0.04395751	0.82440000	0.99594000	0.00549469	59.04593000	0.00193226	4.765
F8	64	0.92181531	0.04608232	0.81416000	0.99953000	0.00576029	58.99618000	0.00212358	4.999
F9	64	1.04368516	0.04561892	0.92359000	1.17844000	0.00570236	66.79585000	0.00208109	4.371
F10	64	0.99772422	0.03494274	0.92373000	1.08141000	0.00436784	63.85435000	0.00122100	3.502
F11	64	1.00142594	0.05224823	0.86504000	1.15225000	0.00653103	64.09126000	0.00272988	5.217
F12	64	0.99594141	0.05270858	0.84772000	1.13277000	0.00658857	63.74025000	0.00277819	5.292

Table 5. Statistical Analysis of Monthly Factors Using FHWA Groupings

Texas yr = 86 FHWA w/o oultiers

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VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE	C.V.
GROUP=INTERSTATE RURAL									
F1	15	1.10638400	0.07371870	0.94987000	1.20397000	0.01903409	16.59576000	0.00543445	6.663
F2	15	1.21471800	0.09475901	1.02802000	1.34087000	0.02446667	18.22077000	0.00897927	7.801
F3	15	0.97125667	0.03189551	0.91976000	1.03761000	0.00823538	14.56885000	0.00101732	3.284
F4	15	1.07452733	0.03889964	1.00239000	1.12728000	0.01004384	16.11791000	0.00151318	3.620
F5	15	0.97960267	0.03744136	0.92246000	1.04953000	0.00966732	14.69404000	0.00140186	3.822
F6	15	0.95009467	0.03000269	0.89494000	0.99732000	0.00774666	14.25142000	0.00090016	3.158
F7	15	0.89580067	0.04460344	0.82440000	0.97653000	0.01151656	13.43701000	0.00198947	4.979
F8	15	0.88376333	0.04809788	0.81416000	0.98420000	0.01241882	13.25645000	0.00231341	5.442
F9	15	1.08190933	0.04167157	1.01833000	1.17844000	0.01075955	16.22864000	0.00173652	3.852
F10	15	1.02086867	0.03027422	0.98558000	1.08141000	0.00781677	15.31303000	0.00091653	2.966
F11	15	0.98578067	0.03378950	0.94799000	1.05512000	0.00872441	14.78671000	0.00114173	3.428
F12	15	0.95398200	0.04968993	0.84772000	1.03156000	0.01282989	14.30973000	0.00246909	5.209
GROUP=OTHER RURAL									
F1	68	1.08734206	0.05969539	0.94502000	1.21875000	0.00723913	73.93926000	0.00356354	5.490
F2	68	1.20083691	0.07365653	1.01133000	1.36495000	0.00893217	81.65691000	0.00542528	6.134
F3	68	0.95316250	0.04556324	0.76763000	1.02147000	0.00552535	64.81505000	0.00207601	4.780
F4	68	1.02281147	0.03940262	0.94168000	1.14012000	0.00477827	69.55118000	0.00155257	3.852
F5	68	0.95706456	0.03080780	0.87979000	1.03317000	0.00373599	65.08039000	0.00094912	3.219
F6	68	0.96776559	0.03942105	0.87047000	1.04728000	0.00478050	65.80606000	0.00155402	4.073
F7	68	0.92340838	0.04823018	0.76867000	1.00769000	0.00584877	62.79177000	0.00232615	5.223
F8	68	0.92427559	0.04858335	0.78968000	1.01781000	0.00589160	62.85074000	0.00236034	5.256
F9	68	1.03731176	0.04607561	0.92359000	1.19752000	0.00558749	70.53720000	0.00212296	4.442
F10	68	0.99864956	0.04210677	0.92373000	1.12846000	0.00510620	67.90817000	0.00177298	4.216
F11	68	1.01222735	0.05727316	0.86504000	1.15225000	0.00694539	68.83146000	0.00328022	5.658
F12	68	1.00415956	0.05170712	0.89865000	1.17714000	0.00627041	68.28285000	0.00267363	5.149
GROUP=INTERSTAE URBAN									
F1	26	1.05194308	0.04935846	0.92045000	1.17706000	0.00967999	27.35052000	0.00243626	4.692
F2	26	1.14258154	0.05896691	0.95453000	1.24601000	0.01156436	29.70712000	0.00347710	5.161
F3	26	0.97821500	0.03781695	0.86391000	1.06356000	0.00741651	25.43359000	0.00143012	3.866
F4	26	0.99353385	0.04108931	0.85726000	1.06421000	0.00805828	25.83188000	0.00168833	4.136
F5	26	0.95788308	0.03056808	0.84895000	0.98708000	0.00599489	24.90496000	0.00093441	3.191
F6	26	1.02429385	0.23861396	0.88524000	2.18682000	0.04679605	26.63164000	0.05693662	23.295
F7	26	0.98493846	0.28761476	0.78704000	2.37643000	0.05640590	25.60840000	0.08272225	29.201
F8	26	0.93982115	0.03337909	0.84284000	1.01292000	0.00654618	24.43535000	0.00111416	3.552
F9	26	1.01503346	0.03471789	0.90115000	1.08532000	0.00680874	26.39087000	0.00120533	3.420
F10	26	0.97306808	0.04025342	0.86810000	1.09222000	0.00789434	25.29977000	0.00162034	4.137
F11	26	1.04957000	0.05319889	0.92423000	1.22049000	0.01043316	27.28882000	0.00283012	5.069
F12	26	1.00175577	0.05453630	0.90576000	1.18661000	0.01069545	26.04565000	0.00297421	5.444

Table 5 (continued). Statistical Analysis of Monthly Factors Using FHWA Groupings

Texas yr = 86 FHWA w/o outliers

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VARIABLE	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN	SUM	VARIANCE	C.V.
GROUP=OTHER URBAN									
F1	15	1.04088067	0.10611753	0.89765000	1.38423000	0.02739943	15.61321000	0.01126093	10.195
F2	15	1.10811467	0.09314125	0.93620000	1.31037000	0.02404897	16.62172000	0.00867529	8.405
F3	15	0.93515533	0.06819540	0.73017000	1.00187000	0.01760798	14.02733000	0.00465061	7.292
F4	15	0.98518200	0.03002832	0.93321000	1.05628000	0.00775328	14.77773000	0.00090170	3.048
F5	15	0.96839267	0.02882380	0.89547000	1.01667000	0.00744227	14.52589000	0.00083081	2.976
F6	15	1.00357400	0.07852715	0.77614000	1.12649000	0.02027562	15.05361000	0.00616651	7.825
F7	15	0.96325067	0.09579499	0.67406000	1.09388000	0.02473416	14.44876000	0.00917668	9.945
F8	15	0.97444667	0.07637450	0.75525000	1.10998000	0.01971981	14.61670000	0.00583306	7.838
F9	15	1.03629667	0.05000257	0.99025000	1.17005000	0.01291061	15.54445000	0.00250026	4.825
F10	15	0.99671867	0.09431702	0.93645000	1.32335000	0.02435255	14.95078000	0.00889570	9.463
F11	15	1.06382200	0.10972689	0.97852000	1.43958000	0.02833136	15.95733000	0.01203999	10.314
F12	15	1.02721533	0.15012084	0.91492000	1.54886000	0.03876103	15.40823000	0.02253627	14.614

Using the coefficient of variation (i.e., ratio of the standard deviation to the mean), the following equation is equivalent and applies to the monthly factors:

$$D = T_{1-d/2,n-1} \frac{C}{\sqrt{n}}$$

where D = precision interval as a proportion or percentage of the mean
C = coefficient of variation of the monthly factors

For example, the average coefficient of variation for Interstate Rural sites was 4.52% for 15 sites with complete data. Substituting these values into the equation given above, using a 95% confidence level, the precision interval is ± 2.3%, which is well within the prescribed tolerances given in the TM Guide.

Similar calculations were made for the five groups recommended by the TM Guide based on the assumption of 95% confidence. It was determined that the FHWA default level of 5 to 8 ATR sites per group was adequate for use in Texas for the HPMS and TM Guide programs.

Modification of Existing Continuous ATR Locations

Although it is suggested in the TM Guide that the number of ATR sites be reduced if a smaller number can produce the systematic results specified, the benefits derived from a larger sample are worth the expense of continued operation at the present level for the near future. This is due to the fact that many of the Department's uses for the data require accurate site-specific estimates that are not necessarily available from the traffic data activities mandated by either HPMS or the TM Guide. These should be relocated as needed to provide a basis for site-specific traffic estimates.

Computed Monthly Factors

The resulting monthly factors for the period between 1980 and 1987 were calculated. The most recent factors will be used in the new functional class-based office data processing procedures described in a later section.

Current procedures use analogous monthly factors for the defined groups of ATR locations. Monthly factors are derived for each group as the average of the monthly factors for all of the locations within the group. Tables of factors are used to perform a computerized expansion of short duration counts.

Development and Acquisition of Hardware and Software for Data Management and Analyses

The management and analysis functions for the ATR data are accomplished through a completely computerized process using high speed microcomputers and the Department's mainframe computer. In addition, the Department intends to integrate the battery of microcomputer-based computer traffic monitoring data processing programs under development by FHWA when they become available.

At that time, it is expected that a larger proportion of the data processing will be carried out on microcomputers. Equipment has already been purchased for this purpose.

It is recommended that the Department modify its current ATR system as appropriate, depending on the results of the statistical and engineering analyses described elsewhere in this report. Both the number and distribution of ATR sites can be revised without loss of statistical validity of data provided to FHWA. The computation of seasonal factors should be based on the new functional classification groups defined in the TM Guide. The appropriate number of continuous ATR locations is based on the TM Guide reliability levels, and the results of the analyses of existing ATR data are 5 to 8 in each group.

HPMS Traffic Volume Sample

The TM Guide recommends conducting short-term traffic volume counting for 48 continuous hours on each HPMS sample section once every 3 years. The SDHPT is now collecting traffic volume counts on every section once each year, at almost exactly the same time each year. It is not yet clear whether the TM Guide approach or the current SDHPT approach produces more statistically reliable results. The Texas practice of making three 24-hour counts per 3-year cycle provides more data on which to base growth factors. The TM Guide approach, however, allows a better estimate of the traffic volume in the year the count is made. It is not obvious that this value is a better estimator of the AADT and Vehicle-Miles of Travel (VMT).

In fact, the Texas practice of collecting three 24-hour traffic volumes at the same time each year actually provides a sample size of three days of information rather then one day. It is stated in paragraph 3 on page 3-3-2 of the TM Guide that the basis for the recommendation for 48-hour counts on a 3-year cycle is found in the final report for an FHWA-sponsored study entitled "Development of a Statewide Traffic Counting Program Based on the Highway Performance Monitoring System." The relevant discussion is found on page IV.20 of that document. These conclusions are based, in turn, on Exhibit 3-3-1 of the TM Guide (Figure 1) which is plotted by substituting typical values into Equation 2 of the report, as follows. The Exhibit is repeated as Figure 1:

$$SVOL_j^2 = \frac{SVOLD2}{nd} + SVOLS^2 * \left(1 + \frac{1}{ncc}\right) + SVOLA^2 * \left(1 + \frac{1}{nvc}\right)$$

where SVOLj = the standard deviation of the volume count at location j
SVOLD = the standard deviation of volume across days
SVOLS = the standard deviation of volume across seasons
SVOLA = the standard deviation of the average number of axles per vehicle per day
ncc = the number of counts locations used to calculate seasonal factors
nvc = the number of vehicle classification counts taken to calculate the axle correction factor
nd = the length of the count in days

The term nd in the above equation is the only factor in this accuracy expression that is dependent on the duration of the counting session. In fact, it can be reasonably argued that nd is the total number of days of data collection at the particular site during the three-year cycle. That is, while it may be at first thought that the Texas program compares to Point A (24-hour count on a 1-year cycle) in Figure 1, it actually corresponds to Point B (72-hour count on a 3-year cycle). In this context, the Texas procedure exceeds the precision recommendations of the TM Guide.

Current procedures for expanding the short-term counts to AADT are to apply the appropriate monthly adjustment factor for the group of ATR sites in the region of the State in which the HPMS sample section is located. It was recommended in the previous discussion that this activity be reassessed to determine the desirability of following the TM Guide recommendation to apply adjustment factors by functional classification. New factors will then be developed for each functional class within the previously described regions.

Estimation of Daily Vehicle Miles of Travel

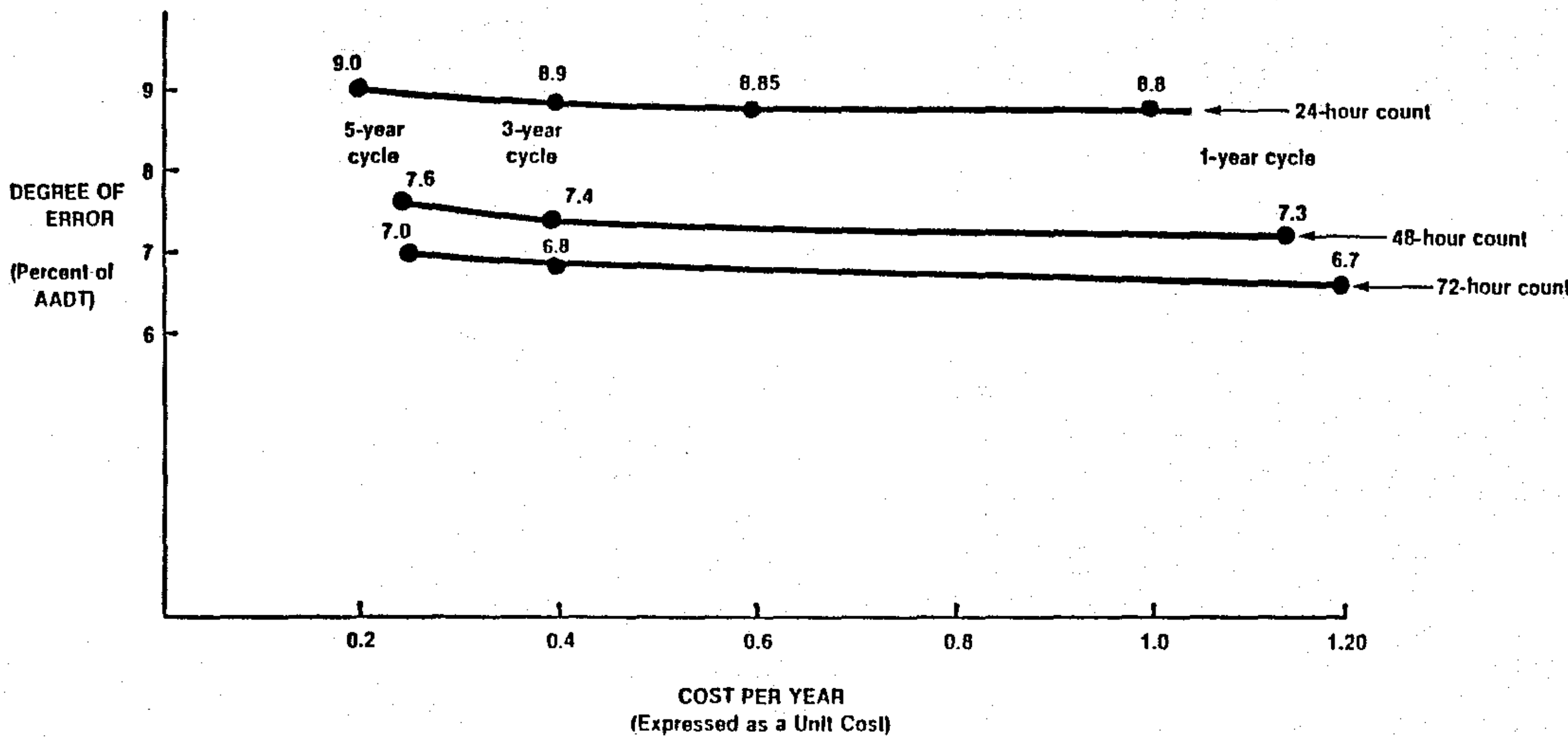
Estimates of Daily Vehicle Miles of Travel (DVMT) for each HPMS sample section are obtained by multiplying the sample section AADT by the section length. The sections are then summed to provide estimates for the appropriate HPMS stratification level.

INTERSTATE UNIVERSE PROCEDURES

Appendix K of the HPMS Field Manual specifies that each section of interstate highway between interchanges that is not an HPMS sample section must be monitored at least once every six years. Texas collects traffic volume data on every section of interstate highway once every year, providing a greater level of precision than is required.

VEHICLE CLASSIFICATION DATA COLLECTION

The current vehicle classification program in Texas consists of 995 unique data collection samples that are obtained over a 3-year cycle. The procedure consists of four consecutive six-hour shifts by a crew of four data collection technicians. The result is a continuous 24-hour data collection session at each of the sites. The distribution of the sites by highway functional class and HPMS volume group is shown in Table 6. In addition, each summer approximately 125 additional vehicle classification sessions are conducted at locations for which site-specific data are needed.



Assumes: SVOLD = .07 SGF = .01
SVOLS = .04 N_{gf} = 40
SVOLA = .03 Cost of 1-Day Count = 1
Ncc = 6 Cost of 2nd 24 hours = 0.15
Nvc = 12 Cost of additional 24 hours = 0.05

Figure 1. Relative Cost and Accuracy of Count Duration and Frequency.

Table 6. Distribution of Texas Vehicle Classification Sites by HPMS Volume Groups and Functional Class

HPMS VOLUME GROUP	I/R	O/R	I/U	O/U
1	12	703	2	47
2	13	132	6	8
3	7	34	4	3
4	2	9	3	
5	3	2		2
6		2		
7		1		
8				
TOTAL	37	883	15	60

The TM Guide recommends a minimum of 300 48-hour vehicle classification measurements over a 3-year cycle. In response to this recommendation, the Department has prepared procurement specifications for 100 automatic vehicle classification (AVC) devices. A major program is currently underway to install permanent axle sensors at 432 current and proposed vehicle classification sites plus approximately 100 SHRP LTPP monitoring sections. This equipment will be used to conduct 48-hour vehicle classification data collection at each site during each year, which will result in the following numbers of classification data collection sessions per year:

FISCAL YEAR	24-HOUR CLASSIFICATION SESSIONS
1989-90	432
1990-91	1194
1991-92	1274

The 432 24-hour vehicle classification sessions for FY 1989-90 are all manual efforts. The 1194 sessions for 1990-91 include 432 manual 24-hour sessions, 50 AVC sessions, and 712 quarterly sessions at the 89 SHRP sites. The 1991-92 sessions also include the data from 10 additional SHRP sites.

The resulting vehicle classification program clearly exceeds the TM Guide recommendation of 100 sites per year. A further issue considered is that the distribution of the AVC sites be structured to provide the required minimum number of locations in each volume group/functional classification cell in accordance with the analyses described in Chapter 4 of the TM Guide and summarized in the following paragraphs.

The first step in allocating the AVC locations among the HPMS functional class/volume group stratification cells was to identify the desired distribution of sites. This was accomplished by preparing summary tables of the HPMS statistics by area, functional class, and volume group, as indicated in Exhibit 4-2-1, Tables 7 for rural and Table 8 for urban, of the TM Guide repeated from Tables 2 and 3, respectively. The FHWA default value of 300 vehicle classification sites was also used. The desired distribution of vehicle classification sites by area, functional class, and volume group was then determined in accordance with Exhibit 4-2-2 of the TM Guide, as shown in Tables 9 through 17 for the individual functional classifications within each area type.

The distribution of existing vehicle classification sites indicated in Tables 9 through 17 indicates the need for either additional locations or a reallocation of sites for some volume groups within each functional classification and area type. The number of additional sites that are needed and the corresponding HPMS sample sites available are indicated in Columns 9 and 12, respectively.

Table 7. Distribution of HPMS Samples, Vehicle-Miles of Travel, Mileage, and ATR Sites by Functional Classification and HPMS Volume Group for Rural Highways.

HPMS VOLUME GROUP	TYPE	INT	OPA	MA	MAJOR COLLECTOR	MINOR COLLECTOR
1	A	89	270	107	135	136
	B	6511.6	12337.9	5536.2	17803.4	4582.0
	C	1055.4	4834.4	4433.3	31422.0	16968.1
	D	4	14	5	7	1
2	A	54	127	43	22	12
	B	11249.1	14863.4	6614.7	7966.7	681.0
	C	794.7	2276.2	1925.2	2309.1	520.1
	D	4	5	-	2	1
3	A	26	40	24	20	5
	B	7741.3	6475.8	3585.4	4829.4	145.1
	C	325.2	521.6	504.0	761.7	69.3
	D	-	2	4	2	-
4	A	4	13	7	9	7
	B	1394.9	3368.5	962.2	2892.5	209.6
	C	40.2	192.8	63.2	184.7	60.5
	D	1	2	-	1	-
5	A	5	8	1	3	1
	B	820.9	1479.0	104.1	403.5	22.2
	C	17.8	57.7	4.9	18.3	4.0
	D	1	1	-	-	-
6	A	2	6	1	1	-
	B	326.2	1072.6	20.8	41.8	-
	C	5.9	30.0	0.59	1.3	-
	D	-	-	-	-	-
7	A	2	-	-	-	-
	B	998.7	-	-	-	-
	C	14.9	-	-	-	-
	D	-	-	-	-	-
8	A	-	1	-	1	-
	B	-	416.4	-	31.8	-
	C	-	7.0	-	0.58	-
	D	-	-	-	-	-

Table 7(continued). Distribution of HPMS Samples, Vehicle-Miles of Travel, Mileage, and ATR Sites by Functional Classification and HPMS Volume Group for Rural Highways.

13	A	-	1	-	-	-
	B	-	196.8	-	-	-
	C	-	1.6	-	-	-
	D	-	-	-	-	-

LEGEND

A = Number of HPMS Section
B = DVMT (Expanded) in Thousands
C = Mileage (Expanded)
D = Fixed Existing Sites

Table 8. Distribution of HPMS Samples, Vehicle-Miles of Travel, Mileage, and ATR Sites by Functional Classification and HPMS Volume Group for Urban Highways.

HPMS VOLUME GROUP	TYPE	INT	OFW	OPA	MINOR ARTERIAL	COLLECTOR
1	A	31	67	106	52	6
	B	1672.1	3487.8	926.3	708.9	32.8
	C	113.5	247.7	267.8	480.9	89.7
	D	1	-	-	1	-
2	A	57	65	123	50	3
	B	8479.0	7019.3	3446.1	1474.5	26.50
	C	247.1	210.5	533.8	389.0	16.7
	D	8	1	1	-	-
3	A	28	24	150	54	7
	B	9236.2	5583.3	5535.3	4280.7	157.8
	C	170.8	97.6	572.3	602.4	41.1
	D	5	-	-	1	-
4	A	28	18	136	22	2
	B	13436.5	4197.7	6707.1	1545.9	54.5
	C	165.4	57.6	500.7	126.6	6.2
	D	2	1	2	1	-
5	A	17	12	92	19	6
	B	7505.4	3467.7	6154.5	1130.0	75.0
	C	78.3	31.0	340.6	65.2	5.6
	D	1	-	-	-	-
6	A	17	9	62	6	1
	B	7236.2	3454.3	5879.4	501.5	16.3
	C	59.7	29.3	255.0	23.0	1.0
	D	3	1	-	-	-
7	A	14	3	60	4	-
	B	6319.7	3590.5	6244.2	110.1	-
	C	40.7	21.6	208.7	4.1	-
	D	-	1	-	-	-
8	A	8	1	14	3	-
	B	5119.9	156.4	2183.8	148.2	-
	C	29.6	0.85	51.8	4.2	-
	D	-	-	-	-	-

Table 8(continued). Distribution of HPMS Samples, Vehicle-Miles of Travel, Mileage, and ATR Sites by Functional Classification and HPMS Volume Group for Urban Highways.

9	A	6	-	6	2	-
	B	2636.1	-	685.6	358.7	-
	C	15.5	-	13.9	0.78	-
	D	-	-	-	-	-
10	A	-	-	3	-	-
	B	-	-	493.1	-	-
	C	-	-	8.1	-	-
	D	-	-	-	-	-
11	A	-	-	4	-	-
	B	-	-	630.3	-	-
	C	-	-	8.0	-	-
	D	-	-	-	-	-
13	A	-	-	3	-	-
	B	-	-	309.5	-	-
	C	-	-	1.9	-	-
	D	-	-	1	-	-

LEGEND

A = Number of HPMS Section
B = DVMT (Expanded) in Thousands
C = Mileage (Expanded)
D = Fixed Existing Sites

Table 9. Analysis of Distribution of Vehicle Classification for Interstate Rural Highways.

IN RURAL

Volume Group	Desired Distribution DVMT (000)	Percent	Desired Sample Sections	Existing Sites HPMS Match	Close Match	No Match	Total	Remaining Usable Existing Sites	Sites Additional Sites Needed	Sample Frames HPMS Samples	Existing Sites	Samples Available
	1	2	3	4	5	6	7	8	9	10	11	12
1	6511.6	22	7	22	0	7	29	22	0	89	22	67
2	11249.1	39	13	16	0	3	19	16	0	54	16	38
3	7741.3	27	9	2	2	4	8	4	5	26	4	22
4	1394.9	5	2	4	0	0	4	4	0	4	4	0
5	820.9	3	1	3	0	0	3	3	0	5	3	2
6	326.2	1	0	0	0	0	0	0	0	2	0	2
7	998.7	3	1	0	0	0	0	0	1	2	0	2
TOTAL	29042.7	100	33	47	2	14	63	49	6	182	49	133

Table 10. Analysis of Distribution of Vehicle Classification for Rural Principal Arterial Highways.

U.S. RURAL (OPA)

	Desired Distribution			Existing Sites				Remaining Sites		Sample Frames		
Volume Group	DVMT (000)	Percent	Desired Sample Sections	HPMS Match	Close Match	No Match	Total	Usable Existing Sites	Additional Sites Needed	HPMS Samples	Existing Sites	Samples Available
	1	2	3	4	5	6	7	8	9	10	11	12
1	12337.9	31	14	66	1	22	89	67	0	270	67	203
2	14863.4	37	17	49	5	28	82	54	0	127	54	73
3	6475.8	16	7	13	1	8	22	14	0	40	14	26
4	3368.5	8	4	6	1	4	11	7	0	13	7	6
5	1479.0	4	2	3	0	0	3	3	0	8	3	5
6	1072.6	3	1	2	0	1	3	2	0	0	2	0
8	416.4	1	0	0	0	0	0	0	0	1	0	1
13	196.8	0	0	0	0	0	0	0	0	1	0	1
TOTAL	40210.4	100	45	139	8	63	210	147	0	460	147	315

Table 11. Analysis of Distribution of Vehicle Classification for Rural Minor Arterial Highways.

S.H. RURAL (MA)

	Desired Distribution			Existing Sites				Remaining	Sites	Sample Frames		
Volume Group	DVMT (000)	Percent	Desired Sample Sections	HPMS Match	Close Match	No Match	Total	Usable Existing Sites	Additional Sites Needed	HPMS Samples	Existing Sites	Samples Available
	1	2	3	4	5	6	7	8	9	10	11	12
1	5536.2	33	6	12	2	18	32	14	0	107	14	93
2	6614.7	39	8	16	2	15	33	18	0	43	18	25
3	3585.4	21	4	12	1	12	25	13	0	24	13	11
4	962.2	6	1	0	0	0	0	0	1	7	0	7
5	104.1	1	0	0	0	0	0	0	0	1	0	1
6	20.8	0	0	0	2	0	2	2	0	1	2	0
TOTAL	16823.4	100	19	40	7	45	92	47	1	183	47	137

Table 12. Analysis of Distribution of Vehicle Classification for Rural Major Collector Highways.

F.M. RURAL (MAJOR COLLECTOR)

	Desired Distribution			Existing Sites				Remaining Sites		Sample Frames		
Volume Group	DVMT (000)	Percent	Desired Sample Sections	HPMS Match	Close Match	No Match	Total	Usable Existing Sites	Additional Sites Needed	HPMS Samples	Existing Sites	Samples Available
	1	2	3	4	5	6	7	8	9	10	11	12
1	17803.4	52	20	67	0	10	77	67	0	135	67	68
2	7966.7	23	9	11	0	9	20	11	0	22	11	11
3	4829.4	14	5	12	0	1	13	12	0	20	12	8
4	2892.5	9	3	4	0	2	6	4	0	9	4	5
5	403.5	2	1	0	0	0	0	0	1	3	0	3
6	41.8	0	0	0	0	0	0	0	0	1	0	1
8	31.8	0	0	0	0	0	0	0	0	1	0	1
TOTAL	33969.1	100	38	94	0	22	116	94	1	191	94	97

Table 13. Analysis of Distribution of Vehicle Classification for Rural Minor Collector Highways.

CO. RD. RURAL(MINOR COLLECTOR)

	Desired Distribution			Existing Sites				Remaining	Sites	Sample Frames		
Volume Group	DVMT (000)	Percent	Desired Sample Sections	HPMS Match	Close Match	No Match	Total	Usable Existing Sites	Additional Sites Needed	HPMS Samples	Existing Sites	Samples Available
	1	2	3	4	5	6	7	8	9	10	11	12
1	4582.0	81	5	13	0	17	30	13	0	136	13	123
2	681.0	12	1	5	0	3	8	5	0	12	5	7
3	145.1	3	0	0	0	0	0	0	0	5	0	5
4	209.6	4	0	0	0	0	0	0	0	7	0	7
5	22.2	0	0	0	0	0	0	0	0	1	0	1
TOTAL	5639.9	100	6	18	0	20	38	18	0	161	18	143

Table 14. Analysis of Distribution of Vehicle Classification for Interstate Urban Highways.

IH URBAN

Volume Group	Desired Distribution: DVMT (000)	Desired Distribution: Percent	Desired Distribution: Desired Sample Sections	Existing Sites: HPMS Match	Existing Sites: Close Match	Existing Sites: No Match	Existing Sites: Total	Remaining Sites: Usable Existing Sites	Remaining Sites: Additional Sites Needed	Sample Frames: HPMS Samples	Sample Frames: Existing Sites	Sample Frames: Samples Available
	1	2	3	4	5	6	7	8	9	10	11	12
1	1672.1	3	2	1	0	0	1	1	1	31	1	30
2	8479.0	14	10	12	0	3	15	12	0	57	12	45
3	9236.2	15	10	8	0	2	10	8	2	28	8	20
4	13436.5	22	15	11	0	1	12	11	4	28	11	17
5	7505.4	12	8	0	0	0	0	0	8	17	0	17
6	7236.2	12	8	0	0	0	0	0	8	17	0	17
7	6319.7	10	7	0	0	0	0	0	7	14	0	14
8	5119.9	8	6	0	0	0	0	0	6	8	0	8
9	2636.1	4	3	0	0	0	0	0	3	6	0	6
TOTAL	61641.1	100	69	32	0	6	38	32	39	206	32	176

Table 15. Analysis of Distribution of Vehicle Classification for Other Freeways.

US URBAN (OFW)

Volume Group	Desired Distribution DVMT (000)	Percent	Desired Sample Sections	Existing Sites HPMS Match	Close Match	No Match	Total	Remaining Sites Usable Existing Sites	Additional Sites Needed	Sample Frames HPMS Samples	Existing Sites	Samples Available
	1	2	3	4	5	6	7	8	9	10	11	12
1	3487.8	11	4	1	0	0	1	1	3	67	1	66
2	7019.3	23	8	7	0	2	9	7	1	65	7	58
3	5583.3	18	6	1	0	1	2	1	5	24	1	23
4	4197.7	13	5	1	0	0	1	1	4	18	1	17
5	3467.7	11	4	0	0	0	0	0	4	12	0	12
6	3454.3	11	4	0	0	0	0	0	4	9	0	9
7	3590.5	12	4	0	0	0	0	0	4	3	0	3
8	156.4	1	0	0	0	0	0	0	0	1	0	1
TOTAL	30957.0	100	35	10	0	3	13	10	25	199	10	189

Table 16. Analysis of Distribution of Vehicle Classification for Other Principal Arterial Urban Highways.

S.H. URBAN (OPA)

Volume Group	Desired Distribution DVMT (000)	Percent	Desired Sample Sections	Existing Sites HPMS Match	Close Match	No Match	Total	Remaining Usable Existing Sites	Sites Additional Sites Needed	Sample Frames HPMS Samples	Existing Sites	Samples Available
	1	2	3	4	5	6	7	8	9	10	11	12
1	926.3	2	1	4	0	1	5	4	0	106	4	102
2	3446.1	9	4	4	0	1	5	4	0	123	4	119
3	5535.3	14	6	5	0	0	5	5	1	150	5	145
4	6707.1	17	7	2	0	4	6	2	5	136	2	134
5	6154.5	16	7	1	2	0	3	3	4	92	3	89
6	5879.4	15	7	0	0	0	0	0	7	62	0	62
7	6244.2	16	7	0	0	3	3	0	7	60	0	60
8	2183.8	6	3	0	0	0	0	0	3	14	0	14
9	685.6	2	1	0	0	0	0	0	1	6	0	6
10	493.1	1	1	0	0	0	0	0	1	3	0	3
11	630.3	2	1	0	0	0	0	0	1	4	0	4
13	309.5	0	0	0	0	0	0	0	0	3	0	3
TOTAL	39195.0	100	45	16	2	9	27	18	30	759	18	741

Table 17. Analysis of Distribution of Vehicle Classification for Major Collector Urban Highways.

F.M. URBAN (MINOR ARTERIAL)

	Desired Distribution			Existing Sites				Remaining Sites		Sample Frames		
Volume Group	DVMT (000)	Percent	Desired Sample Sections	HPMS Match	Close Match	No Match	Total	Usable Existing Sites	Additional Sites Needed	HPMS Samples	Existing Sites	Samples Available
	1	2	3	4	5	6	7	8	9	10	11	12
1	708.9	7	1	0	0	0	0	0	1	52	0	52
2	1474.5	15	2	2	0	4	6	2	0	50	2	48
3	4280.7	43	5	3	0	1	4	3	2	54	3	51
4	1545.9	16	2	0	0	0	0	0	2	22	0	22
5	1130.0	11	1	0	0	0	0	0	1	19	0	19
6	501.5	5	0	0	0	0	0	0	0	6	0	6
7	110.1	1	0	0	0	0	0	0	0	4	0	4
8	148.2	2	0	0	0	0	0	0	0	3	0	3
9	35.8	0	0	0	0	0	0	0	0	2	0	2
TOTAL	9935.6	100	11	5	0	5	10	5	6	212	5	207

Table 18. Analysis of Distribution of Vehicle Classification for Local Urban Streets.

CO. RD. URBAN (COLLECTOR)

	Desired Distribution			Existing Sites				Remaining Sites		Sample Frames		
Volume Group	DVMT (000)	Percent	Desired Sample Sections	HPMS Match	Close Match	No Match	Total	Usable Existing Sites	Additional Sites Needed	HPMS Samples	Existing Sites	Samples Available
	1	2	3	4	5	6	7	8	9	10	11	12
1	32.8	9	1	0	0	0	0	0	1	6	0	6
2	26.5	7	0	0	0	0	0	0	0	3	0	3
3	157.8	44	1	1	0	0	1	1	0	7	1	6
4	54.5	15	0	0	0	0	0	0	0	2	0	2
5	75.0	21	0	0	0	0	0	0	0	6	0	6
6	16.3	4	0	0	0	0	0	0	0	1	0	1
TOTAL	362.9	100	2	1	0	0	1	1	1	25	1	24

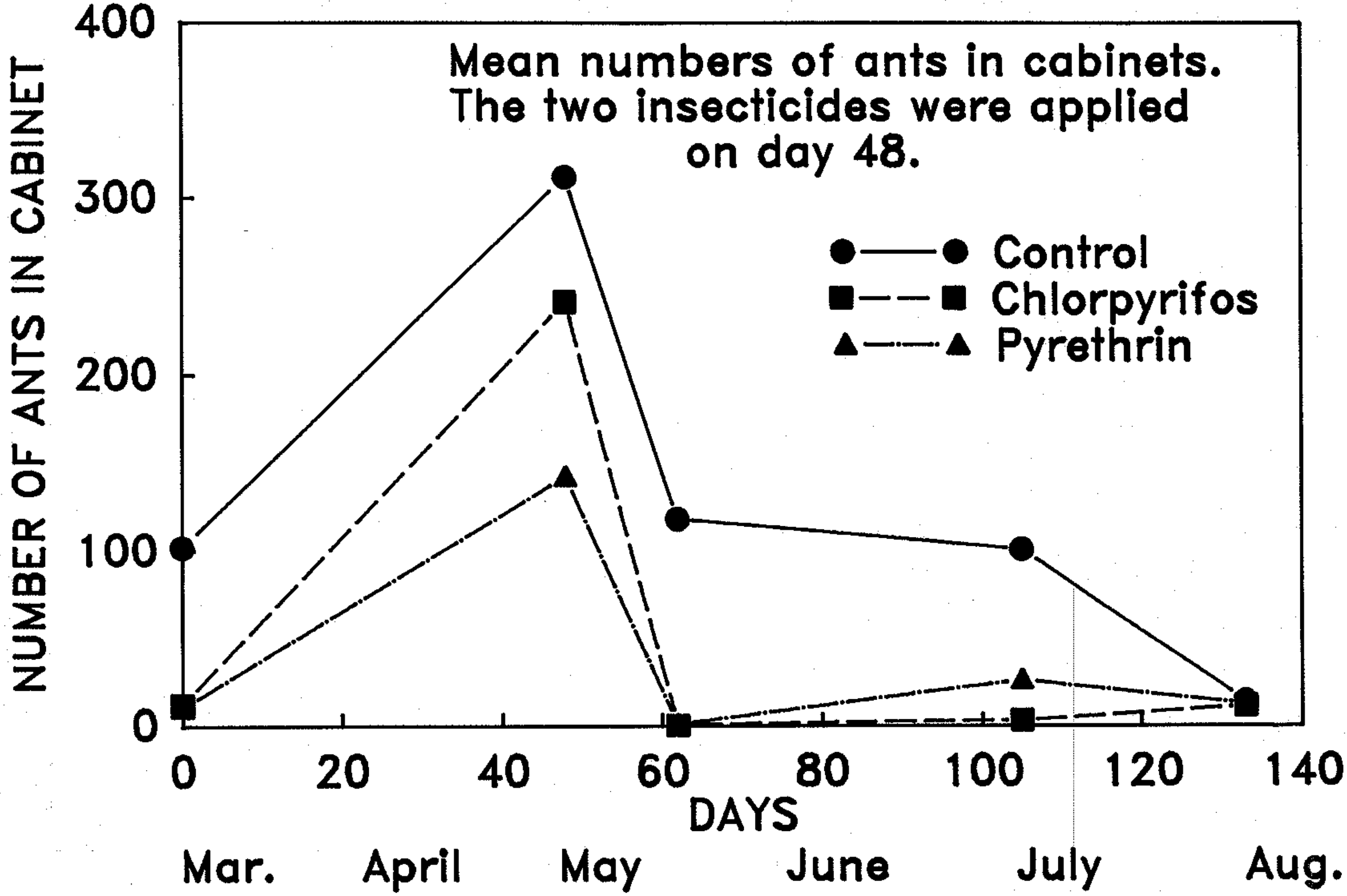


Figure 20. Control of the Red Imported Fire Ant in Traffic Control Cabinets in College Station, Using Two Different Insecticides.

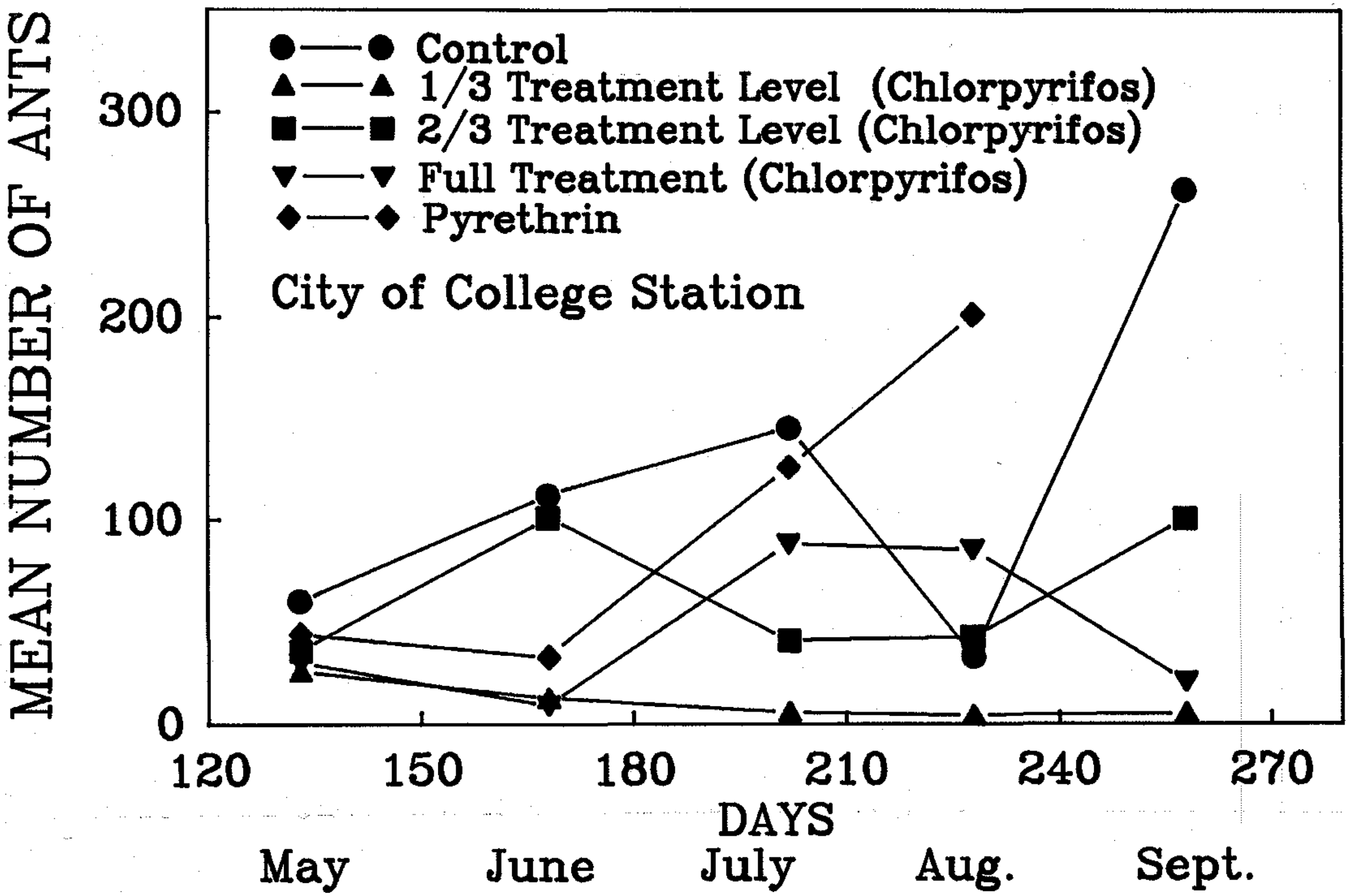


Figure 21. Control of the Imported Fire Ant in Traffic Control Cabinets in College Station, Using Different Dosage Levels.

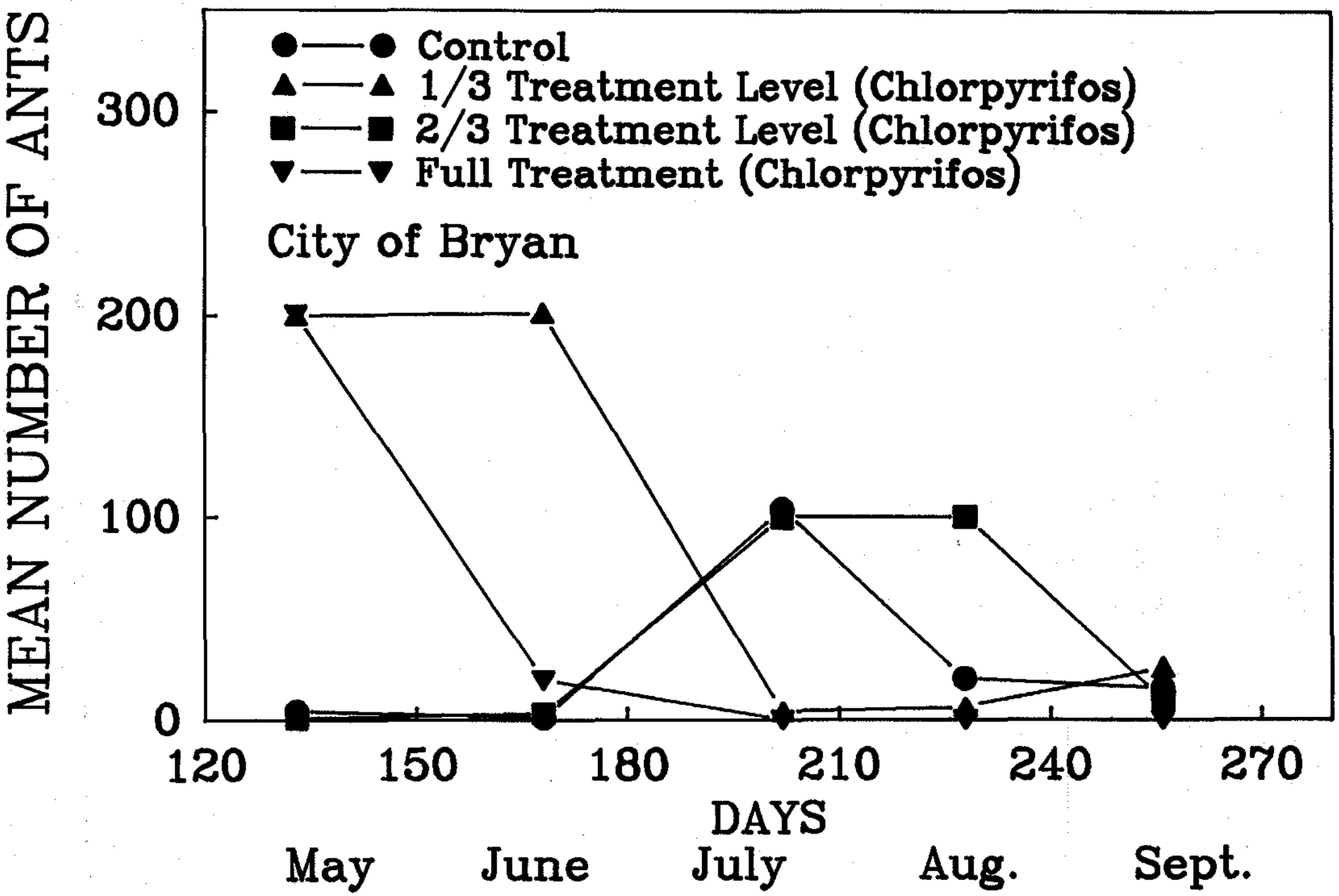


Figure 22. Control of the Imported Fire Ant in Traffic Control Cabinets in the City of Bryan, Using Different Dosage Levels.

Table 1. Wilcoxon's Signed Ranks Tests of the Effects of Insecticidal Treatment.

ALPHA LEVELS

COLLEGE STATION	ANTS	LEVEL OF INSECTICIDE	DATE
ANTS	1.000		
LEVEL	0.002	1.000	
DATE	0.001	1.000	1.000

ALPHA LEVELS

BRYAN	ANTS	LEVEL OF INSECTICIDE	DATE
ANTS	1.000		
LEVEL	0.159	1.000	
DATE	0.198	1.000	1.000

the environment. Chlorpyrifos may be effective in some areas, but not in others if environmental conditions are significantly different. Thus, further experimentation may be necessary to enable the use of the procedures developed within this research project in other locations and with other equipment.

Several insecticides containing 0.5% chlorpyrifos are available for long-term fire ant control (Table 2), manufactured and marketed by companies such as Green Light, Kenco, Rainbow Manufacturing Company, and Whitmire. Products containing a higher percentage of chlorpyrifos (Table 2) may have an equal or greater effectiveness, but they were not tested in this study. The price of the products containing a higher percentage of chlorpyrifos would be expected to be higher. Effectiveness of these products would probably not extend into the second year and thus make the added cost questionable. In addition, the disposal of the used insecticide may be more difficult, due to the higher initial concentration. The other insecticides were not observed to be as effective as chlorpyrifos over an extended period of time. Pyrethrin (0.1%) was not very effective (Fig. 21) and ultimately one cabinet had to be treated with chlorpyrifos due to the ineffectiveness of the product. Insecticide based on 1,1,1 trichloroethane was observed in the field to rapidly kill fire ants, but the treated cabinets generally would be reinfested the following day.

Many insecticides (Table 3) would be useful for the rapid "knockdown" of ants before work could be done on a heavily infested cabinet. Chemical 1,1,1 trichloroethane is perhaps the most used, but the hornet and wasp killers could also be used for wasp and native bee nests found in the cabinets.

2. PREVENTING FIRE ANTS FROM ENTERING RELAY SWITCHES

The electromechanical relay used in traffic signal control cabinets is enclosed in a clear plastic box. The pins of the relay come out through a black plastic base. In section III-3, it was clearly shown that fire ants are attracted to the relay switches. Although the experiment was carried out under laboratory conditions, the results were similar to what was happening in the traffic control cabinets. The fire ants were observed to enter relays and accumulate until the relays became inoperable. This caused a malfunction, and required sending a crew to replace the damaged relay switches and reset the controller to normal operation.

The sealed relays were first tested in laboratory nests, then in the field under actual conditions.

Table 2. Partial List of Insecticide Products Containing Chlorpyrifos, and Registered for Fire Ant Control.

Company Name	Product Name	Use*	% Active Ingredient
Black Flag	Fire Ant Killer Concentrate	1	1.0%
Cessco	Accudose Aerosol®	3	1.0%
Dexol	Fire Ant Killer Dexa-Klor Soil Insect Spray Dexa-Klor Insect Spray	1 1 1	6.7% 6.7% 6.7%
Dow Chemicals USA	Dursban® 50W Dursban® 2E Dursban® 4E	4 1 1	50.0% 22.4% 44.4%
ESCO	End-A-Bug® Fire Ant Killer End-A-Bug® Lawn Granules	1 2	6.7% 1.0%
Ferti-Lome	Fire Ant Killer Mound Drench Dursban® Fire Ant 10% Granular Insecticide	1 2,4	6.7% 10.0%
Ford's	Fire Ant Concentrate Dursban® 1E Fire Ant 2.5G Insecticide Dursban® Fire Ant 10% Granular Insecticide	1 1 2 2	5.4% 12.6% 2.5% 10.0%
Green Light	Double Dursban® Granules Fire Ant Killer Granules Fire Ant Killer Fire Ant Mound Drench	2 2 1 1	10.0% 0.5% 6.27% 0.1%
Hi-Yield	Fire Ant Killer	1	6.7%
S. C. Johnson	Raid® Fire Ant Killer	1	6.7%
Kenco	Rid-A-Bug® Fire Ant Killer	1	0.5%
Ortho	Fire Ant Control Lawn Insect Spray Ortho-Klor® Soil Insect and Termite Killer	1 1 1	5.3% 5.3% 12.6%
Rainbow Manufacturing Co.	Insect Control	2	0.5%
Rigo	Dursban® Lawn and Ornamental Insect Spray	1	22.4%
Staffel's	Ant Granules	2,4	1.0%
Starbar	Fire Ant Killer	1	6.7%
Vaporette	Fire Ant Killer Concentrate	1	6.7%
Whitmire	PT 270 Dursban®	3	0.5%
Zoecon	Strike®	1	6.7%

* 1 = mound drench; 2 = granule; 3 = injectable into mound; 4 = broadcast

Table 3. Partial List of Insecticide Products for Short-Term "Knockdown" of Fire Ants.

Company Name	Product Name	Active Ingredients (%)
Bengal Chemical Co.	Fire Ant Killer	1,1,1 trichloroethane or methyl chloroform (96.75%)
Banner Labs Inc.	MC96 Fire Ant Killer	Methyl chloroform (96.00%)
Chevron-Ortho	Hornet and Wasp Killer	2-(1-methylethoxy) phenol methylcarbamate (0.50%)
d-Con	d-Con Bug Killer	Resmethrin (0.250%)
Johnson Wax	Raid Wasp and Hornet Killer	Tetramethrin (0.252%), O-isopropoxyphenyl methylcarbamate (0.475%)
Rampart Industries	MC96	Methyl chloroform (96.00%)

To prevent fire ants from entering relay switches, several types of sealants were tested:

-Silicon sealants:
1. Duncan 25-year siliconized acrylic caulk.
2. Duncan all-purpose adhesive and caulk.

-Epoxy cements:
1. Duncan 5-minute.
2. Plastic Steal.

The process of sealing the relays consisted of applying silicon sealant or epoxy cement to the area around the base of the relays and to the base of the protruding pins inside as well as outside of the containing box. One relay manufacturer contacted indicated that electromechanical relays for traffic signals could be readily sealed during the manufacturing process if so requested by specification.

Two cabinets were in the flash mode throughout the summer (relay switches active at all times). One of these was randomly selected to be treated with the chlorpyrifos-based insecticide chlorpyrifos (Section IV-1), the other was randomly selected to be the control cabinet. These cabinets were the only two which were continuously in the flash mode in College Station.

Three additional cabinets (not in the flash mode) were randomly selected: one was treated with chlorpyrifos, the second was used as control, the third was equipped with epoxy-sealed relays.

Each of the cabinets had three relay switches. The relays in the control cabinet in flash mode accumulated large numbers of ants (Fig. 23), significantly more than the control cabinet used for comparison (Wilcoxon's signed rank test, $\alpha < 0.05$). The treated cabinet had statistically equal numbers of ants in the active relays, as did the cabinet with sealed relays and the cabinets which were not in flash mode. Obviously active relays accumulate ants at faster rates in both laboratory experiments and under actual field conditions. Additionally, the treatment of a cabinet with chlorpyrifos effectively reduced the numbers of ants which enter the relays to levels similar to those of relays that were not active.

Epoxy was much more effective than any of the other sealants tested. No ants have entered any of the relays that were sealed with epoxy, either in field experiments or lab experiments. Relays sealed with the other products and tested in laboratory nests accumulate hundreds or thousands of ants within a month.

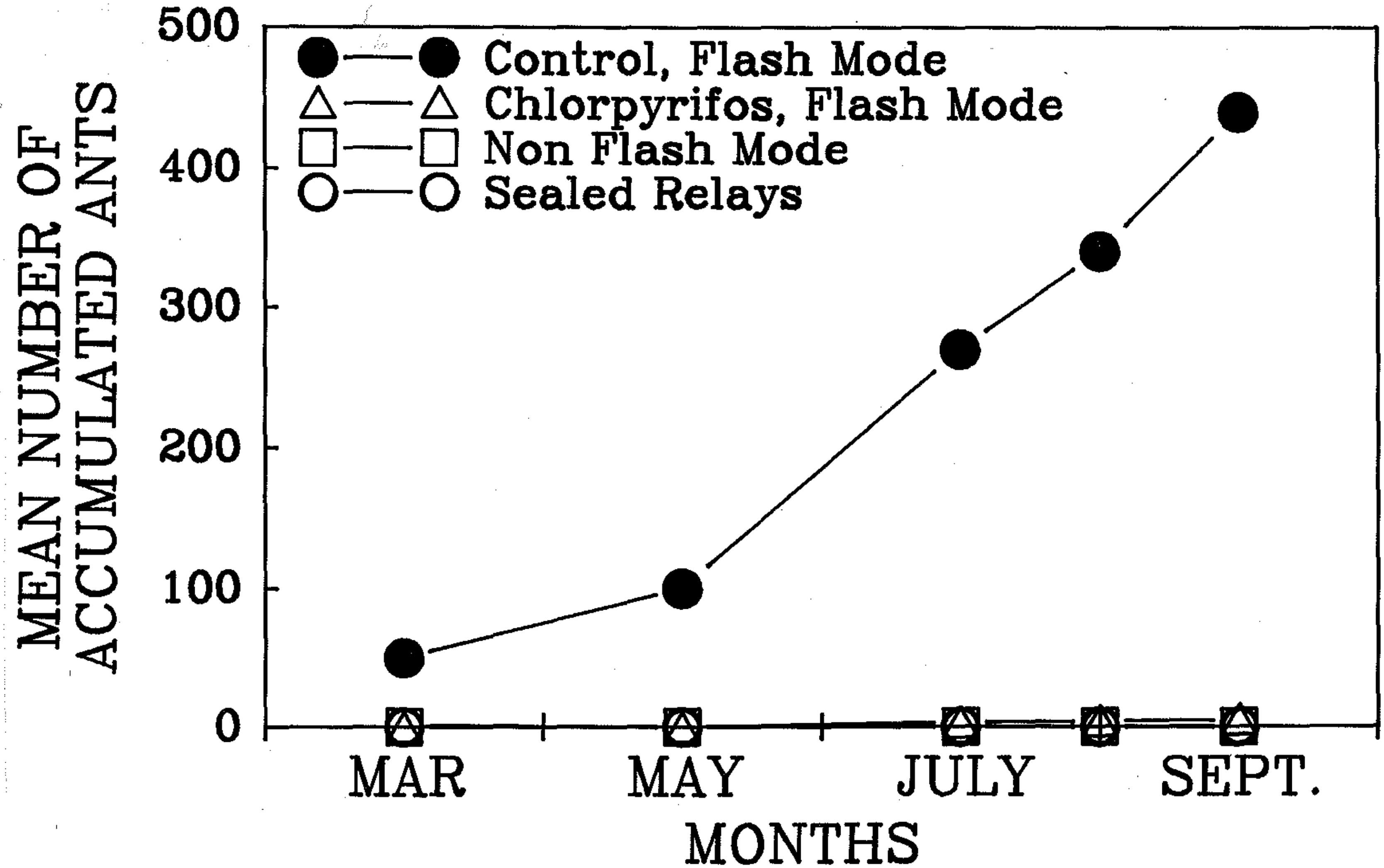


Figure 23. Accumulation of Fire Ants Inside Sealed and Unsealed Relay Switches.

V. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and treatment recommendations are provided from this research study of the imported fire ant and its infestation of traffic signals. These results are a synthesis of the initial field survey, the subsequent laboratory experiments, the signal cabinet experiments conducted in nearby cities for two years, and the research team's collective judgments.

1. GENERAL CONCLUSIONS

The imported fire ant has rapidly spread across the southern United States since the 1940's. Recent evidence indicates that they will become a more serious problem in Texas due to the expansion of multiple-queen colonies. These colonies occur at much higher densities than did the original single-queen colonies.

Fire ants have a typical annual activity cycle in Texas that is strongly influenced by ambient temperature and precipitation. Fire ants become dormant when the temperature falls below 45ºF. Activity increases with increasing temperature until very hot and/or extremely dry summer conditions are reached. The annual activity cycle of fire ants in Texas begins in late winter or early spring as the temperature rises.

New colonies are formed beginning in late April when thousands of virgin queens and mates leave each mound and begin their mating flights. These flights usually begin around 10:00 a.m. one or two days following a rain, if that day is warm (above 75ºF), not too windy and generally sunny. Mated females fly toward reflective or moist areas on which to land. Curbsides make attractive landing sites and nesting areas. Queens begin laying eggs within 24 hours. If there is sufficient time during the season to build a colony, it will probably survive.

Fire ant activity remains high during the spring and early summer as thousands of foragers search for food. Other ants tend the queens, larvae, eggs and provide other services to the colony. It is during the summer season that fire ants become a serious problem in signal cabinets.

Traffic signal cabinets are believed to be attractive to fire ants for several reasons:

1. They are usually located next to street and road curbsides, which are attractive to queens for nest building.

2. They provide protection from cold weather and the elements. In addition, surrounding landscape may be treated with insecticide which may push ants into the cabinets.
3. The cabinets are connected to buried electrical conduits which provide a pathway for the ants.
4. They contain many sources of electrical fields. Our research has shown, corroborated by other significant empirical evidence, that fire ants (and other species of ants) are strongly attracted to electrical fields. The larger the field magnitude, the stronger the attraction.
5. Electromechanical relays are a prime target of fire ants due to the intense electrical field strength at their contact points. Generated ozone is not an attractor.

Signal technicians want an extraordinarily powerful insecticide that kills all fire ants in cabinets, and keeps them out without any need to return for treatment again. Several insecticides were tested in signal cabinets. Of those tested, insecticides containing chlorpyrifos appear to be the most effective in traffic signal cabinets. We recommend that heptachlor-based products should not be used in traffic signal cabinets. We believe that heptachlor is too toxic to be used safely in signal cabinets, which are exposed to the elements and the public, and which must be serviced regularly. At the present time, heptachlor is only produced by one company in the United States (Rainbow Manufacturing Corporation, [4]). Chlorpyrifos is not as toxic to humans as heptachlor and has a shorter effective life span. It is EPA approved for treatment of surface installed electrical equipment. The chlorpyrifos product tested in this study contains 0.5% chlorpyrifos and is conveniently packaged in small bags (3 oz.) to safely expedite the treatment program in the field (provided by Rainbow Manufacturing Corporation).

An insecticidal treatment program using the chlorpyrifos-based insecticide was developed and implemented in both cities of Bryan and College Station, Texas. This treatment resulted in the destruction of all ants in treated cabinets within three hours. The effectiveness of this treatment lasted an entire year.

The treatment of cabinets with chlorpyrifos effectively reduced the number of ants that entered the relays, but sealing the relays with epoxy totally eliminated any accumulation of ants inside relay switches.

It is also important to take advantage of natural forms of control of fire ants. Spiders are a biological control of the fire ant in electrical equipment. Some species, such as *Steatoda triangulosa*, are specialist predators on the fire ant.

2. LABORATORY CONCLUSIONS

Laboratory experiments convincingly and repeatedly demonstrated that imported fire ants are strongly attracted to electric fields. Attraction is proportional to voltage level; the higher the voltage, the stronger the attraction. Fire ants were observed to quickly move to and accumulate on electrically charged points. Fire ants also showed some possible habituation, as they were not as strongly attracted when the experiment was replicated on the same day.

Experiments with other factors such as magnetic fields and ozone indicated no observable effect on the red imported fire ants. Thus, it appears that the electric field generated in electric circuits is the primary reason ants are attracted to electrical equipment.

Shorted circuitry is one of the major problems caused by fire ants in electrical equipment. Fire ants will remove insulation from wires in signal cabinets, allowing a short to occur. Both in laboratory and field experiments, it was established that there was no component in the insulation of various types of wire which attracted ants. Although not demonstrated in the laboratory, it appears that ants only attack wire when it is carrying electrical current.

Another major problem caused by the imported fire ant is the interference with the normal operation of electromechanical relay switches. This was observed in most cases when ants invade traffic signal control cabinets. The ants are highly attracted to active relay switches inside the cabinets because of the electric field generated between the contact points. They can accumulate inside the relays so tightly that the switch will no longer operate.

3. RECOMMENDED TREATMENT PROGRAM

Traffic signal technicians must be prepared to annually battle the potential invasion of fire ants into traffic signal cabinets in much of Texas. Consequently, the following annual treatment program is recommended:

1. Obtain the desired treatment products and supplies, such as:
   a. Cans of wasp and hornet spray for quick kill of insects in the cabinets.
   b. Plastic bottles of insecticide 1,1,1 trichloroethane for quick kill situations of fire ants in cabinets and around cabinet pads.
   c. An approved chlorpyrifos-based granular insecticide for treating fire ant infestation in signal cabinets. It is recommended to use a conveniently packaged product (0.5% in 3-ounce packages). Currently Rainbow Manufacturing Corporation may be the only supplier of such packages, which are also specifically labeled to control insects in electrical equipment [4]. Four 3-ounce packages are to be used in the smaller cabinets (floor area up to 4 sq. ft.); 8 packages in the larger cabinets (floor area up to 8 sq. ft.). Packages containing 24 ounces would be even more convenient for treating a cabinet with a base area up to 8 sq. ft. One-half of the package could be used for smaller cabinets (base area of up to 4 sq. ft.). It would require at least one year for such packages to be produced and approved by the EPA [4]. A number of companies market 0.5% chlorpyrifos products (Table 2). These products have an indefinite shelf life as long as the package is not opened [4]. Once a package is opened, the contents should be used within a few days. If the package is folded shut and wrapped with a rubber band or taped shut, the insecticide will be effective for at least six months [4].
   d. Vacuum and use environmentally safe disposal bags for used insecticide. The used insecticide can be packaged in strong plastic bags and legally disposed of with other buried waste [4]. It should never be left on the soil surface, as it can poison birds and other wildlife.
   e. Liquid insecticides based on chlorpyrifos or diazinon can be used to form a chemical barrier around signal cabinets.
   f. Wear appropriate protective clothing, including rubber gloves, when treating cabinets with insecticides.
2. Inspect all signal cabinets within assigned territory for fire ant infestation during the spring when the ants have become active in the local area. Typically, ant activity is high on a warm spring day following a major rain (1 inch in 24 hours). These conditions will usually occur in Texas during April or May.

3. Check for fire ant activity and nests around exterior of cabinet and look for ant trails leading into the cabinet. Eliminate the possibility that killer bees are in the cabinet. If killer bees are suspected to be in the cabinet, call an entomologist and do not open or disturb the cabinet.
4. Open a safe cabinet and visually inspect the interior of the cabinet for fire ants and their nests. Check for the presence of ants in electromechanical relays. Examine insulation on electrical cables to determine the extent, if any, of fire ants chewing on wiring.
5. Check previous year's maintenance records and insecticide treatment records for the installation. Rank the fire ant infestation situation for each cabinet as being one of the following cases:
   a. No problem - No fire ants visible inside or outside of cabinet. None for last year. No insecticide treatment performed last year.
   b. Small problem - A few fire ants observed foraging within or on the cabinet, but no nest or damage. No insecticide treatment last year.
   c. Infestation problem - All other cases. Many fire ants are seen in cabinet, dead ant piles observed, nests observed, chewed wires observed, ants observed in relays.
6. Vacuum and clean the cabinet. Save and carefully dispose of old insecticide removed from the cabinet in an environmentally safe and approved way, as described above (para. 1.d, page 47).
7. Where fire ants have entered electromechanical relays, remove the ants, and then seal the relays with an appropriate quick-setting epoxy. In future purchases, specify fire ant proof relay designs where possible.
8. Select the appropriate insecticidal treatment program for the cabinet, based on the level of problem observed:
   a. No problem - There is no apparent need to treat the cabinet.
   b. Small problem - A few ants around is normal nowadays in infested areas of the state, but this usually does not cause a big problem with annual maintenance. Since the cabinet is now clean, you should either spray or broadcast a chemical barrier of chlorpyrifos or diazinon insecticide around the inside base of the cabinet, or completely treat the inside of the cabinet with an appropriate commercial, chlorpyrifos-based granular insecticide. See below for a description of the latter treatment inside the cabinet.

c. Infestation problem - To the now clean cabinet, cautiously apply a chlorpyrifos-based granular insecticide evenly over the floor of the cabinet according to the manufacturer's recommendations. Note that the dosage level (and depth of coverage) is related to the floor size (area) of the cabinet. Never apply the granular insecticide in a cabinet where it will become wet. Dampness encourages the growth of mold (which reduces or eliminates the effectiveness of the product), and free water around the area where the insecticide is applied may contaminate the environment. Therefore, the base of the cabinet, including any holes in the concrete pad and PVC conduits, should be sealed to keep water out and to minimize the accessibility of the cabinet to fire ants. Once the cabinet has been sealed, apply the insecticide.

9. Appropriately record the insecticide treatment for the cabinet, including insecticide, dosage level, date and initial conditions observed upon inspection of the cabinet. Apply stickers (supplied by the insecticide company) both inside and outside the cabinet (near door handle) to warn others that the cabinet was treated with a toxic material. The stickers should indicate the insecticide used, the date it was applied, and a toll-free number (printed on the sticker supplied by the insecticide company) which can be used to obtain more information on the product.
10. All signal maintenance personnel must be informed that they are working with a toxic material and to take all necessary safety precautions to protect themselves when applying insecticides.
11. Holes in the concrete pad for the passage of cables should be sealed with concrete. A newly constructed cabinet should have a solid pad. Fire ants will construct nests in any hole in the pads. The open ends of the conduits should be sealed as well as possible, as they allow access of the ants into the cabinet.
12. The base of the cabinet should be sealed as well as possible with a silicon sealer. This may reduce the invasion of ants into the cabinet and would reduce the amount of moisture entering the cabinet.

This recommended treatment program should be monitored by SDHPT for rate of implementation, effectiveness, and for suggested revisions by field personnel and empirical evidence.

VI. FUTURE RESEARCH

Our research has generated a number of relevant questions, which should be answered in a timely manner:

1. What are the best methods for controlling ants in pull-boxes and conduits?
2. Why do ants remove insulation from wires? Does it only happen when the wire is carrying a current? What factors attract ants to the wires?
3. Why are ants attracted to electricity? How can circuitry be modified to reduce the attractiveness?
4. Can an electric trap be developed which would automatically remove the ants from a cabinet or other electrical equipment?

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