U.S. Department
of Transportation

**Federal Highway
Administration**

Publication No. FHWA-RD-96-109
December 1996

Detection Technology for IVHS

Volume II: Final Report Addendum

Research and Development
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101-2296

FOREWORD

This final report addendum presents additional results and conclusions of a comprehensive study to measure the field performance of commercial vehicle detectors under different traffic conditions on freeways and surface-street arterial sites. The detectors were installed in three states having diverse climates ranging from cold winter and snow in Minneapolis, Minnesota; humidity, rain, lightning, and heat in Orlando, Florida; warm, dry weather in Phoenix and Tucson, Arizona; and hot summer temperatures with thunderstorms in Phoenix.

Sufficient copies of the report are being distributed to provide a minimum of two copies to each FHWA regional and division office, and five copies to each State highway agency. Direct distribution is being made to division offices.

A. George Ostensen, Director
Office of Safety and Traffic Operations
Research and Development

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof. This report does not constitute a standard, specification, or regulation.

The United States Government does not endorse products or manufacturers. Trade and manufacturers' names appear in this report only because they are considered essential to the object of the document.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-RD-96-109		PB97-126353
4. Title and Subtitle DETECTION TECHNOLOGY FOR IVHS Volume II: Final Report Addendum		5. Report Date December 1996 6. Performing Organization Code
7. Author(s) Lawrence A. Klein and Michael R. Kelley		8. Performing Organization Report No.
9. Performing Organization Name and Address Hughes Aircraft Company Fullerton Operations P.O. Box 3310 Fullerton, CA 92634		10. Work Unit No. (TRAIS) 3B1C2021 11. Contract or Grant No. DTFH61-91-C-00076
12. Sponsoring Agency Name and Address Office of Engineering and Highway Operations R & D Federal Highway Administration 6300 Georgetown Pike McLean, VA 22101-2296		13. Type of Report and Period Covered Final Report Addendum Sept 1991-April 1995 14. Sponsoring Agency Code HSR-2

15. Supplementary Notes

Contracting Officer's Technical Representative (COTR): Milton (Pete) K. Mills, HSR-2

16. Abstract

This addendum contains the results of analyses for an additional 39 runs. These runs were selected to be representative of the widest possible range of traffic and weather conditions that were encountered. The number of runs for each site analyzed in this addendum was chosen giving consideration to the amount of data collected at each particular site.

The goal of the additional analysis was to study more results and thus, have a larger base by which to judge the performance of the technologies represented in the detector field tests. Understanding the operation of the detectors under test and the various layouts and configurations employed are an integral part of interpreting the results contained in this addendum. The necessary background information is contained in the Task L final report in Chapters 9 and 10 and is not reproduced in this addendum. Indeed, this volume is not intended to be a stand-alone document, but a complement to the work already published.

The Detection Technology for IVHS project identified traffic parameters and their required accuracies for characterizing traffic flow in conventional and newer intelligent transportation systems (ITS), obtained state-of-the-art detectors, installed and evaluated them in three states having diverse climates, and studied the need and feasibility of establishing a national detector evaluation facility.

The other report in this series is: FHWA-RD-95-100 Volume 1: Final Report

This project also used pooled funds from HPR-2(157) title "Testing and Evaluating Traffic Detectors." The states which participated are Colorado, Florida, Iowa, Maryland, Minnesota, Missouri, Nebraska, New York, Oklahoma, Oregon, Virginia, and Wisconsin.

17. Key Words	18. Distribution Statement
Detection Technology, Detectors, Sensors, ITS, Microwave, Infrared, Video Image Processing, Ultrasound, Inductive Loops, Magnetometers, Presence, Speed, Occupancy	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	100	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

This form was electronically produced by Elite Federal Forms, Inc.

ACKNOWLEDGMENTS

Many people and organizations contributed to the success of this project. We feel fortunate to have had the generous support and expertise from several city and state departments of transportation. The Minnesota Department of Transportation (DOT) was instrumental in getting the project started correctly by supplying not only cables, equipment mounting racks, and power supplies, but indispensable knowledge of how to label, wire, and keep track of the hundreds of wires required to send power to the detectors and transmit information from them to the data logger. We followed the plans they developed at all of the test locations. The City of Minneapolis was a warm host to us as well during the Winter of 1993. They cut loops in their streets, cored holes for our magnetometers, and provided us with a test site not far from the best rib joint we found during the project. Our contacts and support in Minnesota were through Jim Wright, Ping Yi, Dave Long, and Tim Bangsund.

The Florida DOT helped us set up a unique test site along the I-4 corridor into Orlando where the same data acquisition trailer location was used for freeway and surface arterial detector evaluation. We simply moved the detectors from the freeway below to the overpass above when we were ready to switch highway types. In addition to the usual cutting of loops and coring for magnetometers, they designed a chain-link fence protective screen to shield our detectors from inquisitive onlookers. They also provided an out-of-the-ordinary technique for mounting the self-powered magnetometers under the overpass so that the vehicles above could be counted. Our Florida coordination was through George Gilhooley and Jon Cheney, with support from Steve Hull, Don Carmer, Mark Candella, and Larry Gross.

With the aid of the Arizona DOT, we selected a test site on the west side of the I-10 freeway in downtown Phoenix. We didn't use the pipe tree to support the overhead detectors at this site, but instead mounted them directly on the sign-bridge structure that spanned the westbound lanes. The cat-like ability and the fearlessness of the DOT personnel were greatly appreciated during this adventure. The Arizona DOT personnel who supported the project were Dan Powell, Sarath Joshua, Jim Shea, Larry Cummings, Andy Murray, and Sam Stubbs.

Not to be out done, the City of Tucson Department of Transportation provided a test location across the street from the largest shopping mall in the area. Only at this site did we bury our cable run from the signal mast arm and pole to the data acquisition trailer. After warding off prairie dogs and water from a spring storm, we got the detectors operating. Once more, the technicians made available to the project by the city were outstanding in their willingness and ability to aid us in mounting and diagnosing any problems with the detectors. Our appreciation is extended to Dennis Sheppard, Ray Svec, John Swanson, and Edwin Daugherty for arranging for the support of the city and assisting us in connecting and aiming the detectors.

The research division at FHWA provided an ideal technical representative. The project would not have been as successful without his many thought-provoking comments and suggestions and his general support. The efforts of the contracting officer to keep the proverbial checks in the mail were certainly appreciated. We are also indebted to the FHWA Program Manager for establishing the need for a project of this type and for his continued support throughout its many phases.

With the assistance of JHK and Associates, we were able to develop a team that understood the need for acquiring accurate traffic parameter data and could develop methods for acquiring them. Many people at JHK helped develop one of the major outputs of the project, the Task A Report *Development of IVHS Traffic Parameter Specifications*. In particular, Scott MacCalden, Jr. and Craig Gardner provided the insights that are incorporated in the document.

Rick Anderson of Hughes and Steven Birch of Iron Mountain Systems designed the hardware and software used in the data logger to acquire and convert the detector output data into a user-friendly database format. Their expertise was instrumental in being able to simultaneously record and time-tag data from the approximately 20 detectors that represented the technologies under evaluation.

There is one more person to whom the project owes a great debt, Michael Kelley. As the key participant in the installation, data acquisition, and data analysis tasks, his contributions are priceless. He displayed his enthusiasm by spending long weeks and days in the field, getting up before sunrise and retiring after dark to make sure that the necessary data were recorded. With the encouragement of the Principal Investigator, he helped seek out the best ribs in each city we visited.

Lawrence A. Klein
Principal Investigator

PREFACE

The *Detection Technology for IVHS* project began in September 1991 and continued through April 1995. In the first part of the project, parameters used in characterizing traffic flow for conventional traffic control systems and for newer Intelligent Vehicle-Highway Systems (IVHS) applications were identified. IVHS applications may place higher accuracy requirements on traffic parameters measured by detectors and may also require the acquisition of traffic data not normally output by the more conventional detectors. The traffic parameter data accuracies developed for IVHS applications are based on available operational test data, traffic control algorithms, and performance prediction analyses. Even though an extensive effort was made to acquire traffic data accuracy requirements, there was not a great deal of this information available. We expect that the accuracies given in this report will be updated as new control algorithms and information continue to be developed.

Detector manufacturers were contacted to determine if they would make their devices available to the program. A cross section of detectors that represented different technologies were obtained, including inductive loop with conventional and high sampling rate detector amplifiers, magnetometers with relatively small detection zones, magnetometer arrays with large multilane detection zones, microwave radar, laser radar, ultrasound, acoustic microphone arrays, passive infrared, imaging infrared, and video image processing.

In the next part of the project, laboratory test plans were developed and tests were conducted for detectors that would eventually be exposed to diverse environmental and traffic conditions during the field tests. The laboratory tests demonstrated the operation and capabilities of the detectors and their limitations. These tests were performed at Hughes Aircraft Company facilities in Fullerton, CA, and by the City of Los Angeles Department of Transportation.

Once the laboratory tests were completed, the detectors were installed in three states having diverse climates that ranged from cold temperatures and snow in Minneapolis; humidity, rain, lightning, and heat in Orlando; warm, dry weather in Phoenix and Tucson; and hot summer temperatures with thunderstorms in Phoenix. A freeway and a surface-street arterial site were used sequentially in each state. The tests were conducted according to a test plan that described the mounting of the detectors, their power requirements, test patterns, data acquisition and reduction, ground truth procedures, and security at the test sites.

The recorded data were processed using application-specific software designed for each detector. This resulted in a database being created that contained the normal outputs from the detector when a vehicle passed through its field of view, the time of the event, videotape index number, and air temperature and wind speed and direction. By using the video index number, a specific event can be accessed and reviewed on a computer-controlled video recorder.

The feasibility of establishing a national detector evaluation facility was also studied. Letters were sent to the detector manufacturers and several universities soliciting their inputs and thoughts about such a center.

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

Table of Contents

Table of Contents (continued)

Page

List of Figures

List of Figures (continued)

Page

List of Figures (continued)

List of Figures (continued)

List of Tables

ADDENDUM TO THE *DETECTION TECHNOLOGY FOR IVHS* FINAL REPORT

1. INTRODUCTION

This document is an addendum to the Task L *Detection Technology for IVHS* Final Report. The original Task L final report contains results from a total of 17 runs. This addendum contains the results of analyses for an additional 39 runs. These runs were selected to be representative of the widest possible range of traffic and weather conditions that were encountered. The number of runs for each site analyzed in this addendum was chosen giving consideration to the amount of data collected at each particular site. A listing of the runs is given in Table 2.

The goal of the additional analysis was to study more results and, thus, have a larger base by which to judge the performance of the technologies represented in the detector field tests. Understanding the operation of the detectors under test and the various layouts and configurations employed are an integral part of interpreting the results contained in this addendum. The necessary background information is contained in the Task L final report in Chapters 9 and 10 and is not reproduced in this addendum. Indeed, this volume is not intended to be a stand-alone document, but a complement to the work already published.

Table 3 lists the 19 additional runs subjected to ground truth analysis. The recorded video imagery from each ground truth run was observed for a period of 1 hour in each lane of interest and the vehicle counts were tallied manually. These results were used to assess the absolute count accuracies of each detector by comparing the number of events recorded by the data logger against the number that were manually observed.

While the results from the ground truth counts were used as the absolute truth against which the detector outputs were measured, the ground truth counts cannot be considered to be 100 percent accurate because of the inevitable introduction of human error in the manual count process. Human error in the observation of the video-taped events and the manual recording of the results was minimal. Having the ability to pause the VCR allowed the observer to take a break at the onset of fatigue. Several sessions were ground truthed twice to ensure uniformity of results.

The biggest factor regarding the application of ground truth counts comes from the fact that not all detectors were monitoring the same stretch of roadway. The detection zone figures in Chapter 10 of the Task L final report show the sensing areas of the various detectors. These figures visually demonstrate the extent to which the detection zones are sometimes separated. The distance between the footprint from a device oriented directly downward at nadir and the detection zone of a video image processor might be as much as 80 feet (24.4 m).

The analyst must select a point in the lane over which a vehicle must pass to be considered a valid detection. A vehicle in a given lane may indeed pass over this chosen point, only to change into another lane before reaching the detection zones located further downstream. Under this scenario, the detectors in the near part of the lane were correct to register a detection, just as the detectors in the far section of the lane were correct not to register an event. Yet when results are compared on a lane-by-lane basis, each detector in the lane will be considered to either have accurately detected the event or erroneously failed to detect it.

The assumption was made that over the long term such anomalies will cancel each other out. For this reason, it is important that the data collection site be selected to minimize lane changing. Failing that, the lane changes must occur in a random fashion, i.e., there exists no bias or tendency for the lane changes or maneuvers to occur in any given direction. For this reason, sites should not be located in close proximity to freeway exits or on-ramps.

The FHWA plans to make copies of the videotapes of the traffic flow that were recorded during each run. These will be made

Table 1. Detectors Used During Field Tests

Symbol	Technology	Manufacturer	Model	Output Data
U-1	Ultrasonic Doppler	Sumitomo	SDU-200 (RDU-101)	Count, speed
U-2	Ultrasonic Presence	Sumitomo	SDU-300	Count, presence
U-3	Ultrasonic Presence	Microwave Sensors	TC-30C	Count, presence
M-1	Microwave Detector Motion Medium Beamwidth	Microwave Sensors	TC-20	Count
M-2	Microwave Detector Doppler Medium Beamwidth	Microwave Sensors	TC-26	Count, speed binning
M-4*	Microwave Detector Doppler Narrow Beamwidth	Whelen	TDN-30	Count, speed
M-5	Microwave Detector Doppler Wide Beamwidth	Whelen	TDW-10	Count, speed
M-6	Microwave Radar Presence Narrow Beamwidth	Electronic Integrated Systems	RTMS-X1	Count, presence, speed, occupancy
IR-1	Active IR Laser Radar	Schwartz Electro-Optics	780D1000 (Autosense I)	Count, presence, speed
IR-2	Passive IR Presence	Eltec	842	Count, presence
IR-3	Passive IR Pulse Output	Eltec	833	Count
IR-4**	Imaging IR	Grumman	Traffic Sensor	Presence, speed
VIP-1	Video Image Processor	Econolite	Autoscope 2003	C
VIP-2	Video Image Processor	Computer Recognition Systems	Traffic Analysis System	C
VIP-3***	Video Image Processor	Traficon	CCATS-VIP 2	C
VIP-4**	Video Image Processor	Sumitomo	IDET-100	C
VIP-5+	Video Image Processor	EVA	2000	C
A-1 ++	Passive Acoustic Array	AT&T	martSonic TSS-1	Count
MA-1	Magnetometer	Midian Electronics	Self-Powered Vehicle Detector	Count, presence
L-1**	Microloop	3M	701	Count, presence
T-1**	Tube-Type Vehicle Counter	Timemark	Delta 1	Count

* M-3 was designated for a microwave radar detector that was not received.
** Used at Tucson, Arizona, test site only. *** Used at all Arizona test sites.
\+ Used in Phoenix, Arizona, 7/94 test only. ++ Used in Phoenix 11/93 and Tucson tests.
C Count, presence, occupancy, speed, classification based on length. Some provide headway, density, and alarm functions.

Site	Run #	Weather Conditions	Time
MN Freeway	01281601	cold, windy, sunny	1700-1800
	01291127	cold, sunny	~1130-1400
	02041220	lt. flurries, mid-hi 20's	~1220-1410
	02101610	mid 20's, lt. flurries	1700-1800
MN Street	03081153	cloudy, cold, windy	1200-1300
	03120842	clear, sunny, cold	1100-1200
FL Freeway	07150617	mid 70's, clear, humid	0700-0800
	07151610	mid-hi 70's, thunderstorm, rain showers	1830-1930
	07201429	heavy rain, mid-hi 80's	1435-1535
	07210613	hi 70's, hi humidity	0700-0800
	07230615	sunny, hi 70's, very humid	0700-0800
	07291653	mid 90's, humid	1800-1900
FL Street	08261617	lt. rain, mid 70's	1700-1800
	09021523	mid-80's, lt. overcast	~1525-1915
	09081603	overcast, low 80's	~1610-2030
	09090713	mid-hi 70's, humid	~0715-0900
Phoenix '93 Freeway	11110642	lt. rain, low 60's	~0645-1000
	11171612	low 70's	~1615-1910
	11230648	low 60's, lt. drizzle	0700-0800
	12021502	low 70's	1700-1800
	12030636	cool, low 50's	0700-0800
	12080626	low 50's	~0630-1030
	12081534	overcast	1730-1830
	12091632	low 70's	~1640-1940
Phoenix '94 Freeway	07190448	partly cloudy, low 80's	~0500-0900
	07210438	clear, mid 80's	~0445-0900
	07211619	~100 degrees F	~1620-2100
	08011613	~107 degrees F	1700-1800
	08021550	~110 degrees F	1700-1800
	08031611	~112 degrees F	1700-1800
	08050438	mid 90's, clear	0700-0800
Tucson Street	03220633	mid 50's, clear	~0640-0950
	03230635	hi 50's, clear	~0640-0930
	03291723	cool, low 50's	~1725-1910
	03300558	low-mid 50's	~0600-0900
	03301610	clear, low 80's	~1615-1900
	04111629	clear, mid 70's	~1630-1830
	04140607	hi 50's to mid 60's	~0615-0930
	04141705	low-mid 80's	~1710-2000

Table 3. Additional Vehicle Count Ground Truth Runs

Run #	Site	Weather Conditions	Time	Vehicle Counts		
				Lane 1	Lane 2	Lane 3
01281601	MN Fwy	cold, windy, sunny	1700-1800	-	1885	2196
02101610	MN Fwy	mid 20's, lt. flurries	1700-1800	-	1978	2093
03081153	MN St	cloudy, cold, windy	1200-1300	127	145	-
03120842	MN St	clear, sunny, cold	1100-1200	133	159	-
07150617	FL Fwy	mid 70's, clear, humid	0700-0800	1620	1349	-
07151610	FL Fwy	mid-hi 70's, T-storm	1830-1930	521	869	-
07201429	FL Fwy	heavy rain, mid-hi 80's	1435-1535	883	1045	-
07210613	FL Fwy	hi 70's, hi humidity	0700-0800	1857	1619	-
07230615	FL Fwy	sunny, hi 70's, humid	0700-0800	1654	1478	-
07291653	FL Fwy	mid 90's, humid	1800-1900	660	1001	-
08261617	FL St	lt. rain, mid 70's	1700-1800	924	914	-
11230648	AZ Fwy	low 60's, lt. drizzle	0700-0800	1488	1652	-
12021502	AZ Fwy	low 70's	1700-1800	1431	1415	-
12030636	AZ Fwy	cool, low 50's	0700-0800	1506	1721	-
12081534	AZ Fwy	overcast	1730-1830	1053	1250	-
08011613	AZ Fwy	~107 degrees F	1700-1800	1223	1292	-
08021550	AZ Fwy	~110 degrees F	1700-1800	1322	1361	-
08031611	AZ Fwy	~112 degrees F	1700-1800	1314	1399	-
08050438	AZ Fwy	mid 90's, clear	0700-0800	1207	1522	-

available by the FHWA to other research personnel who wish to further analyze the database. The data reduction process was described in Section 10 of the Task L final report. An anomaly was observed when overlaying detector data onto the video that was not, however, documented in Section 10. There exists a 6-second lag between the observation of a vehicle from the ground truth tape and the detector data overlay displayed on the monitor. This lag is believed to arise from the time necessary for the mechanical portions of the PC-VCR to actually engage after receiving the command to begin a data recording session. Since this anomaly results in a constant offset, the analyst needs only to add 6 seconds to each value in the Tape Index PG # field when creating the VCR.LOG data/video synchronization file. This manipulation is performed easily using a spreadsheet application such as Microsoft's Excel. Details of the VCR.LOG file structure are given in Section 10.5 of the Task L final report.

2. RESULTS FROM MINNESOTA FREEWAY RUNS

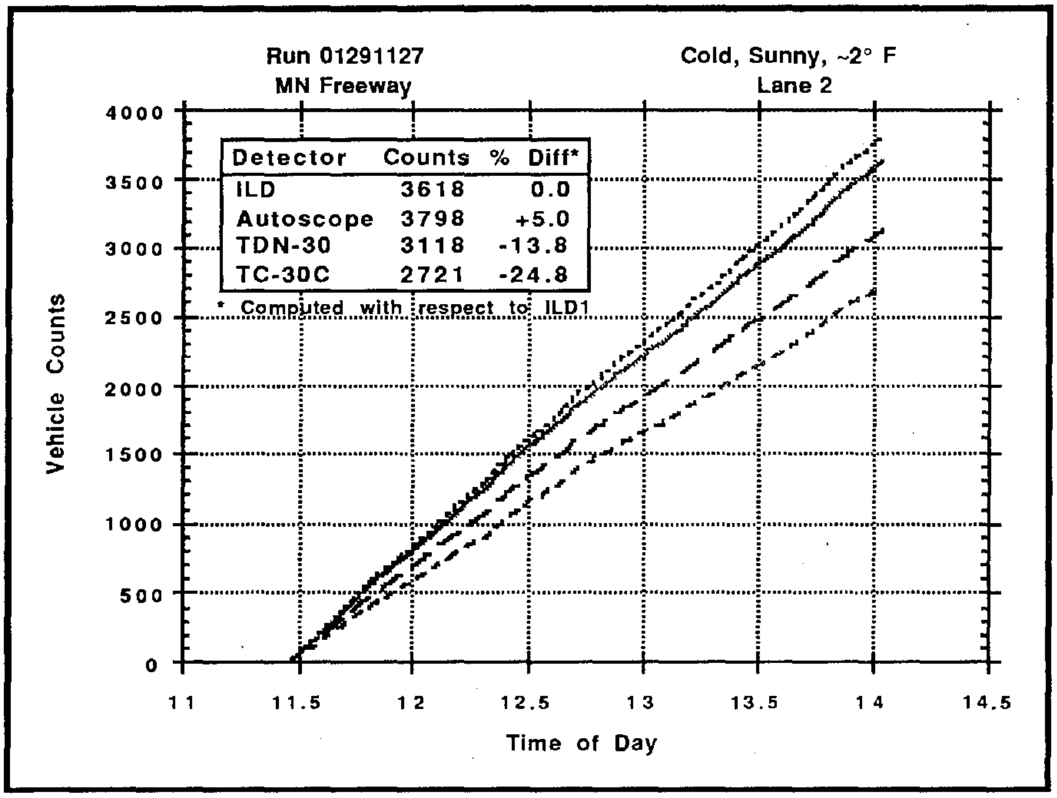
Run 01291127

The weather during this session was cold and sunny with a reported temperature of 2∞F (-16.7°C) at the beginning of the run.

Figure 1 shows the relative count performance for four different detection technologies deployed in lane 2 (left eastbound lane). These include inductive loop detectors (ILDs), a TDN-30 microwave Doppler detector, a TC-30C ultrasonic detector, and the Autoscope 2003 video image processor (VIP).

The ILDs have consistently been among the most accurate count detectors fielded in the Minnesota freeway tests, so their count outputs were used as a reference value against which the outputs from the other devices were compared.

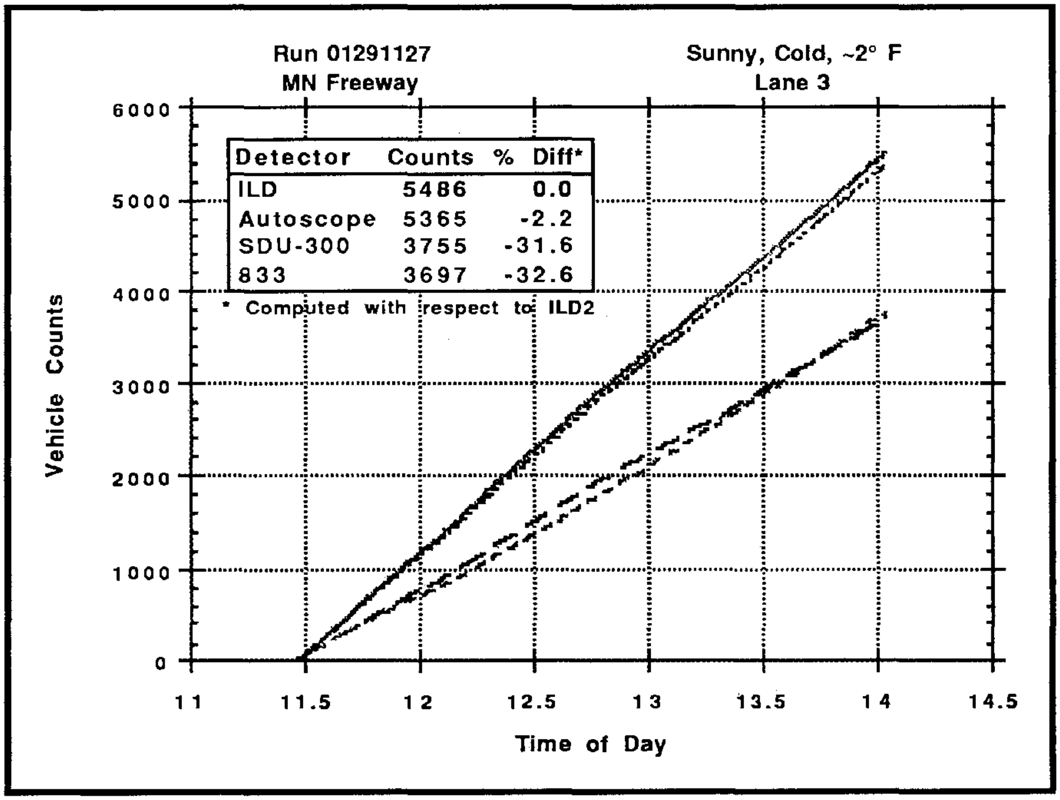
A wide disparity in the reported vehicle counts from the four detectors is apparent. The Autoscope 2003 VIP overcounted with respect to the inductive loop in lane 2, while the TDN-30 microwave Doppler detector and the TC-30C ultrasonic detector both undercounted. As this run was conducted early in the Minnesota freeway tests, the performance of some units was not yet optimized. This might account for the Autoscope's overcount as adjustments to the unit's operating parameters were made by Autoscope's field engineer during the first several days.



°C = 5(°F-32)/9

Figure 1. Comparison of I-394 Vehicle Counts From Four Detectors in Lane 2 From Minneapolis Freeway Site

Figure 2 shows vehicle counts for four different detector technologies for lane 3 (rightmost lane) of the Minnesota freeway site. Again, percent differences in count were computed using the second inductive loop value as a reference. Ground truth results show that counts from this loop typically fell within 0.5 percent of the manual count obtained from video imagery. The duration of the run was approximately 2.5 hours and the weather was sunny and cold. Autoscope was undercounting by 2.2 percent with respect to ILD2, while the SDU-300 ultrasonic detector and the 833 passive infrared detector each undercounted by greater than 30 percent. The results for the TC-30C and the 833 can by no means be considered typical. The substantial undercounts recorded from these devices can likely be attributed to detector malfunctions and/or non-optimal setup. It is not believed that these anomalies can be attributed to weather-related effects.



°C = 5(°F-32)/9

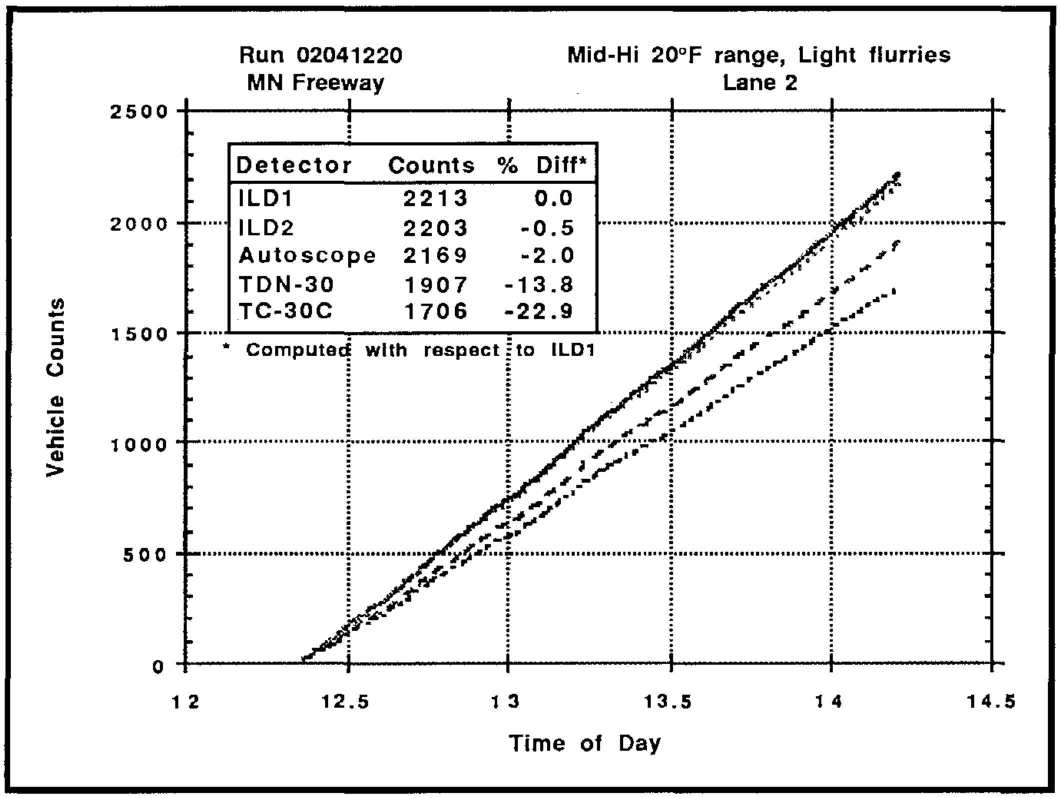
Figure 2. Comparison of Vehicle Counts From Four Detectors in Lane 3 From I-394 Minneapolis Freeway Site

Run 02041220

This run was characterized by light fog and cold temperatures. Intermittent light flurries were evident during the session.

Figure 3 shows lane 2 vehicle counts for five detectors representing four different technologies. Again, the percent difference in counts was computed using the first inductive loop in lane 2 as the reference. The detectors evaluated were a pair of inductive loops (spaced nominally 15 feet (4.6 meters) rom center to center), the Autoscope 2003 video image processor, the TDN-30 microwave Doppler unit, and the TC-30C ultrasonic detector.

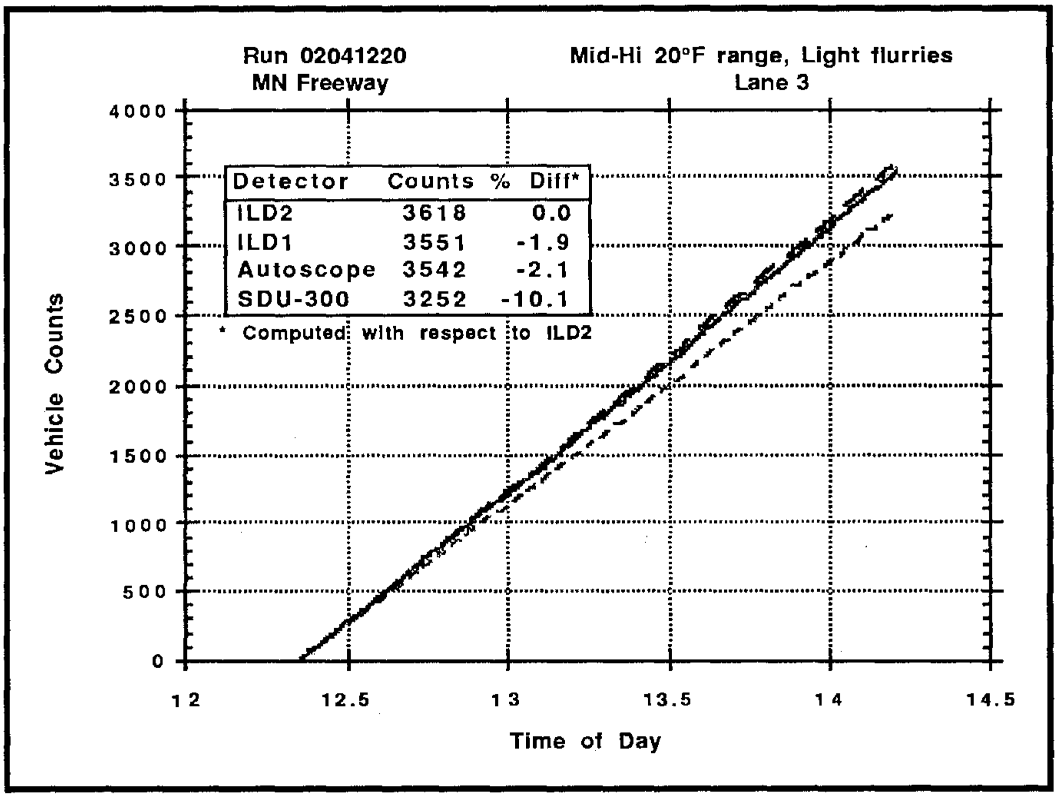
The results are consistent with the lane 2 results from Run 01291127 with the exception of the Autoscope, whose parameters had undergone optimization between the times of these runs. The two loops agree to within 0.5 percent, while the Autoscope followed closely behind showing a 2 percent undercount. Again, the TDN-30 and the TC-30C undercounted by 13.8 and 22.9 percent, respectively (as compared to the 13.8 and 24.8 percent recorded during a comparable time window nearly a week earlier).



°C = 5(°F-32)/9

Figure 3. Comparison of Vehicle Counts From Five Detectors in Lane 2 From I-394 Minneapolis Freeway Site

Figure 4 shows the results for lane 3 of the same run. Represented are two inductive loops, the Autoscope 2003 VIP, and the SDU-300 ultrasonic detector. The count from the lead loop was 1.9 percent below that reported by the second loop. This is likely attributable to a lane swerve and merge phenomenon that occurred in lane 3. The taped video imagery showed that a number of vehicles used the right shoulder as a merging lane into normal freeway traffic. This traffic pattern was most evident during periods of heavy congestion. Since the position of the second loop was further down the road, many vehicles that did not pass over the lead loop were detected by the second loop as the vehicles were completing their late merging maneuver.



°C = 5(°F-32)/9

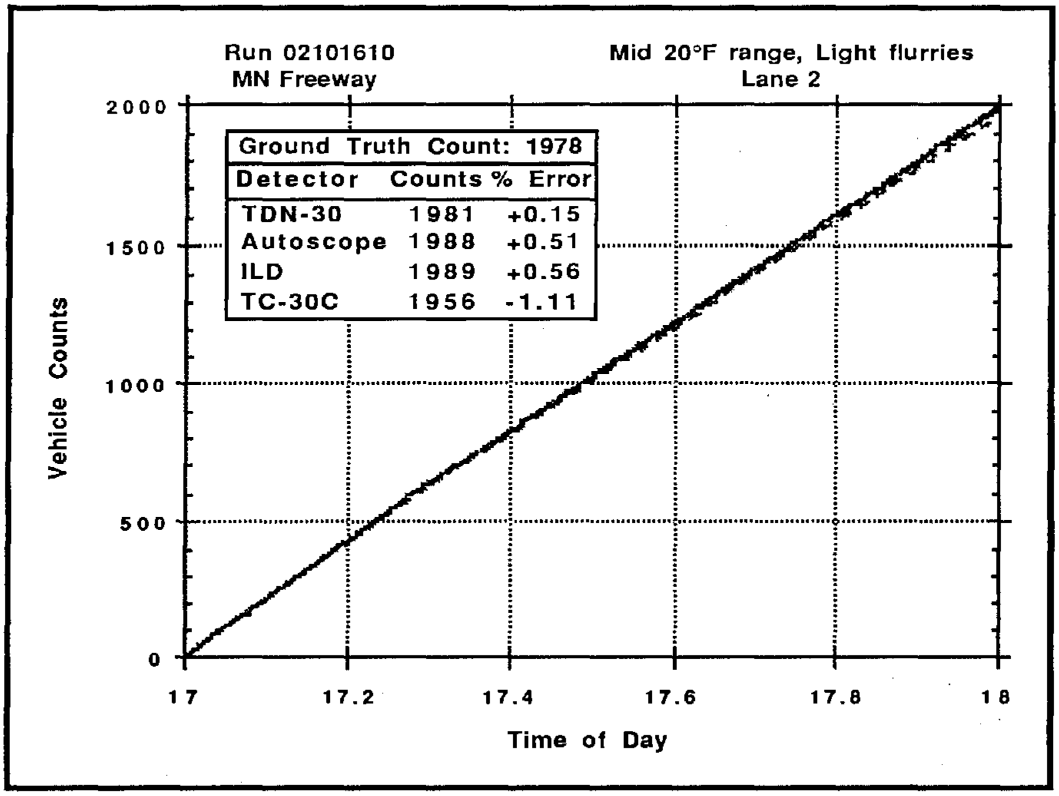
Figure 4. Comparison of Vehicle Counts From Four Detectors in Lane 3 From I-394 Minneapolis Freeway Site

Run 02101610

The weather during this run included intermittent snow flurries and a temperature ranging from the mid to high 20°F (~-2 to -4°C) range.

Figure 5 shows the comparison of vehicle count accumulations for four detectors between 5:00 and 6:00 p.m. Ground truth values were derived manually by means of the video imagery, and the corresponding percent errors were computed for each detector shown.

Three devices in lane 2 registered count accuracies to within 0.6 percent of the ground truth value. These included the TDN-30 narrow-beam microwave Doppler detector, the Autoscope 2003 VIP, and the inductive loop. Following closely behind was the TC-30C ultrasonic detector that undercounted by slightly more than 1 percent.

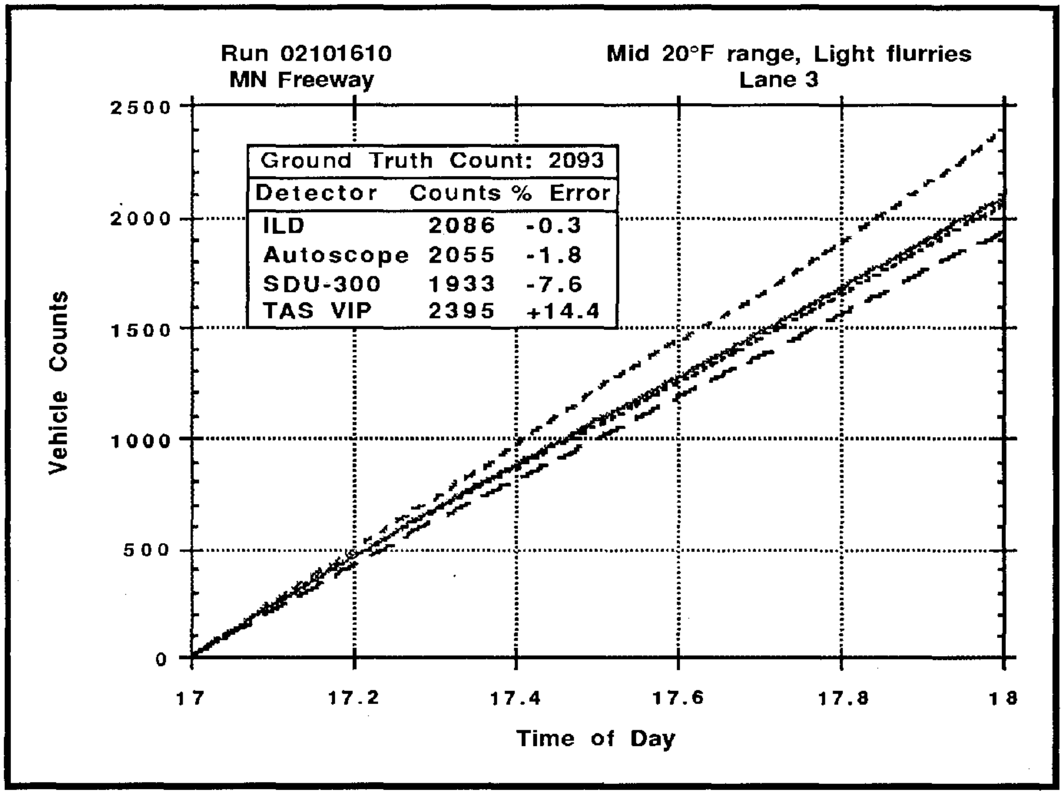


°C = 5(°F-32)/9

Figure 5. Comparison of Vehicle Counts With Ground Truth for Four Detectors in Lane 2 From I-394 Minneapolis Freeway Site

Figure 6 shows the count comparisons with the ground truth value for four detectors monitoring lane 3. These detectors included an inductive loop, the SDU-300 ultrasonic detector, and two video image processors: the Autoscope 2003 and the Traffic Analysis System (TAS).

The lane 3 results show a greater disparity from detector to detector than was evident in the lane 2 results. The loop was within 0.3 percent of the ground truth value, while the Autoscope undercounted by 1.8 percent. The SDU-300 undercounted by 7.6 percent, while the TAS VIP overcounted by 14.4 percent. This TAS result was obtained not from the device's serial interface, but by the accumulation of discrete pulses from an opto-isolator output module supplied by the manufacturer.



Ground Truth Count: 2093		
Detector	Counts	% Error
ILD	2086	-0.3
Autoscope	2055	-1.8
SDU-300	1933	-7.6
TAS VIP	2395	+14.4

°C = 5(°F-32)/9

Figure 6. Comparison of Vehicle Counts With Ground Truth for Four Detectors in Lane 3 From I-394 Minneapolis Freeway Site

3. RESULTS FROM MINNESOTA SURFACE STREET RUNS

Run 03081153

The sky was overcast during this run, with the temperature in the mid 30°F range (around 1°C).

Figure 7 shows the count comparisons for six detectors located in lane 2 (the middle through-lane) of the Minnesota surface street site. The jagged and discontinuous appearance of the curves can be attributed to two main factors. The first is the light traffic experienced at this site. The scarcity of vehicle passages meant that each recorded detection carried a higher weighting in the count accuracy result than was experienced in the preceding freeway tests. This factor manifested itself in sharper delineations between curves, whereas in a situation where 2000 vehicles per hour were passing by, a single erroneous count would not stand out as readily.

The second factor contributing to the "snaky" nature of the curves is caused by vehicles queueing up behind the stop bar, then releasing during the signal's green phase. The oscillatory nature becomes more evident during periods of heavier traffic, but is still discernible at much lighter flow rates.

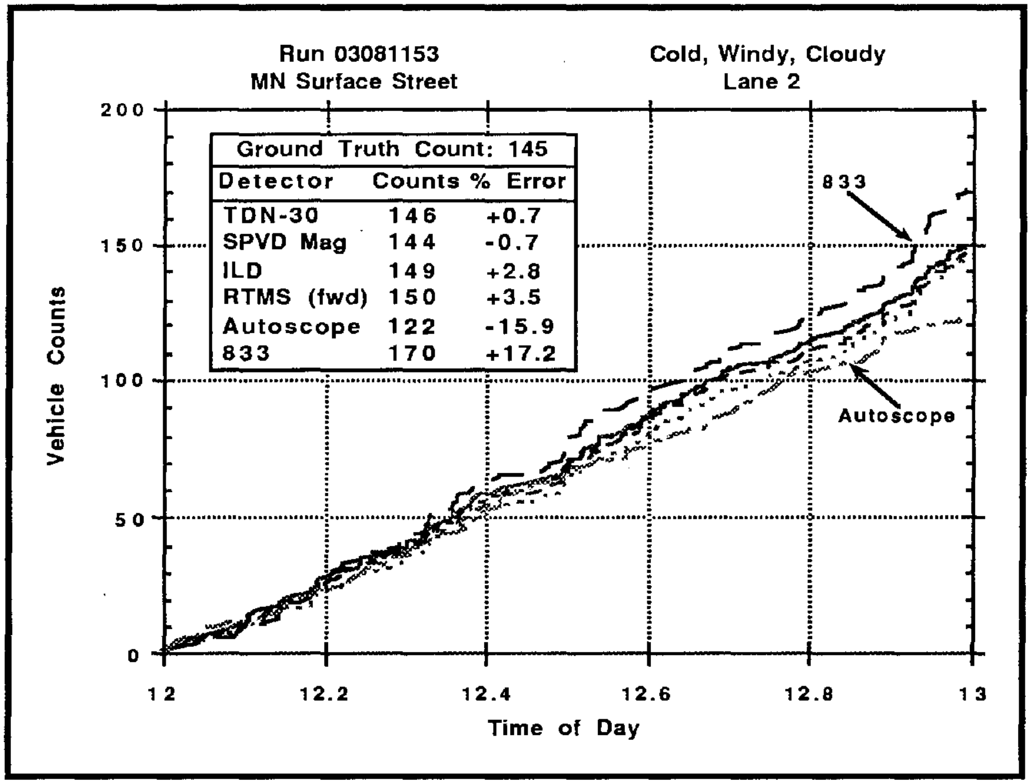


Figure 7. Comparison of Vehicle Counts With Ground Truth for Six Detectors in Lane 2 From the Olson Highway Site

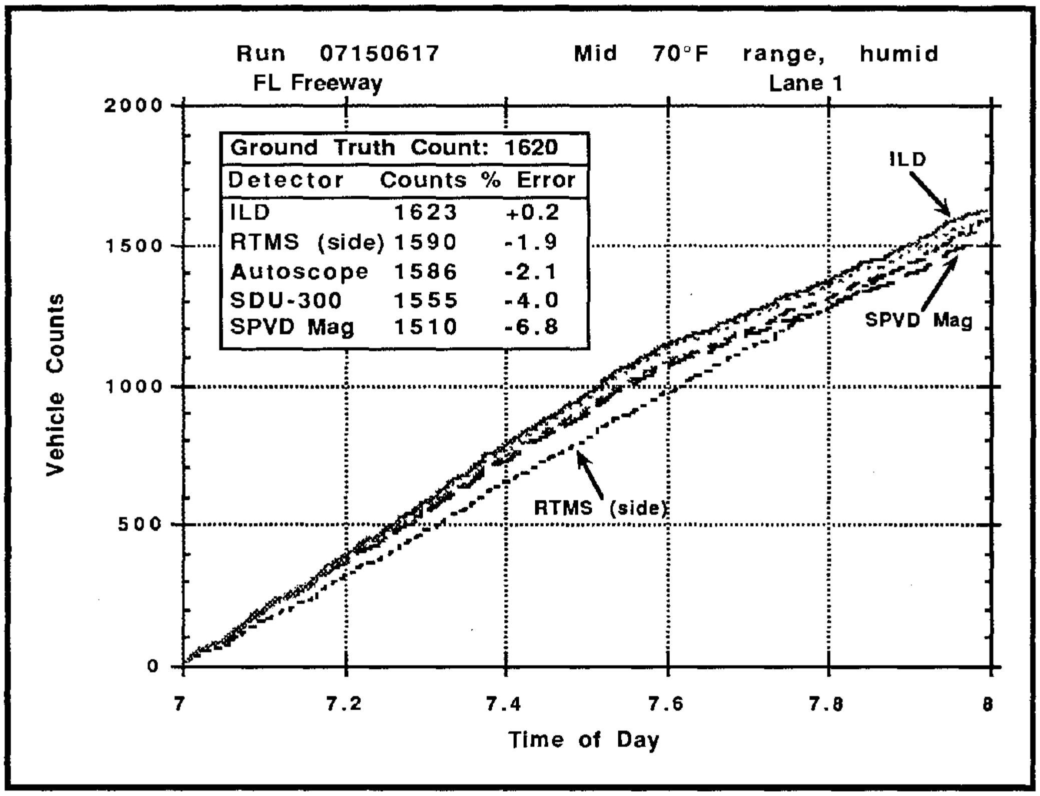
4. RESULTS FROM FLORIDA FREEWAY RUNS

Run 07150617

The temperature during this run ranged from the mid 70's to the mid 80's °F (~24 to 29°C) with high humidity. The latter part of this session was characterized by heavy bumper-to-bumper traffic.

Figure 8 contains the accumulated counts referenced to ground truth values for devices representing five different detection technologies. The most accurate detector in lane 1 (the leftmost lane) in terms of count was the inductive loop whose accuracy was computed to be 99.8 percent over this 1-hour interval. Second in terms of percent error was the side-firing Remote Traffic Microwave Sensor (RTMS) true-presence microwave radar, but this accuracy is overstated. Examination of the curves in Figure 8 shows the RTMS counts lagging those of the other four detectors until about midway through the hour. During the first half hour, traffic flow slowed and eventually resulted in bumper-to-bumper conditions for the remainder of the hour. During the second half of the hour, when the vehicle flow decreased further, the count rate decreased for all detectors except for the side-firing RTMS. Thus, the continued accumulation of vehicles by the RTMS during the second part of the hour compensated for its lower count during the first half of the hour.

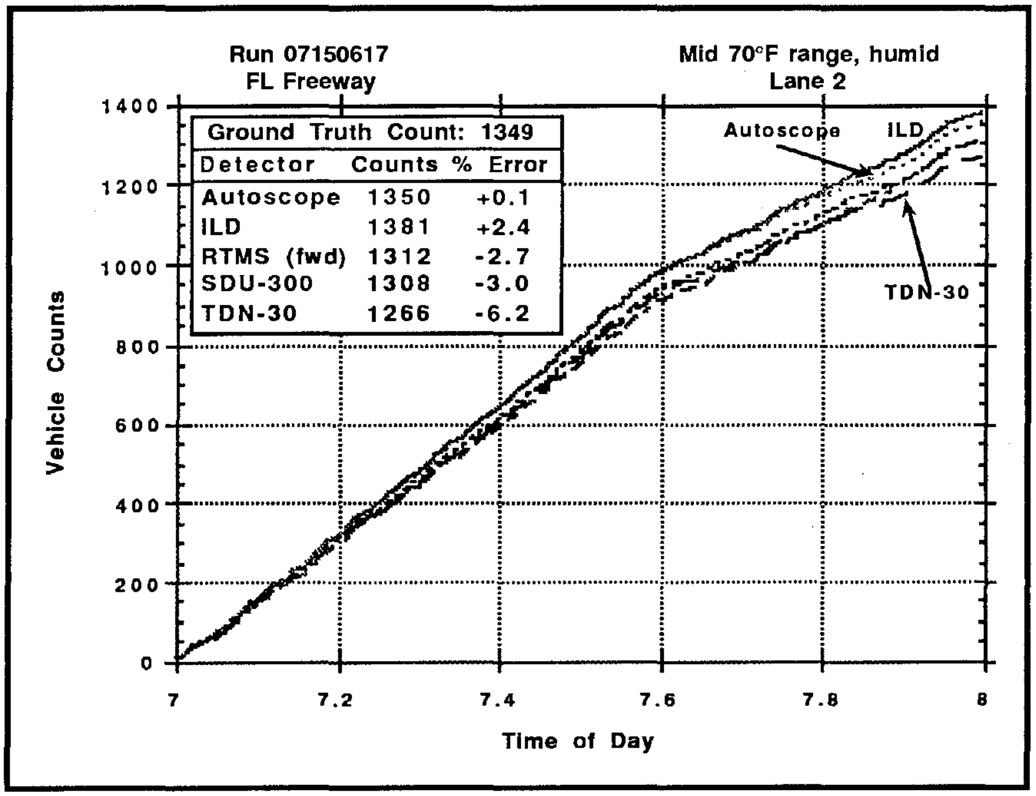
The reason for this seems to be that the RTMS is counting some vehicles more than once during periods of heavy congestion. It is likely that multiple reflections (i.e., radar backscatter signals) from the vehicles contributed to the overcount in the second half of the hour.



°C = 5(°F-32)/9

Figure 8. Comparison of Vehicle Counts With Ground Truth for Five Detectors in Lane 1 From the I-4 Florida Freeway Site

Figure 9 shows plotted results of accumulated vehicle counts for five detectors in lane 2 (middle lane) for a 1-hour ground truth time window. The Autoscope proved to be closest in count to the ground truth value, while the loop was calculated to overcount by 2.4 percent. The remaining three detectors in Figure 9 all undercounted and were, in order of best performance, the forward-looking RTMS true-presence microwave radar, the SDU-300 ultrasonic detector, and the TDN-30 microwave Doppler detector.

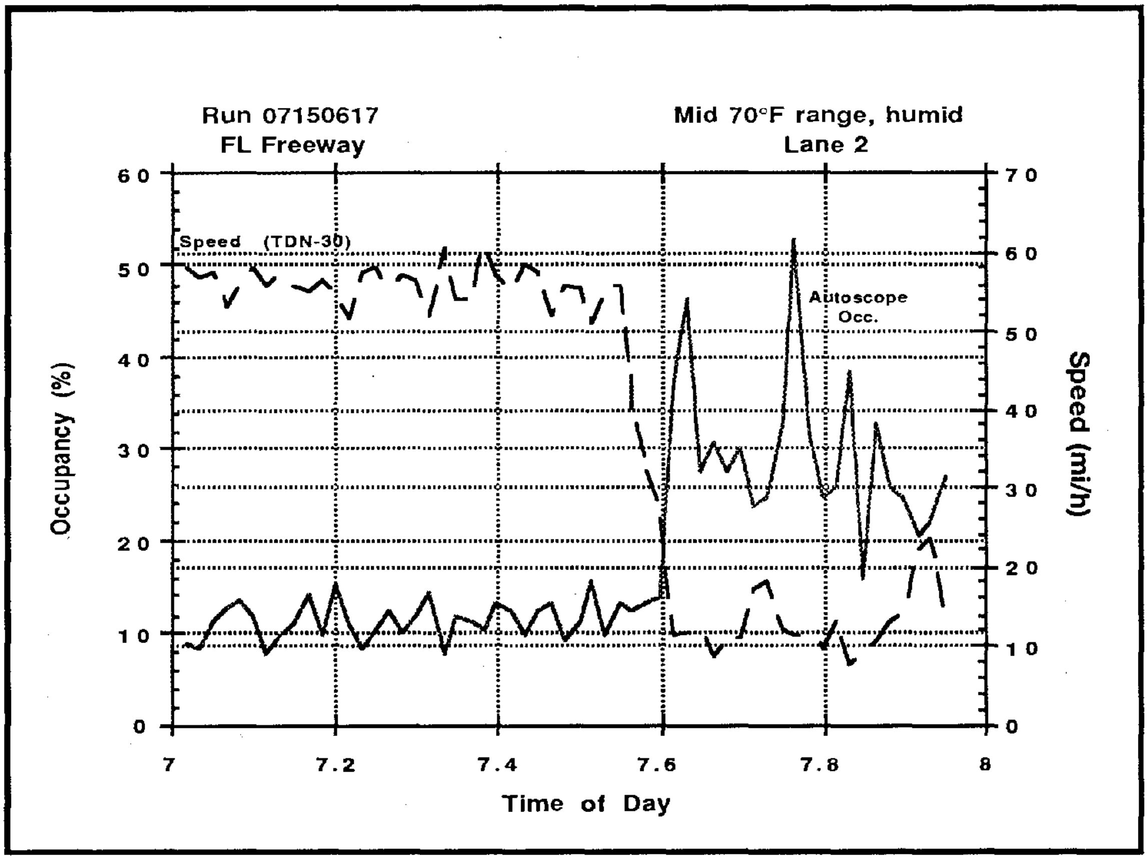


°C = 5(°F-32)/9

Figure 9. Comparison of Vehicle Counts With Ground Truth for Five Detectors in Lane 2 From the I-4 Florida Freeway Site

Figure 10 demonstrates the relationship between vehicle speed and lane occupancy during the same 1-hour period examined in the two previous figures. These results came from the middle traffic lane (lane 2). The speed was provided directly via the RS-232 output from the TDN-30 narrow-beam microwave Doppler detector. The scale corresponding to the speed values is on the right-side vertical axis, while the percentage occupancy is shown on the left-side vertical axis. Occupancy was plotted for the Autoscope 2003 VIP.

The figure demonstrates the inverse relationship that most detectors exhibit between speed and occupancy. Logically, when speeds decrease, vehicles tend to dwell for a longer time period in the detectors' sensing areas. This results in an increase in lane occupancy, such as that displayed by the Autoscope output in Figure 10.



°C = 5(°F-32)/9

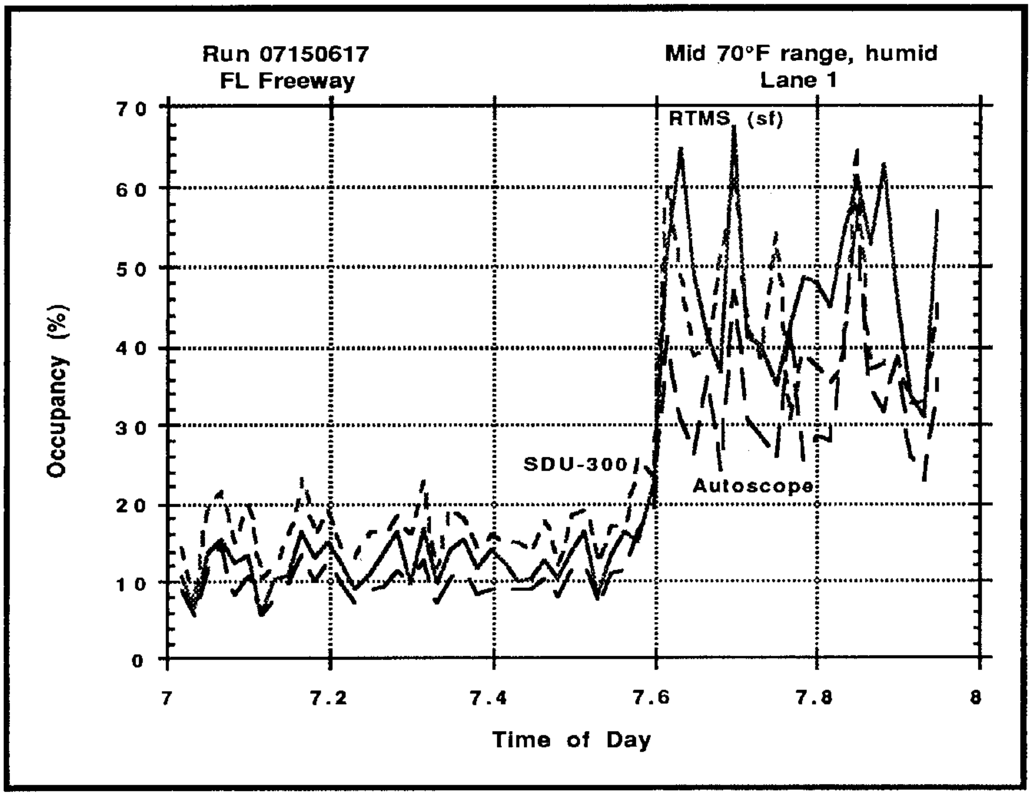
1 mi/h = 1.61 km/h

Figure 10. Comparison of Lane Occupancies and Speed During Heavy Traffic in Lane 2 From the I-4 Florida Freeway Site

Figure 11 shows lane-occupancy curves for three detectors in lane 1 of Run 07150617. This graph illustrates the disparity of results between three devices operating in a presence mode. The three presence-type units were the side-looking RTMS microwave radar, the SDU-300 ultrasonic detector, and the Autoscope 2003 VIP.

Predictably, these presence-type devices generated high-occupancy values when the traffic slowed considerably.

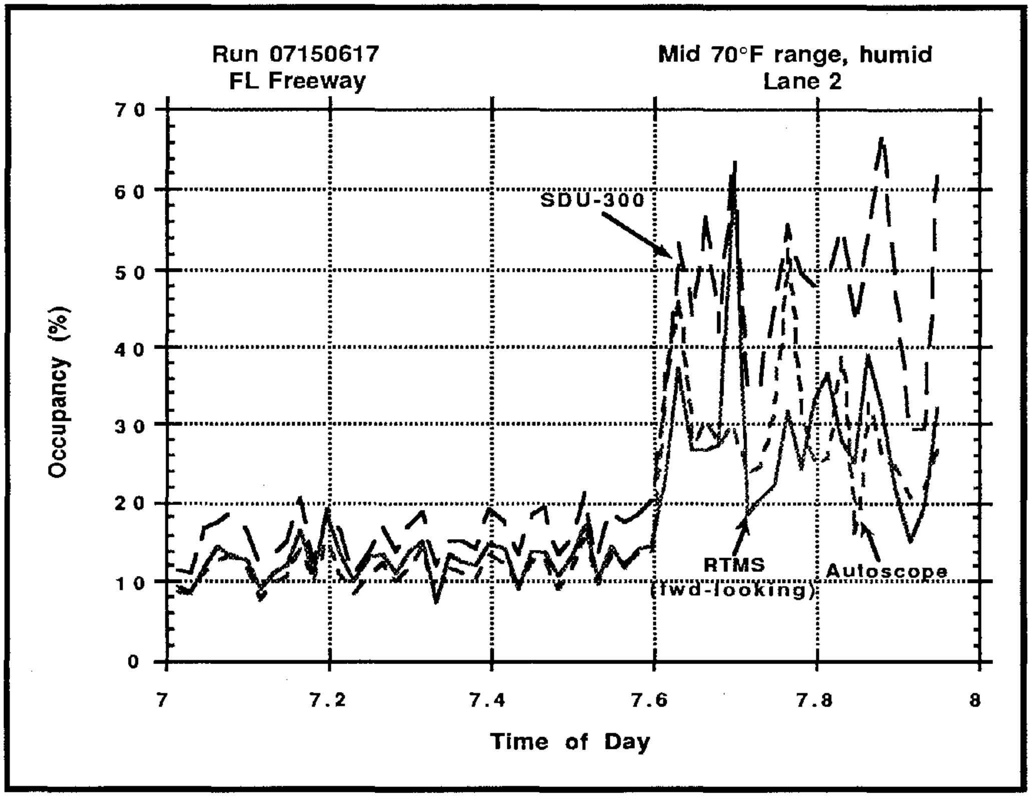
During periods of high occupancy, two closely spaced vehicles occupy a portion of the same detection zone before the falling edge of the pulse generated by the lead vehicle has been processed, causing the passage of these two (or more) vehicles often to be interpreted as a single event. This causes such detectors to undercount during periods of bumper-to-bumper traffic.



°C = 5(°F-32)/9

Figure 11. Comparison of Lane Occupancies From Three Detectors in Lane 1 From the I-4 Florida Freeway Site

Figure 12 reinforces the findings made in the previous section. Three presence-type devices, the SDU-300 ultrasonic detector, the forward-looking RTMS microwave radar, and the Autoscope 2003 VIP, all registered high occupancies when the traffic flow slowed.



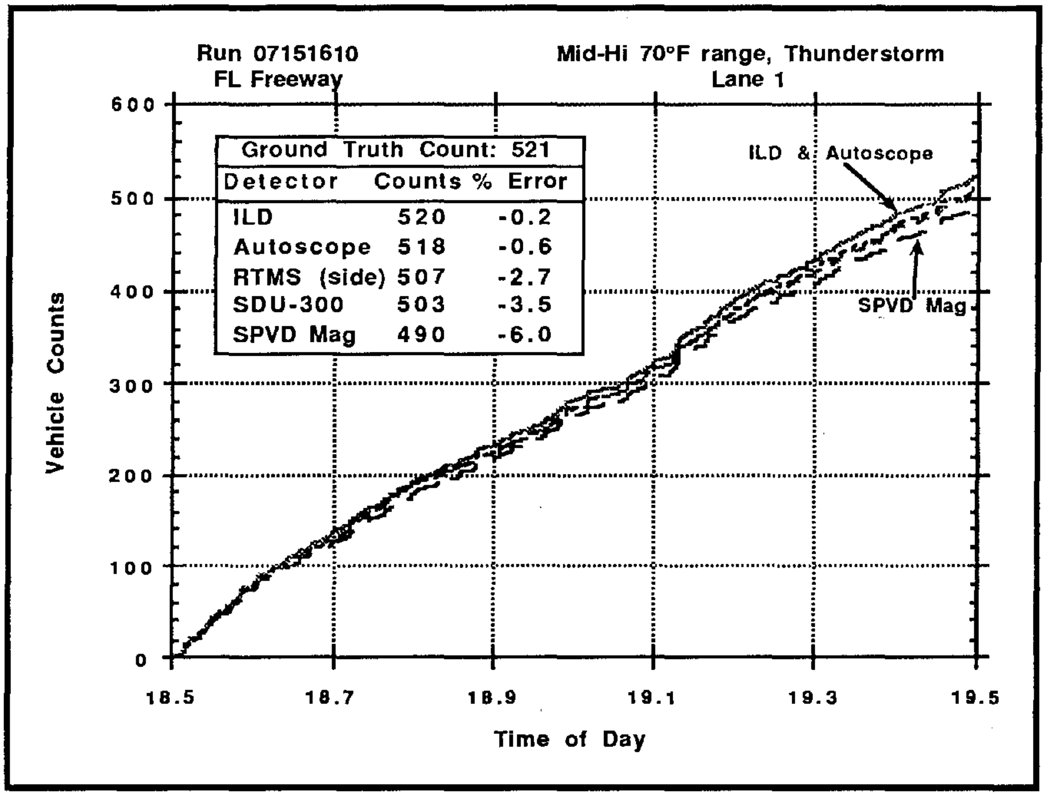
°C = 5(°F-32)/9

Figure 12. Comparison of Lane Occupancies From Three Detectors in Lane 2 From the I-4 Florida Freeway Site

Run 07151610

The temperature during this session ranged from the mid 70's °F to the low 80's °F (around 24 to 28°C). The sky was cloudy and an afternoon thunderstorm brought light drizzle that was evident during the early part of the run.

Figure 13 shows count results for five detectors in lane 1 from this light-traffic run. Again, the inductive loop in lane 1 proved to be the most accurate in terms of vehicle counts, undercounting by a single count over the 1-hour period. The Autoscope 2003 VIP undercounted by only 0.6 percent, while the side-looking RTMS microwave radar, the SDU-300 ultrasonic detector, and the SPVD magnetometer undercounted by 2.7, 3.5, and 6.0 percent, respectively.

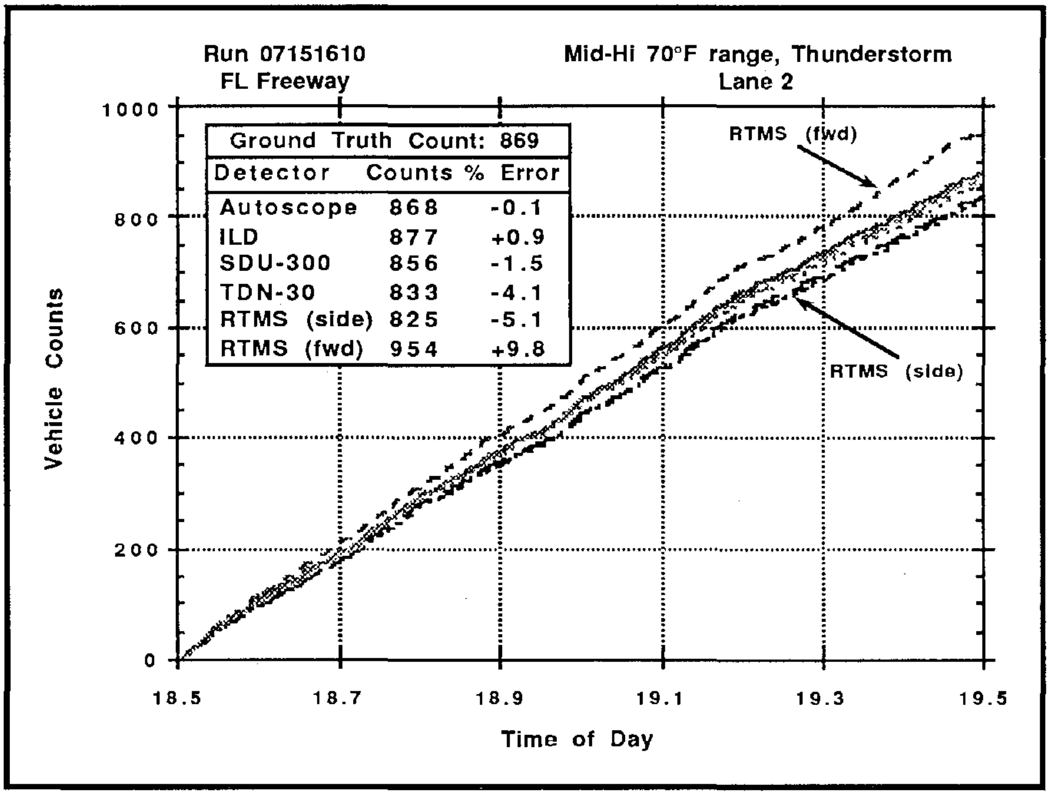


°C = 5(°F-32)/9

Figure 13. Comparison of Vehicle Counts With Ground Truth for Five Detectors in Lane 1 From the I-4 Florida Freeway Site

Figure 14 shows the lane 2 results from the same run for six detectors. The Autoscope 2003 VIP showed the best count accuracy in lane 2, followed closely by the inductive loop. Rounding out the field are the SDU-300 ultrasonic, the TDN-30 microwave Doppler detector, and the side-looking and forward-looking RTMS microwave radars. The nearly 10 percent overcount attributed to the forward-looking RTMS is probably due to "splashing," or the detection of vehicles in lanes of traffic adjacent to the lane under examination.

Splashing is a phenomenon common to detectors that employ relatively wide beams of transmitted energy as part of their detection scheme. It is difficult to optimally match the size of the beam footprint on the roadway to the dimensions of the lane. Thus, the beam is often either too large or too small at the detection zone or point of interest. If the beam is too large, the unit will detect vehicles in adjacent lanes. Conversely, if the beam is too small compared to the width of the lane, it may miss motorcycles or maneuvering vehicles that are not centered in the lane.



°C = 5(°F-32)/9

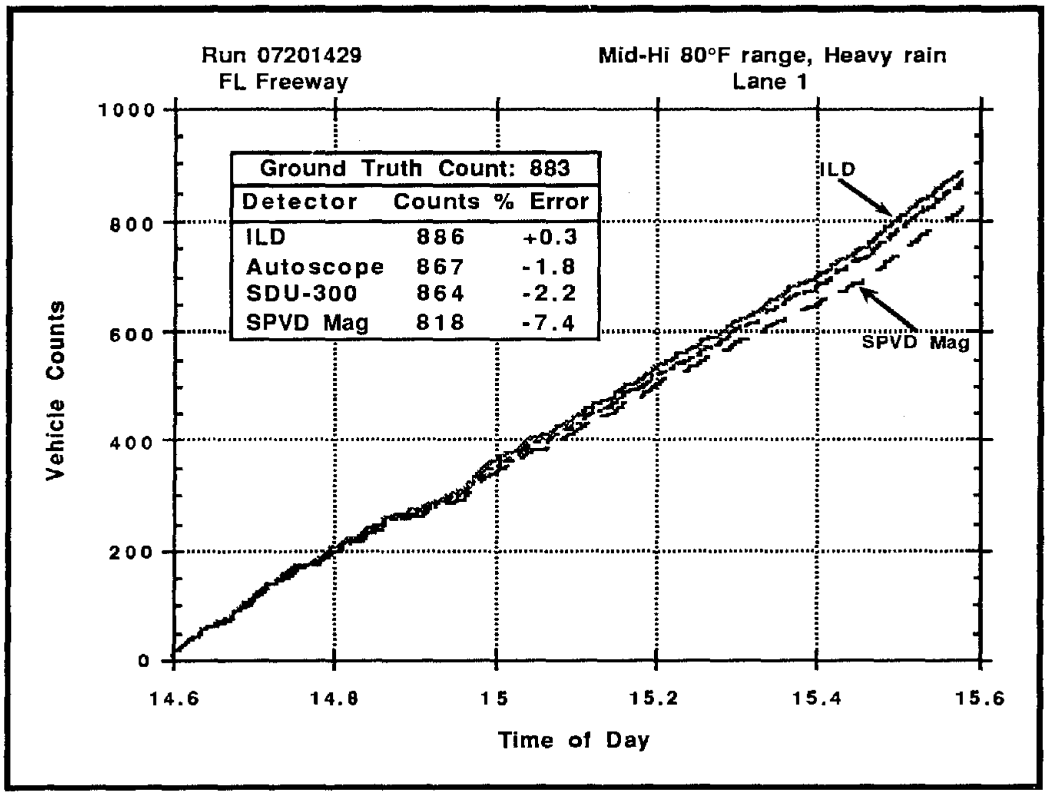
Figure 14. Comparison of Vehicle Counts With Ground Truth for Six Detectors in Lane 2 From the I-4 Florida Freeway Site

Run 07201429

This short run was characterized by a thunderstorm accompanied by heavy rain.

Outputs from four detectors are plotted in Figure 15. Percent errors were computed with respect to ground truth values. The most accurate count detector in lane 1 was again the inductive loop, which was within 0.3 percent of the manually obtained value. The second most accurate device in terms of count was the Autoscope 2003 VIP, followed by the SDU-300 ultrasonic unit and the SPVD magnetometer.

One important result from this run is the apparent insensitivity of the count results to the extreme weather conditions encountered. It is believed that, in general, the traffic conditions are of greater importance than the weather conditions to the reported accuracies. The performance of most of the detectors was comparable or better than results obtained in fair weather runs under similar traffic conditions.

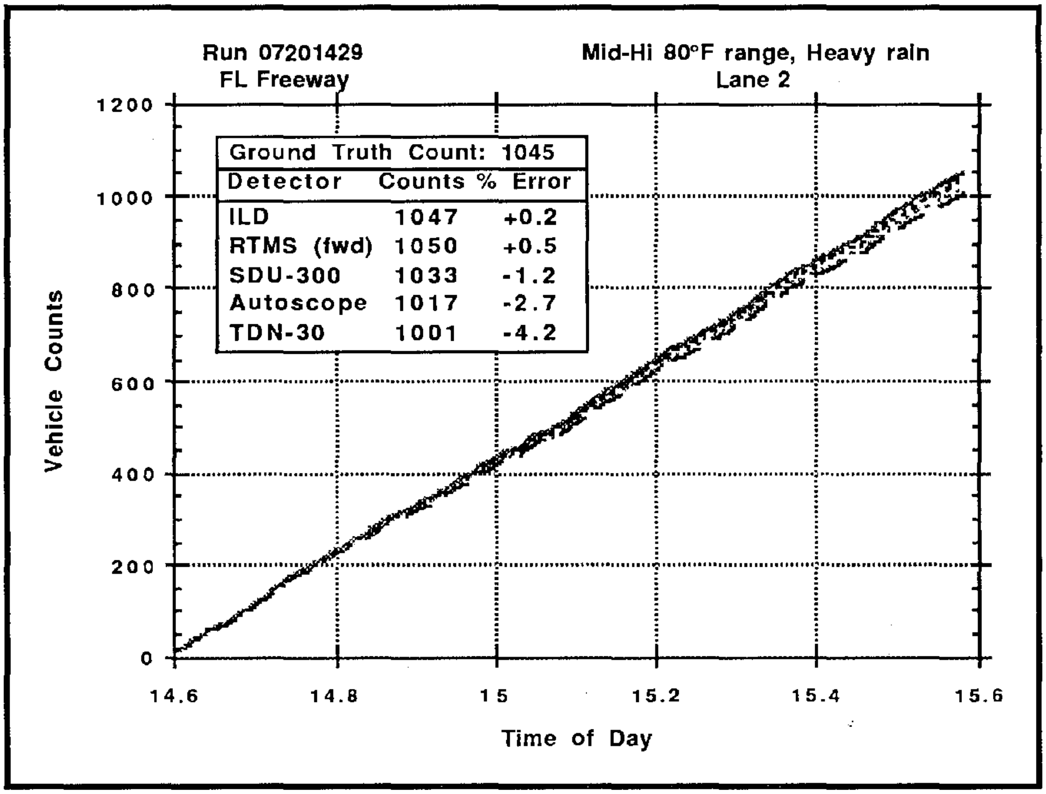


°C = 5(°F-32)/9

Figure 15. Comparison of Vehicle Counts With Ground Truth for Four Detectors in Lane 1 From the I-4 Florida Freeway Site

Figure 16 shows the lane 2 results for the same run. The five curves of detector count are all fairly linear and are consistent in their shapes. The accuracies of the listed detectors compare favorably with results from other Florida freeway runs recorded during a similar time of day under fair weather conditions. This indicates that the adverse weather under which these data were collected had minimal or no impact on detector performance for all of the detection technologies under evaluation.

The inductive loop again led the way in accuracy, showing an overcount of a mere 0.2 percent, while the forward-looking RTMS true-presence microwave radar showed an overcount of only 0.5 percent. The remaining three detectors represented in Figure 16 each undercounted: the SDU-300 ultrasonic detector undercounted by 1.2 percent, the Autoscope 2003 VIP by 2.7 percent, and the TDN-30 microwave Doppler detector by 4.2 percent.



°C = 5(°F-32)/9

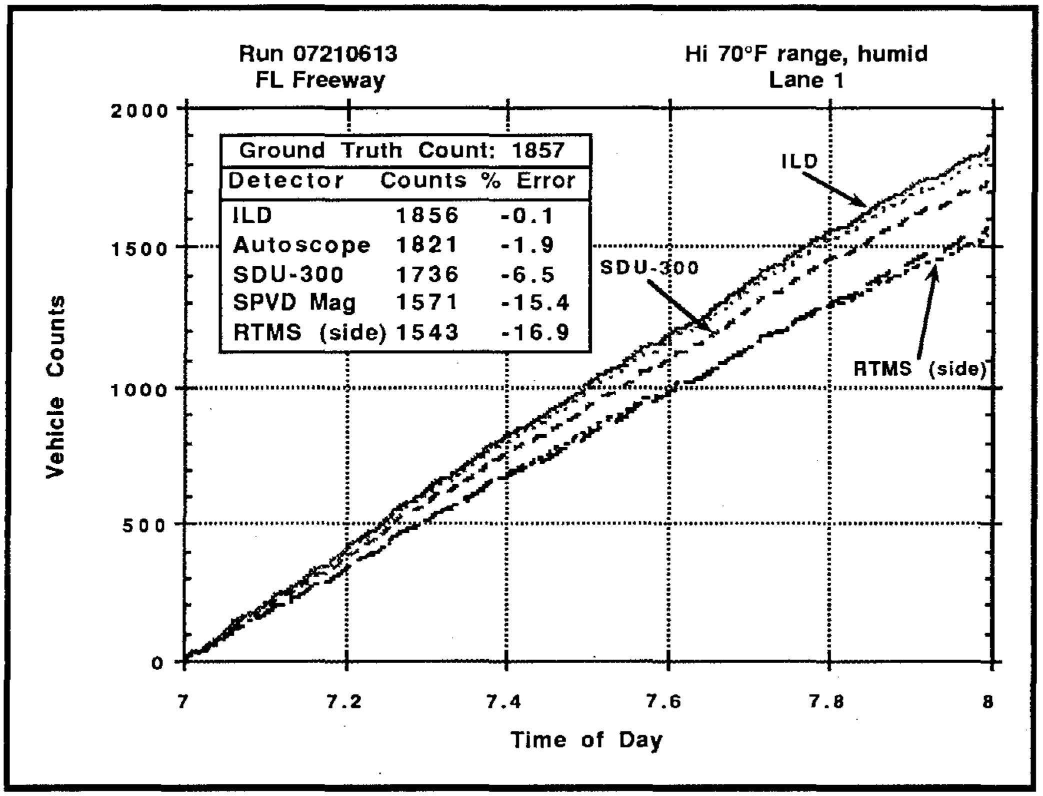
Figure 16. Comparison of Vehicle Counts With Ground Truth for Five Detectors in Lane 2 From the I-4 Florida Freeway Site

Run 07210613

This run was conducted in high humidity with the temperature ranging from the high 70's °F to the high 80's °F (approximately 25 to 31°C).

Figure 17 shows the lane 1 count results versus ground truth for five detectors. The traffic was fairly heavy and the weather was humid.

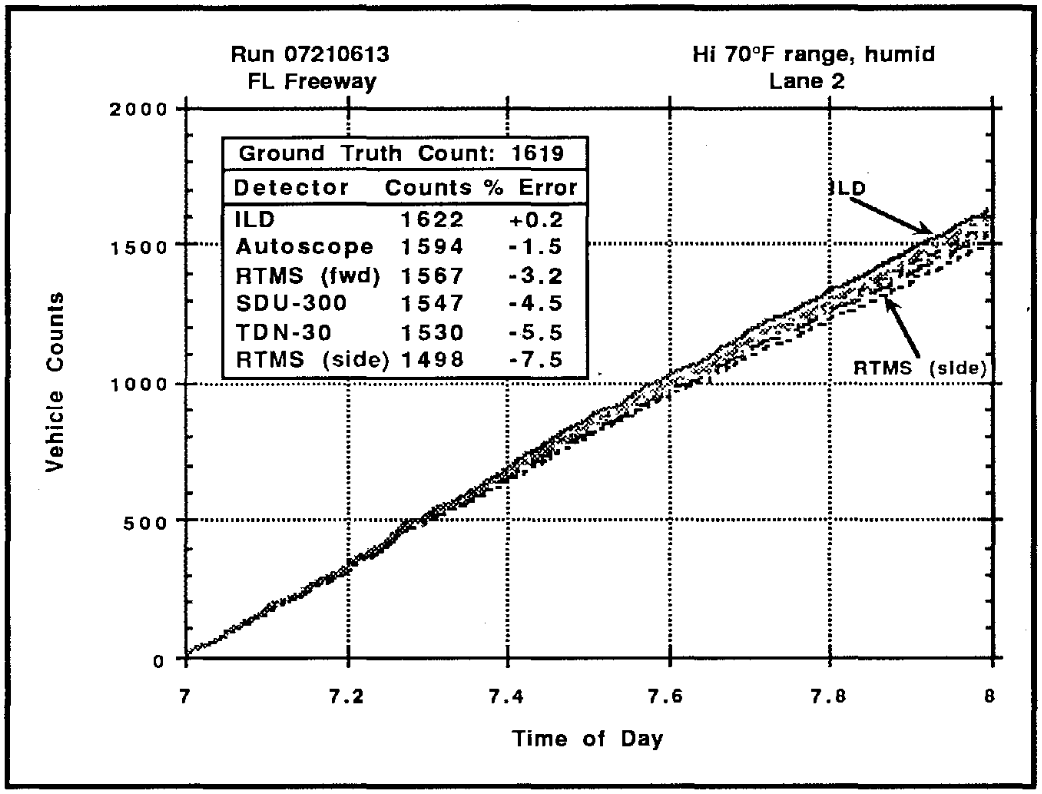
The inductive loop in lane 1 registered to within a single count of the ground truth value obtained from the recorded video imagery. The Autoscope 2003 was accurate to within 2 percent, while the SDU-300 ultrasonic detector undercounted by 6.5 percent. The SPVD magnetometer and RTMS true-presence microwave radar (in a side-looking orientation) both registered double-digit percent errors.



°C = 5(°F-32)/9

Figure 17. Comparison of Vehicle Counts With Ground Truth for Five Detectors in Lane 1 From the I-4 Florida Freeway Site

The lane 2 count results show a much tighter spread when compared to the lane 1 results from the same run. The inductive loop was calculated to have overcounted by 0.2 percent. The remaining five curves all represent detectors that undercounted with respect to the measured ground truth. The Autoscope 2003, the forward-looking RTMS microwave radar, and the SDU-300 ultrasonic unit all undercounted by less than 5 percent, while the TDN-30 and the side-firing RTMS lagged behind. These results are largely consistent with results from the other ground truth runs from the same site under comparable conditions.



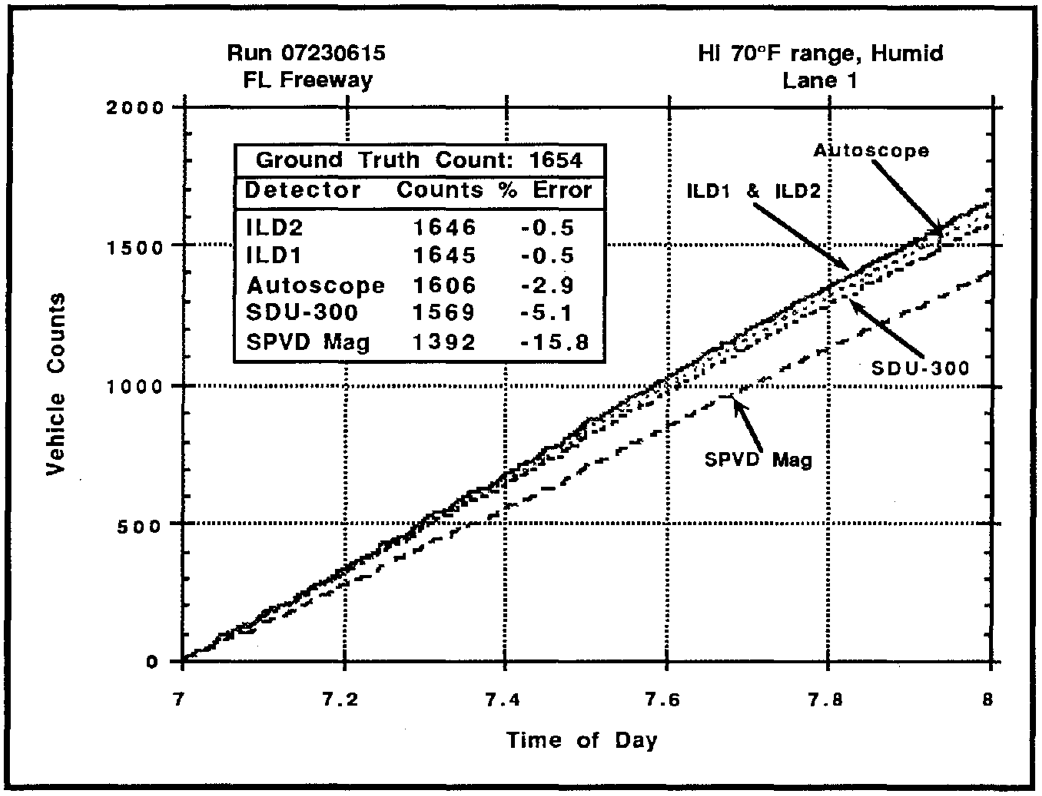
°C = 5(°F-32)/9

Figure 18. Comparison of Vehicle Counts With Ground Truth for Six Detectors in Lane 2 From the Florida Freeway Site

Run 07230615

The weather was bright and sunny with the temperature hovering in the 70 to 80°F range (around 21 to 27°C) and humid.

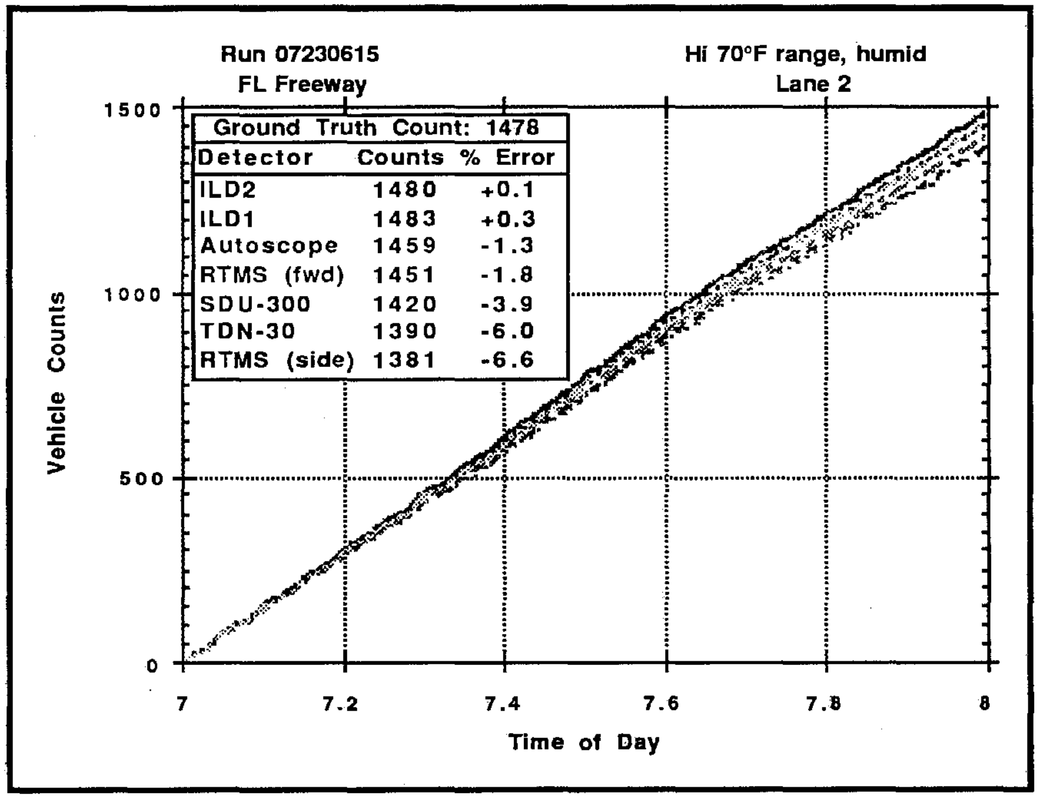
Figure 19 shows count results from five detectors in lane 1 for a ground truth session. Included are both inductive loop outputs, the Autoscope 2003 VIP, Sumitomo SDU-300 ultrasonic detector, and SPVD magnetometer. The two loops showed agreement with one another to within a single count, and were within 0.5 percent of the observed ground truth value. The results from the other three units were comparable to results recorded in other Florida freeway runs.



°C = 5(°F-32)/9

Figure 19. Comparison of Vehicle Counts With Ground Truth for Five Detectors in Lane 1 From the I-4 Florida Freeway Site

Figure 20 includes curves for seven detectors in lane 2, including both inductive loops. The leaders in count accuracy were the two ILDs registering 99.7 for ILD1 and 99.9 percent for ILD2 accuracies. Autoscope 2003 and the forward-looking RTMS registered undercounts of 1.3 and 1.8 percent, respectively. The next most accurate group included the SDU-300 at 3.9 percent, the TDN-30 at 6 percent, and the side-looking RTMS at 6.6 percent.



°C = 5(°F-32)/9

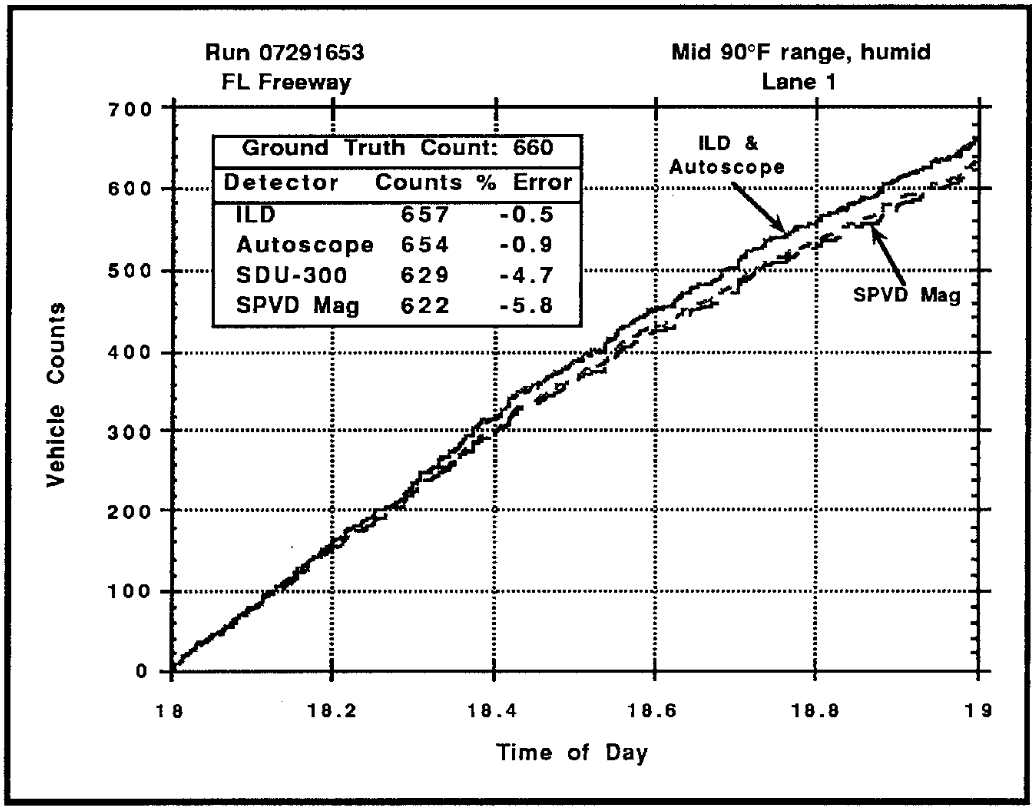
Figure 20. Comparison of Vehicle Counts With Ground Truth for Seven Detectors in Lane 2 From the I-4 Florida Freeway Site

Run 07291653

The temperature during this run was in the mid 90°F range (around 35°C) and the air was humid.

Figure 21 illustrates results from a light-traffic afternoon run. Counts from an inductive loop, Autoscope 2003 VIP, SDU-300 ultrasonic detector, and SPVD magnetometer are shown for lane 1. The SPVD magnetometer performed better under the light-traffic conditions prevalent in the afternoon than it did in the heavier traffic typical of the morning runs.

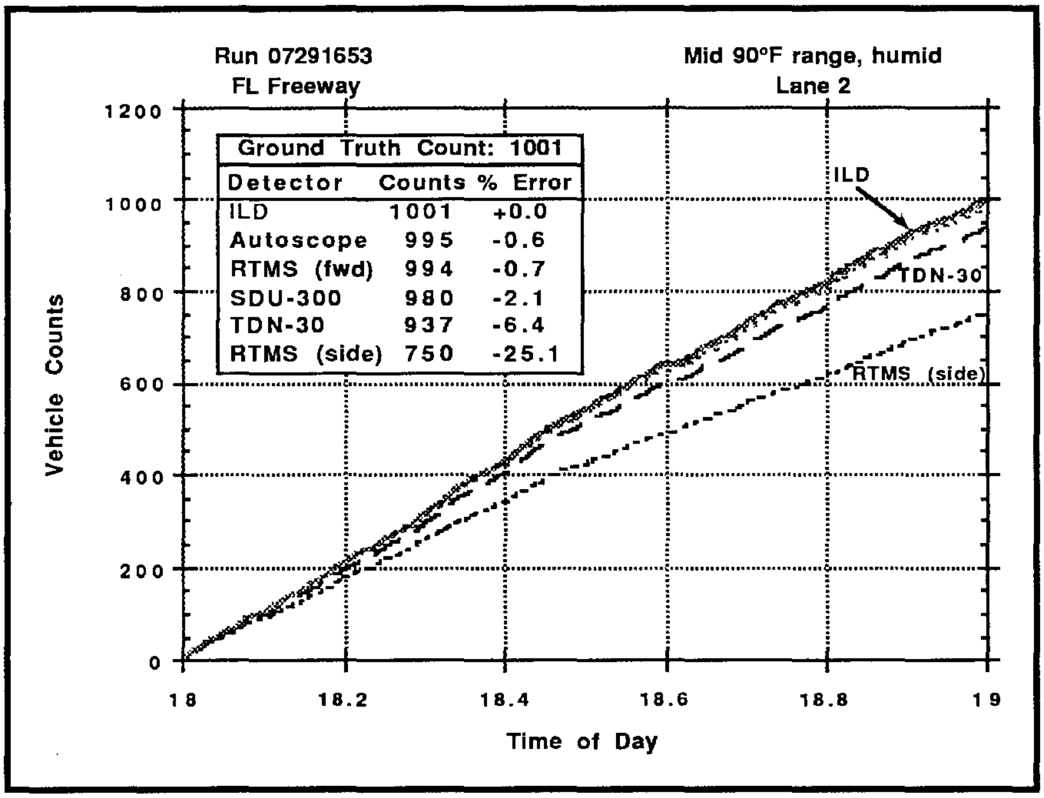
The loop and the Autoscope were both within 1 percent error, while the SDU-300 and SPVD magnetometer showed undercounts of 4.7 and 5.8 percent, respectively.



°C = 5(°F-32)/9

Figure 21. Comparison of Vehicle Counts With Ground Truth for Four Detectors in Lane 1 From the I-4 Florida Freeway Site

The count performance of the inductive loops continued to be impressive in the lane 2 results shown in Figure 22. The counts from the ILD matched the ground truth count exactly. Two other detectors had count accuracies within 1 percent of the ground truth result, those being the Autoscope 2003 VIP and the forward-looking RTMS microwave radar. The counts from the SDU-300 ultrasonic unit and the TDN-30 microwave Doppler detector were consistent with the other ground truth afternoon Florida freeway runs. One device that experienced a noticeable degradation in performance was the side-looking RTMS, which apparently missed detecting one out of every four vehicles.



°C = 5(°F-32)/9

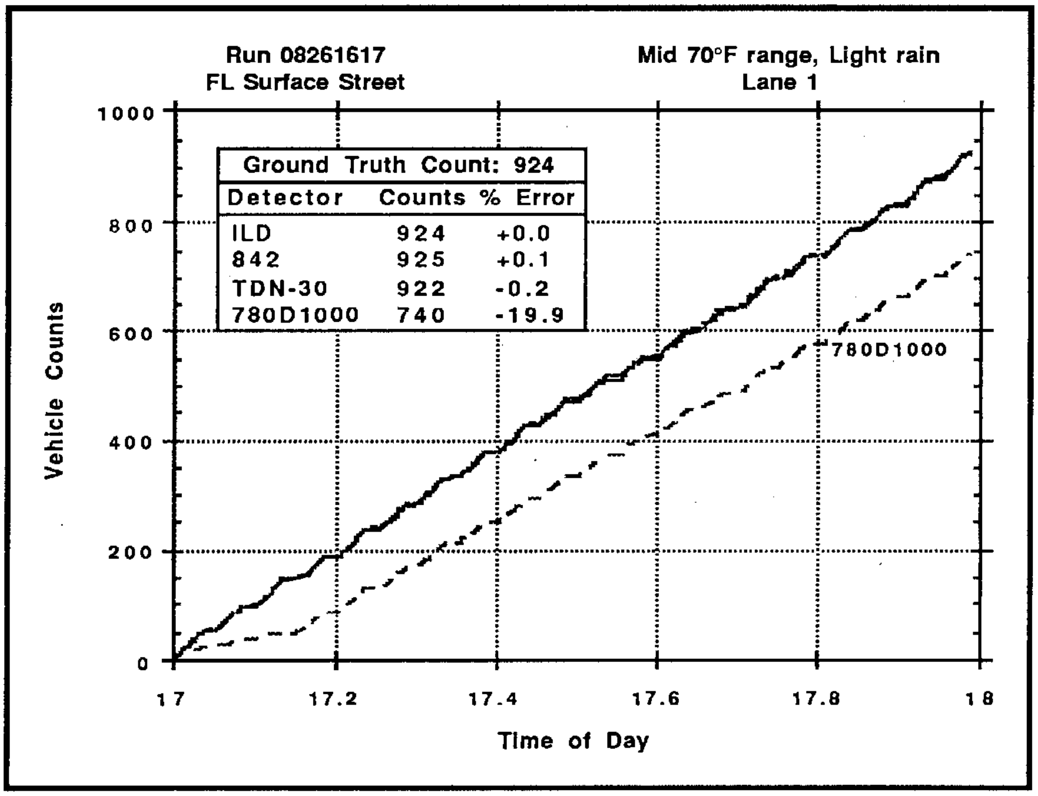
Figure 22. Comparison of Vehicle Counts With Ground Truth for Six Detectors in Lane 2 From the I-4 Florida Freeway Site

5. RESULTS FROM FLORIDA SURFACE STREET RUNS

Run 08261617

Light rain fell during this session, with the temperature hovering in the mid 70°F range (around 24°C).

Figure 23 shows the accumulated counts for four detectors in lane 1. Three detectors showed excellent agreement with the ground truth value. The counts recorded by the inductive loop matched the ground truth identically, while the 842 passive infrared detector and the TDN-30 microwave Doppler detector were off by one and two counts, respectively. The fourth curve in Figure 23 represents the 780D1000 laser radar, which undercounted by nearly 20 percent during the interval. The majority of the undercounts attributed to the laser radar occurred during the first 10 minutes of this 1-hour interval. The reason for this anomaly is not known. The unit later experienced a malfunction and had to be replaced, so it may be assumed that the device might have been experiencing problems during this run.



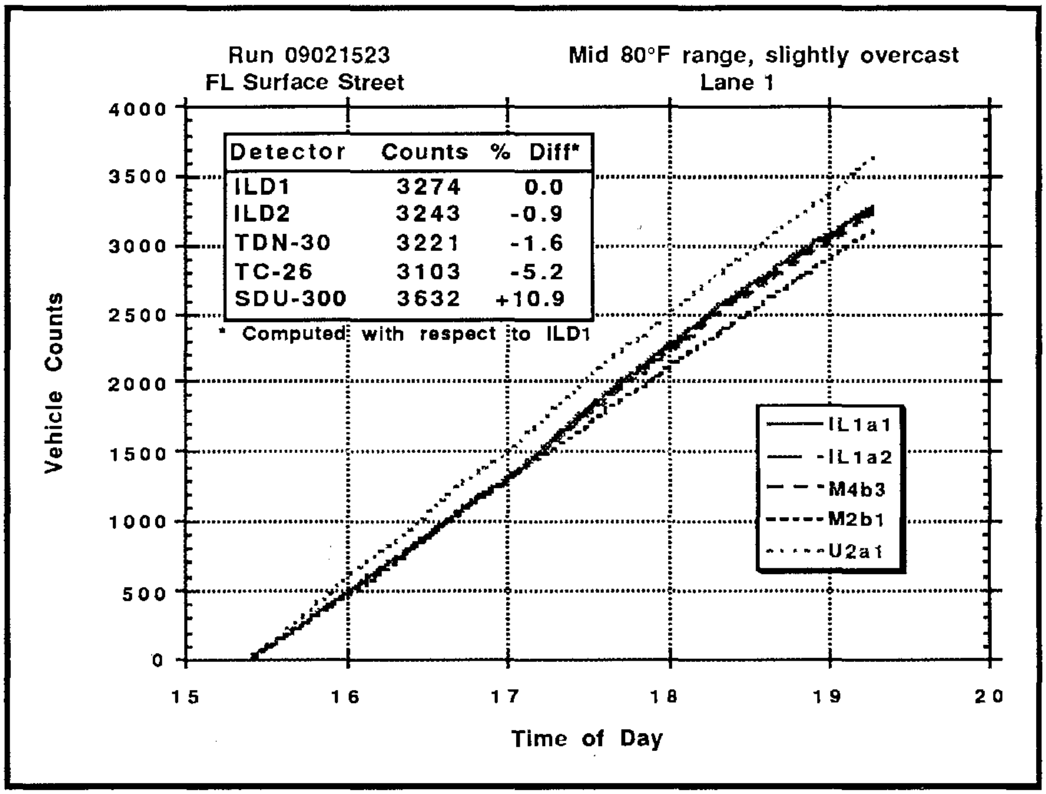
°C = 5(°F-32)/9

Figure 23. Comparison of Vehicle Counts With Ground Truth for Four Detectors in Lane 1 From the I-4 Florida Freeway Site

Run 09021523

Rain stopped just prior to the commencement of the run; thus, the pavement was wet at the beginning of the session. The weather was humid and in the mid 80°F range (around 30°C).

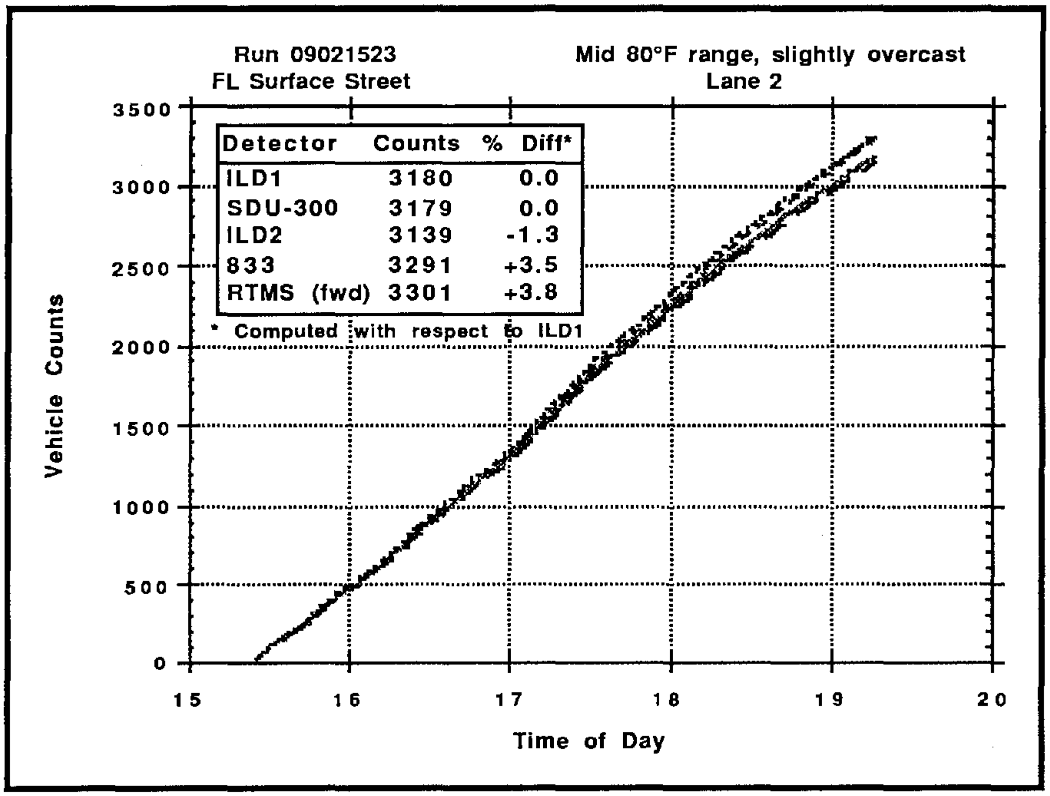
Figure 24 shows count results for five detectors in lane 1. The first inductive loop in the lane was chosen as the reference against which the other devices were compared. The second inductive loop in the lane measured counts to within 0.9 percent of the loop 1 value. The loops were followed in accuracy by two microwave units, the TDN-30 and TC-26, and the ultrasonic SDU-300 detector.



°C = 5(°F-32)/9

Figure 24. Comparison of Vehicle Counts From Five Detectors in Lane 1 From the Florida Surface Street Site

The five detectors represented in Figure 25 show a tight grouping with respect to the referenced count from the first inductive loop (ILD1). The count reported by the SDU-300 differed by only one over the nearly 4-hour period, while the second ILD undercounted by 1.3 percent with respect to the lead loop in lane 2. The 833 passive infrared detector and the forward-looking RTMS true-presence microwave radar overcounted by 3.5 and 3.8 percent, respectively, compared to the loop 1 results.



°C = 5(°F-32)/9

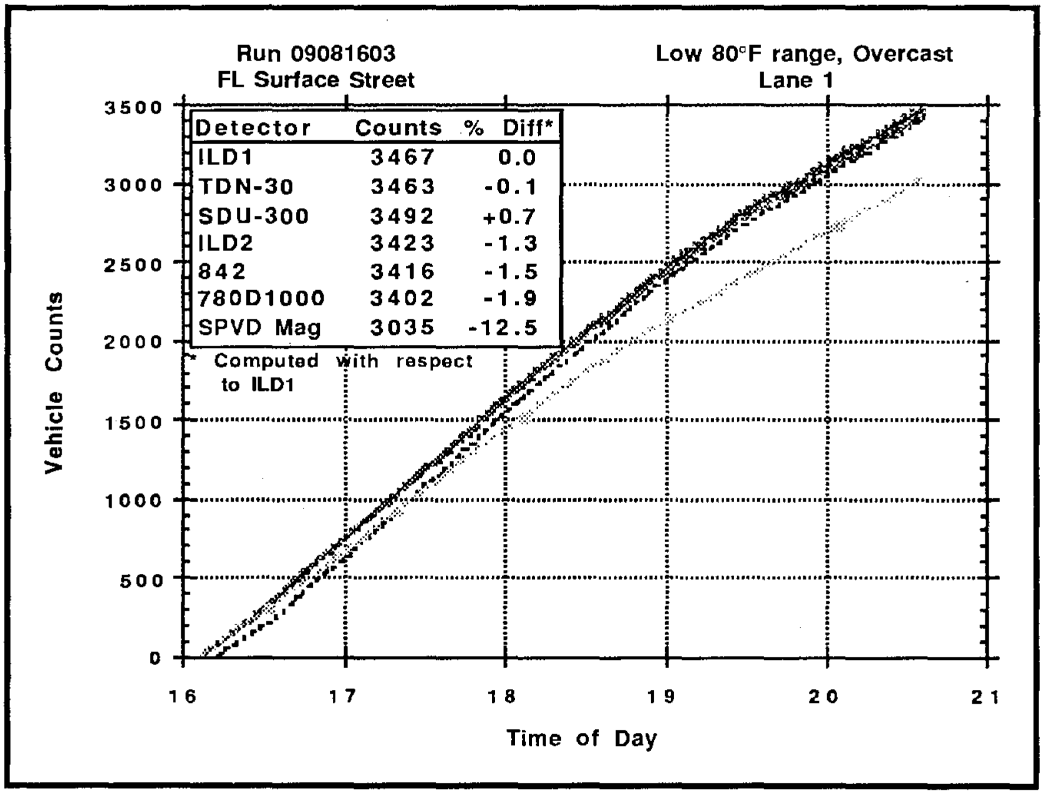
Figure 25. Comparison of Vehicle Counts From Five Detectors in Lane 2 From the Florida Surface Street Site

Run 09081603

The weather at the beginning of the run was overcast With temperatures in the low 80's °F (around 28°C).

Figure 26 shows the count results from seven detectors, using the count from ILD1 as the reference value. The percent difference between the TDN-30 narrow-beam microwave Doppler detector and ILD1 was 0.1 percent lower, while the SDU-300 ultrasonic detector was 0.7 percent higher than the reference value. The second ILD, the 842 passive infrared detector, and the 780D1000 laser radar all undercounted by between 1 and 2 percent With respect to the referenced ILD1 value.

The SPVD magnetometer was deployed underneath the bridge structure that supported the roadway under evaluation. This placement of the SPVD magnetometer was attempted to test the sensitivity of the device, as the unit had to extract signals through thick steel beams, cables, re-bar, and concrete. The SPVD sensitivity was not readjusted for this mounting location from that used in its normal installation beneath a road surface. Although the device registered an undercount of 12.5 percent with respect to the reference loop, it must be stressed that the utilization of the unit in this way was experimental, and the sensitivity demonstrated by the SPVD magnetometer was truly impressive.



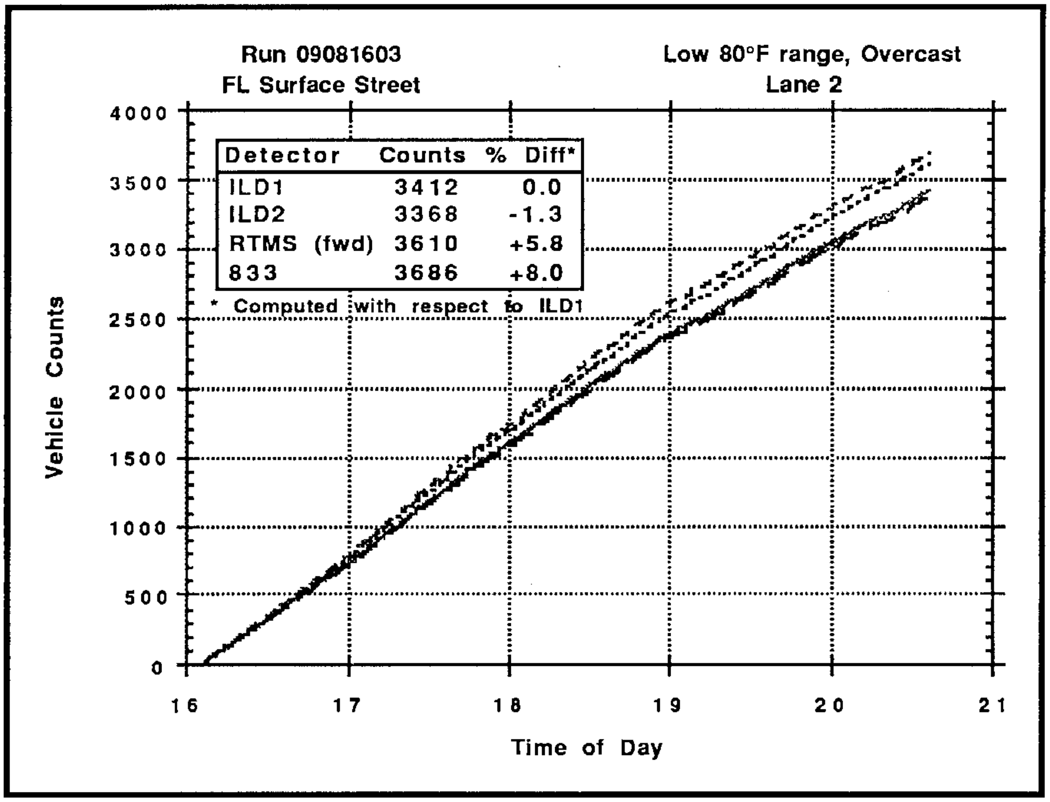
°C = 5(°F-32)/9

Figure 26. Comparison of Vehicle Counts From Seven Detectors in Lane 1 From the Florida Surface Street Site

Figure 27 shows curves representing four detectors monitoring lane 2. The lead loop was used as the reference for purposes of computing percent differences. These plots demonstrate the difficulty encountered when monitoring sections of roadway where traffic tends to jump from lane to lane. The detectors represented in Figure 27 monitor different sections of the roadway. Portions of their sensing areas may overlap, but physical constraints imposed by the detectors, coupled with different mounting geometries, dictated that the units were not all able to monitor a common detection zone.

If the vehicle movements (lane changes, swerving maneuvers, etc.) are of a random nature, then the net effect of these movements over a long enough period of time would be negligible. But, if the movements tend to occur in a given direction more frequently than in another, a statistical bias is created in the numerical results.

An effort was made during the site-selection process to choose locations where the lane changing would be minimized or at least random. For this reason, it was decided not to monitor lanes that were near on-ramps or off-ramps, where lane changing would tend to be in a specific direction.



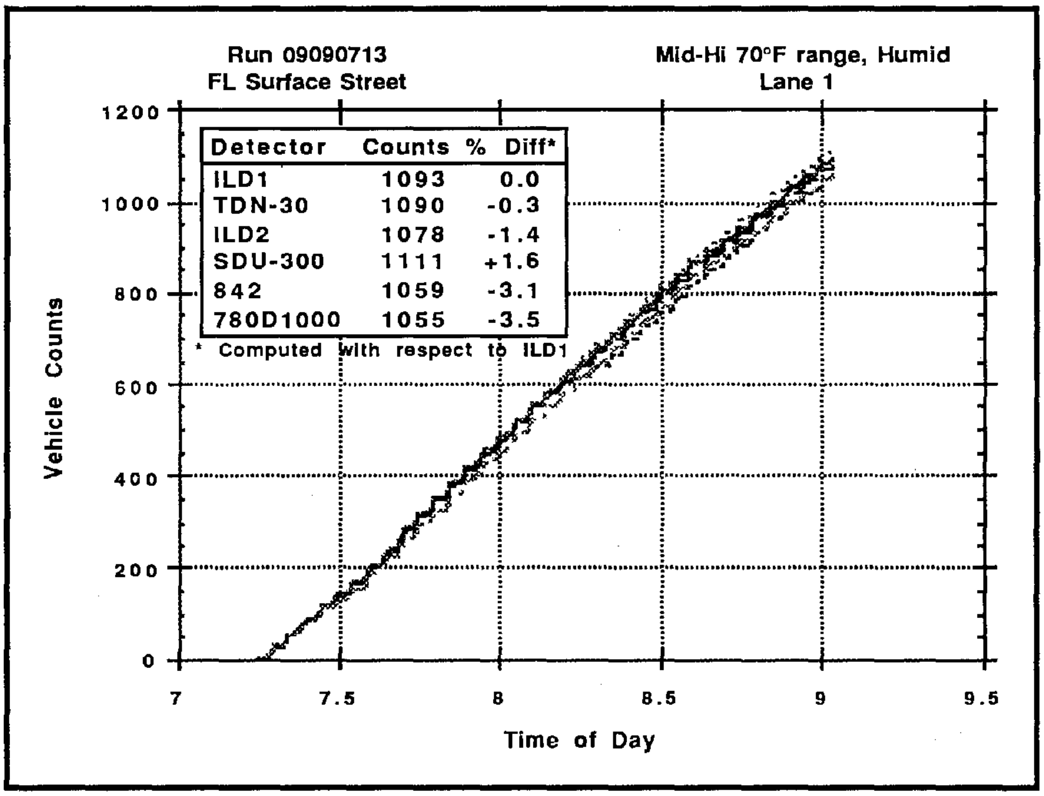
°C = 5(°F-32)/9

Figure 27. Comparison of Vehicle Counts From Four Detectors in Lane 2 From the Florida Surface Street Site

Run 09090713

The weather conditions at the beginning of the run were clear and typically humid, with temperatures in the mid 70's to mid 80's °F range (around 24 to 30°C).

Figure 28 shows lane 1 results from six detectors. Again, the first inductive loop provided the reference for count comparison with the other detectors. The discrete, "jumpy" nature of the curve is an effect attributed to the signalized intersections located both before and after the stretch of roadway used as the evaluation site. The signal's green phase allowed a burst of vehicles to pass through the detection zones, and the red phase blocked the next platoon from entering. The quantized nature of these events manifested itself as a "stairstep" artifact when viewing the accumulated counts.



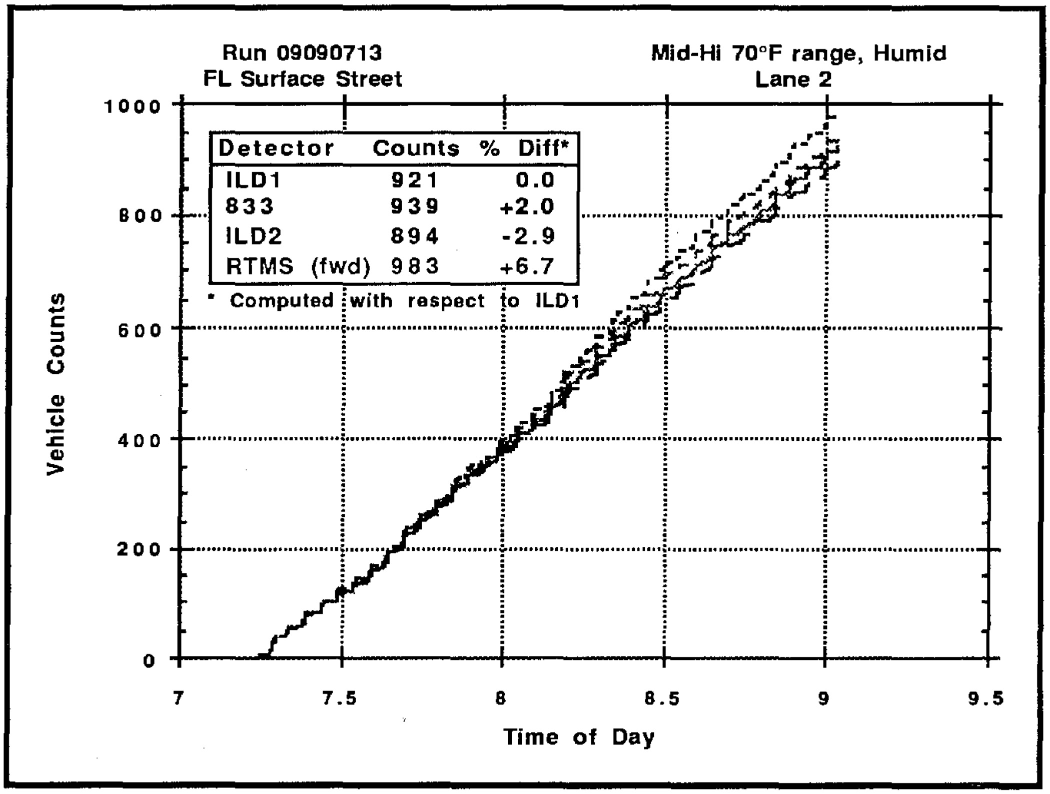
Detector	Counts	% Diff*
ILD1	1093	0.0
TDN-30	1090	-0.3
ILD2	1078	-1.4
SDU-300	1111	+1.6
842	1059	-3.1
780D1000	1055	-3.5

* Computed with respect to ILD1

°C = 5(°F-32)/9

Figure 28. Comparison of Vehicle Counts From Six Detectors in Lane 1 From the Florida Surface Street Site

Figure 29 shows plotted count results from four detectors monitoring lane 2. The first loop in the lane again provides the reference against which the counts from the other units are compared. The 833 passive infrared detector overcounted by 2 percent with respect to the first inductive loop. The second inductive loop in the lane registered 2.9 percent fewer counts than the lead loop, while the forward-looking RTMS reported 6.7 percent more counts than the reference loop. The RTMS consistently overcounted at this site. This was likely due to the increased mounting height at this location, which tended to cause problems with most of the overhead detectors by increasing the footprint on the roadway.



°C = 5(°F-32)/9

Figure 29. Comparison of Vehicle Counts From Four Detectors in Lane 2 From the Florida Surface Street Site

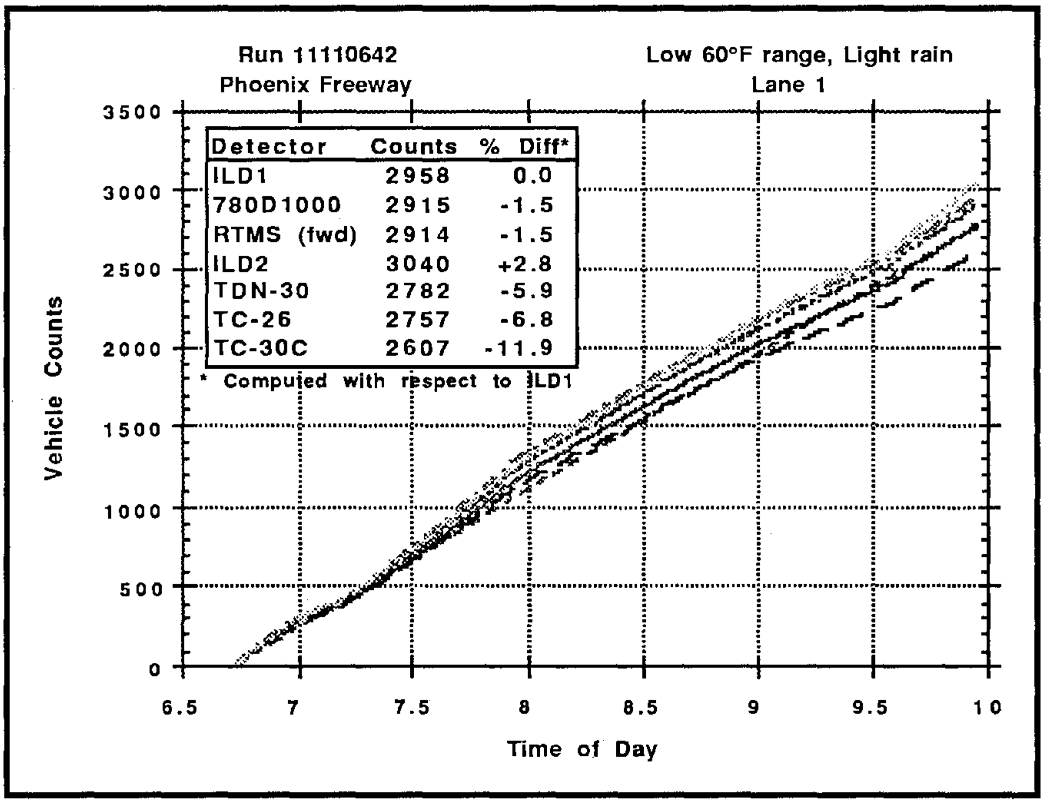
6. RESULTS FROM PHOENIX 1993 FREEWAY RUNS

Run 11110642

The temperature during this run was in the low 60°F range (~17°C) with light rain falling shortly after 7:30 a.m.

Figure 30 shows accumulated counts for seven detectors in lane 1 during the Phoenix 1993 freeway tests. Percent differences were computed using the count from ILD1 as a reference value. It was difficult at the Phoenix freeway site to select one detector that was consistently superior in terms of count performance. For this reason, different detectors were used as references for various runs. The Autoscope 2003 provided a fairly accurate output for most of the runs, but was not installed for this run that occurred early in the test schedule. For the runs that were not ground truthed, computations of *percent difference*, and not *percent error*, were made relative to the detector that was judged by the analyst to be the most accurate for that particular run. The criteria used for these selections included comparisons with results from ground truth runs during similar traffic conditions and times of day.

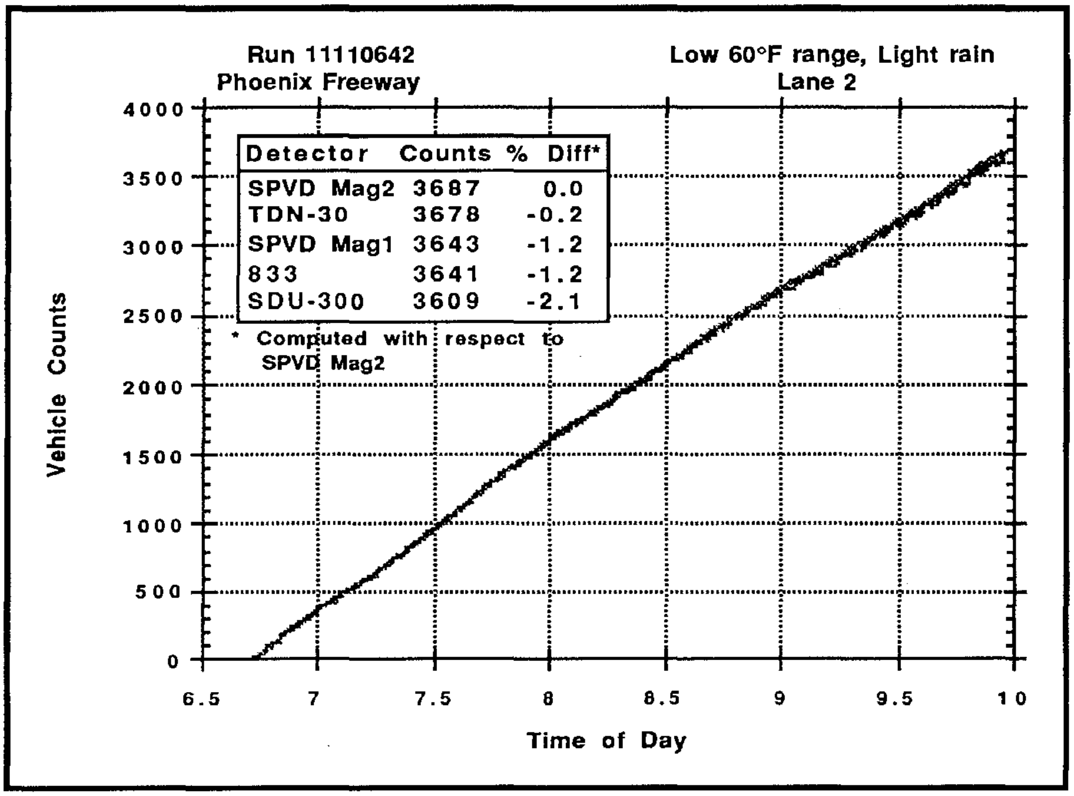
The results shown in Figure 30 indicate a divergence in counts as the greater than 3-hour session unfolds. The 780D1000 laser radar and the forward-looking RTMS microwave radar both counted 1.5 percent less than the lead loop, while the second loop registered 2.8 percent more counts than did ILD1. Two microwave detectors, the TDN-30 and the TC-26, and the ultrasonic TC-30C clearly undercounted.



°C = 5(°F-32)/9

Figure 30. Comparison of Vehicle Counts From Seven Detectors in Lane 1 From the I-10 Arizona Freeway Site

Figure 31 shows the results from lane 2 of the run. For this run, the second SPVD magnetometer was judged to be the most accurate detector; hence, the percent difference calculations were made using this device's output as the reference value. Judging from the relatively narrow spread of the percent difference values, the selection of the magnetometer as the reference appears to have been a good choice.



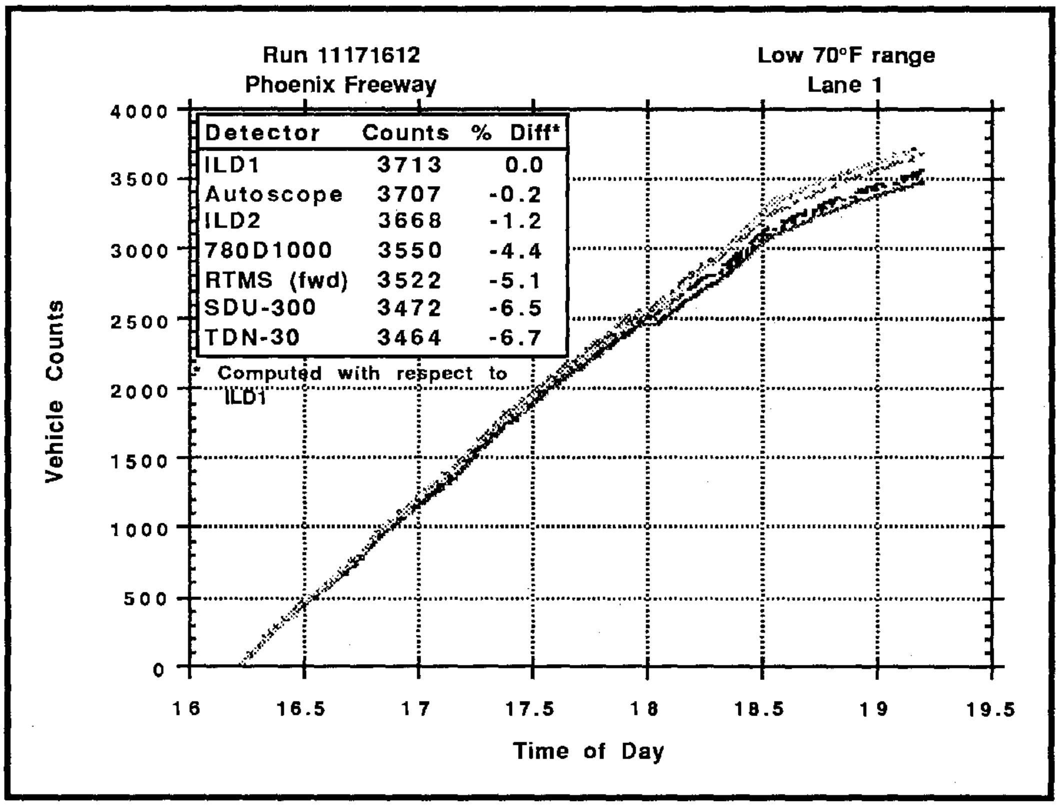
°C = 5(°F-32)/9

Figure 31. Comparison of Vehicle Counts From Five Detectors in Lane 2 From the I-10 Arizona Freeway Site

Run 11171612

The temperature during this run was approximately 70°F (21°C). An accident occurring downstream at around 6:15 p.m. backed traffic up into the detection zones and produced extremely heavy congestion.

Figure 32 contains plotted count results for seven detectors in lane 1 for this run lasting approximately 3 hours. The first loop and the Autoscope 2003 were in close agreement, while the second ILD counted 1.2 percent less than the first ILD. The other four devices— the 780D1000 laser radar, the forward-looking RTMS microwave radar, the SDU-300 ultrasonic detector, and the TDN-30 microwave Doppler detector—all appeared to degrade in performance, apparently due to the congested traffic resulting from the incident that occurred around 6:15 p.m. The TDN-30 Doppler unit is particularly affected in that its operation is dependent on some vehicle motion in the direction expected by the detector. If the vehicles are moving at a speed which is less than the device's threshold detection value (approximately 3 to 5 mi/h [4.8 to 8 km/h), they are not detected or counted.



°C = 5(°F-32)/9

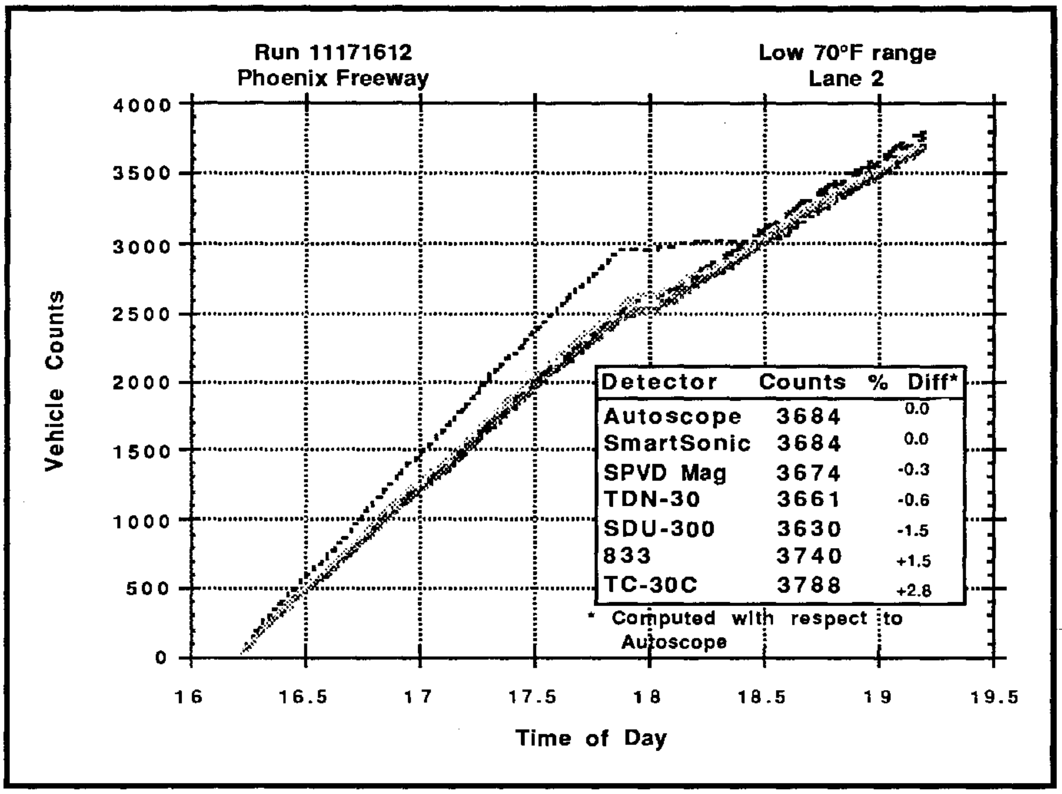
Figure 32. Comparison of Vehicle Counts From Seven Detectors in Lane 1 From the I-10 Arizona Freeway Site

Figure 33 shows the results for seven detectors monitoring traffic in lane 2. Percent differences were computed With respect to the Autoscope 2003 video image processor. A strange anomaly manifested itself in this run. The SmartSonic passive acoustic array appeared to be overcounting by approximately 15 to 20 percent, when an accident occurred downstream shortly before 6:00 p.m. All of the detectors in lane #2 can be seen to "level off" for a 5- to 10-minute period, but the SmartSonic did not seem to recover when the other detectors did. It took a full half hour until the acoustic array resumed detecting vehicles.

Slow bumper-to-bumper traffic presents a difficulty for the passive acoustic array due to a reduction in the signal-to-noise ratio that is inherent in such traffic conditions. The detector tracks the acoustical energy emitted from the interaction of the vehicles' tires and the roadway surface. The energy in this frequency band is less at lower speeds. Couple this With an increase in the noise level due to the congested condition of the stretch of roadway, and the signal-to-noise ratio must inevitably decrease. If the processed result does not exceed the detection threshold set for the system, vehicle detections will cease.

This developmental unit had trouble distinguishing lane 2 events from those occurring in adjacent lanes of traffic. Both the hardware and software have been improved since these field tests and the results from this prototype device should take these facts into consideration. Ironically, the decrease in detection during the time that the SmartSonic did not detect any vehicles offset the overcounts that were recorded up until the time of the accident. Thus, the SmartSonic passive acoustic array yielded a count over the 3-hour data collection interval identical to that reported by the reference detector, the Autoscope 2003 VIP.

The SPVD magnetometer and the TDN-30 narrow-beam microwave Doppler detector undercounted by 0.3 and 0.6 percent, respectively, in comparison to the Autoscope. The SDU-300 ultrasonic detector undercounted by 1.5 percent, while the 833 overcounted by the same amount. The TC-30C ultrasonic unit overcounted by 2.8 percent. The 833 and TC-30C typically undercounted during the Phoenix 1993 tests, so it can be concluded that the heavy traffic conditions were a factor in their overcounting during this run.



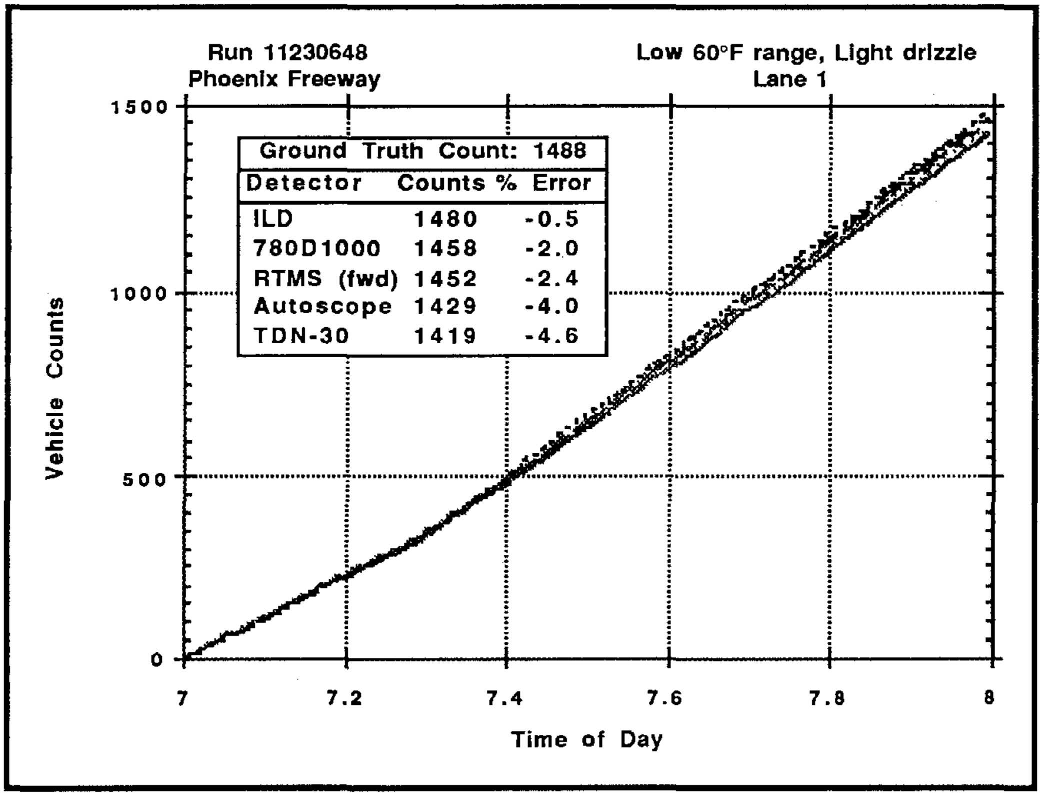
°C = 5(°F-32)/9

Figure 33. Comparison of Vehicle Counts From Seven Detectors in Lane 2 From the I-10 Arizona Freeway Site

Run 11230648

The temperature during this run was in the low 60°F range (around 17°C) with a very light drizzle falling early in the run.

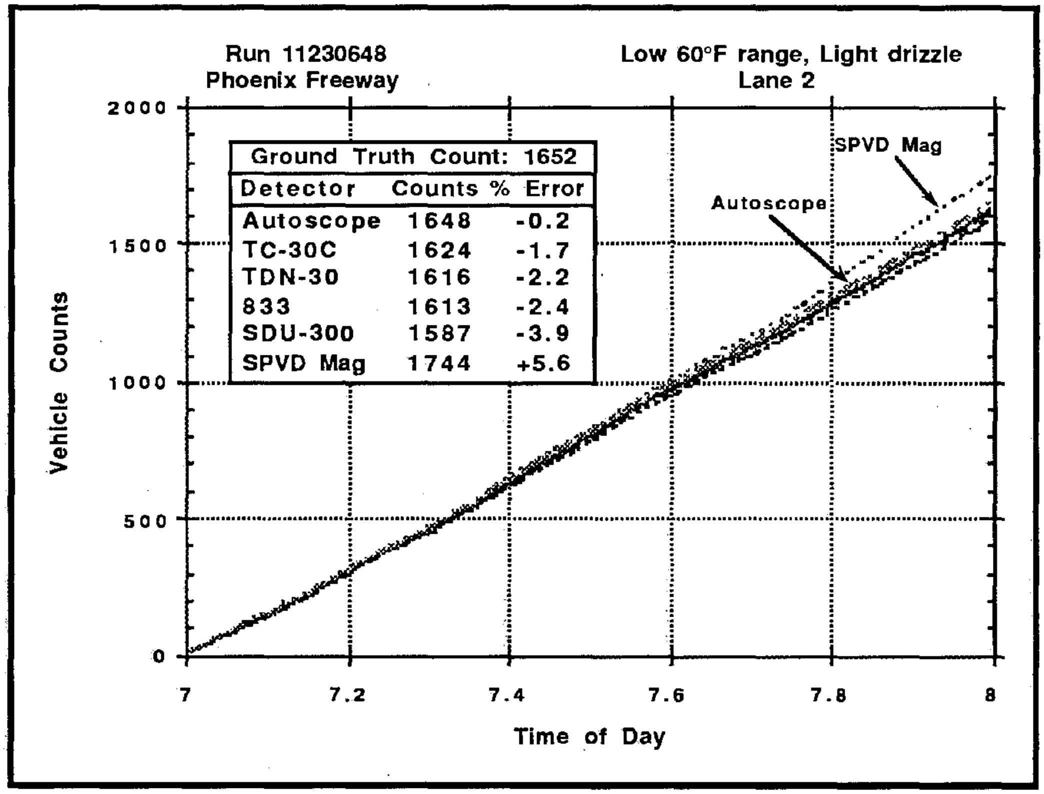
Figure 34 shows the accumulated vehicle counts for five detectors in lane 1 of this ground truth run. The inductive loop was the most accurate count detector, With an error of 0.5 percent on the low side. The laser radar and the forward-looking RTMS microwave radar took up their customary second and third positions. The Autoscope 2003 undercounted by 4 percent with respect to the ground truth, while the TDN-30 microwave Doppler detector was low by 4.6 percent.



°C = 5(°F-32)/9

Figure 34. Comparison of Vehicle Counts With Ground Truth for Five Detectors in Lane 1 From the I-10 Arizona Freeway Site

The lane 2 results in Figure 35 show the Autoscope 2003 as the most accurate device, undercounting by 0.2 percent. It appears that the unit was set up by Econolite personnel in a manner that was more optimal for lane 2. Following the Autoscope in lane 2 count accuracy were the TC-30C ultrasonic detector, the TDN-30 narrow-beam microwave, the 833 infrared detector, the SDU-300 ultrasonic, and the SPVD magnetometer. Both magnetometers seemed to experience some degradation about this time in the testing schedule and were adversely affected for the duration of this testing period. It is believed that at least one of the units sustained some water damage following a rainstorm.



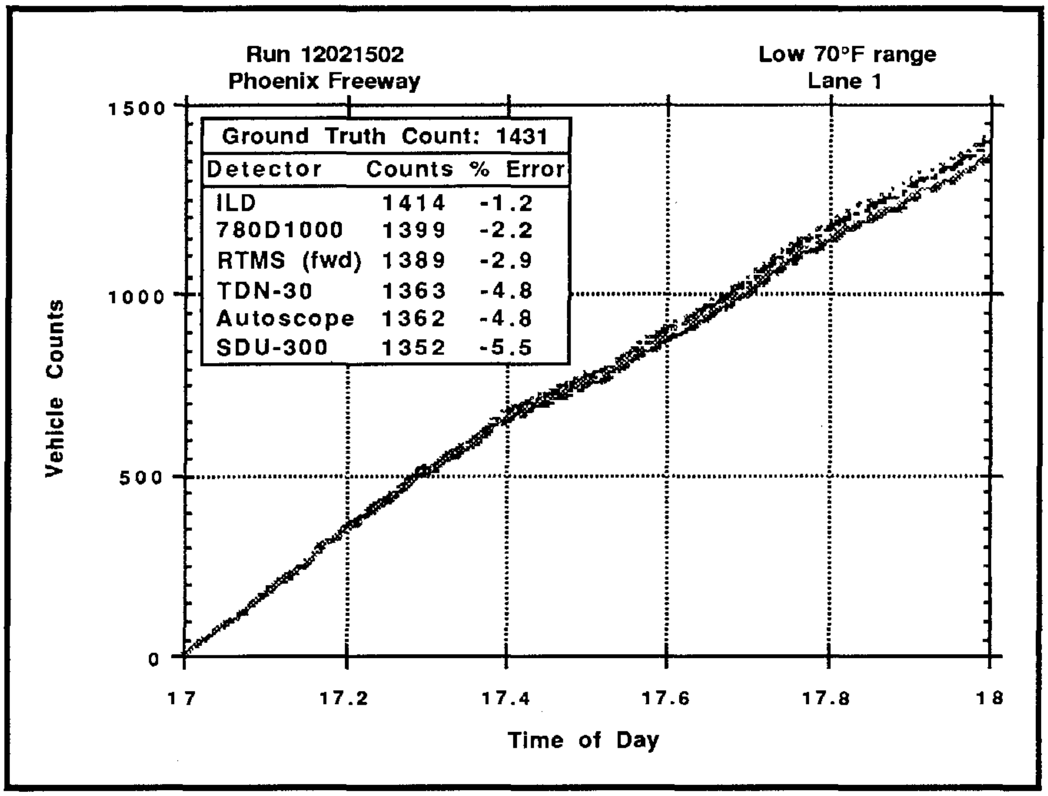
°C = 5(°F-32)/9

Figure 35. Comparison of Vehicle Counts With Ground Truth for Six Detectors in Lane 2 From I-10 Arizona Freeway Site

Run 12021502

The weather conditions during this run were clear skies and a temperature of approximately 70°F (21°C).

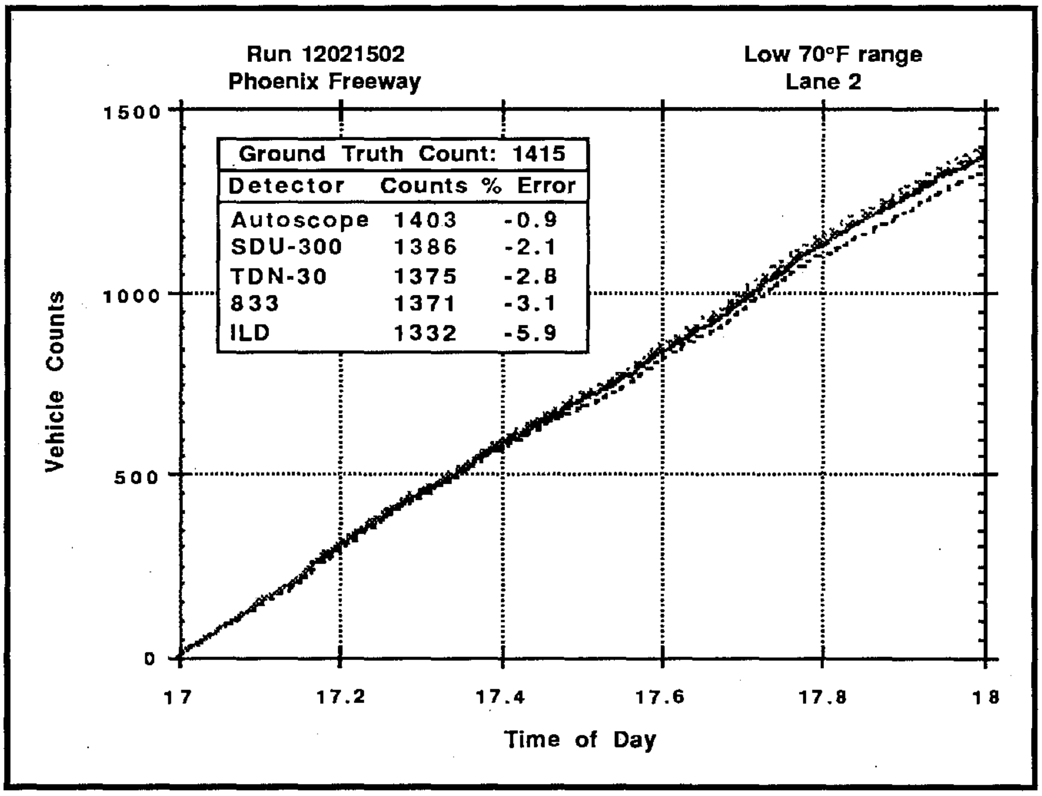
The outputs from six detectors were compared against ground truth obtained from the recorded video imagery. The results are shown in Figure 36. The inductive loop undercounted by 1.2 percent over the 1-hour interval, and proved to be the most accurate count detector in that lane. The laser radar and the forward-looking RTMS microwave radar undercounted by 2.2 and 2.9 percent, respectively. The remaining three plots represent detectors that undercounted in the 5 percent range. These were the TDN-30, the Autoscope 2003 VIP, and the SDU-300.



°C = 5(°F-32)/9

Figure 36. Comparison of Vehicle Counts With Ground Truth for Six Detectors in Lane 1 From I-10 Arizona Freeway Site

Figure 37 shows the comparison of five detectors versus ground truth for lane 2 of the Phoenix freeway site. The Autoscope 2003 VIP demonstrated the best accuracy, with an undercount of 0.9 percent. This performance demonstrates why the Autoscope was typically used as the reference detector in lane 2 of the I-10 freeway. The Autoscope was followed by the SDU-300, the TDN-30, and the 833 in count accuracy. These devices all undercounted by approximately 2 to 3 percent. The last of the plotted curves in lane 2 is for the inductive loop. Problems with the loops were routinely experienced at this site due to some unknown anomaly in the installation process.



°C = 5(°F-32)/9

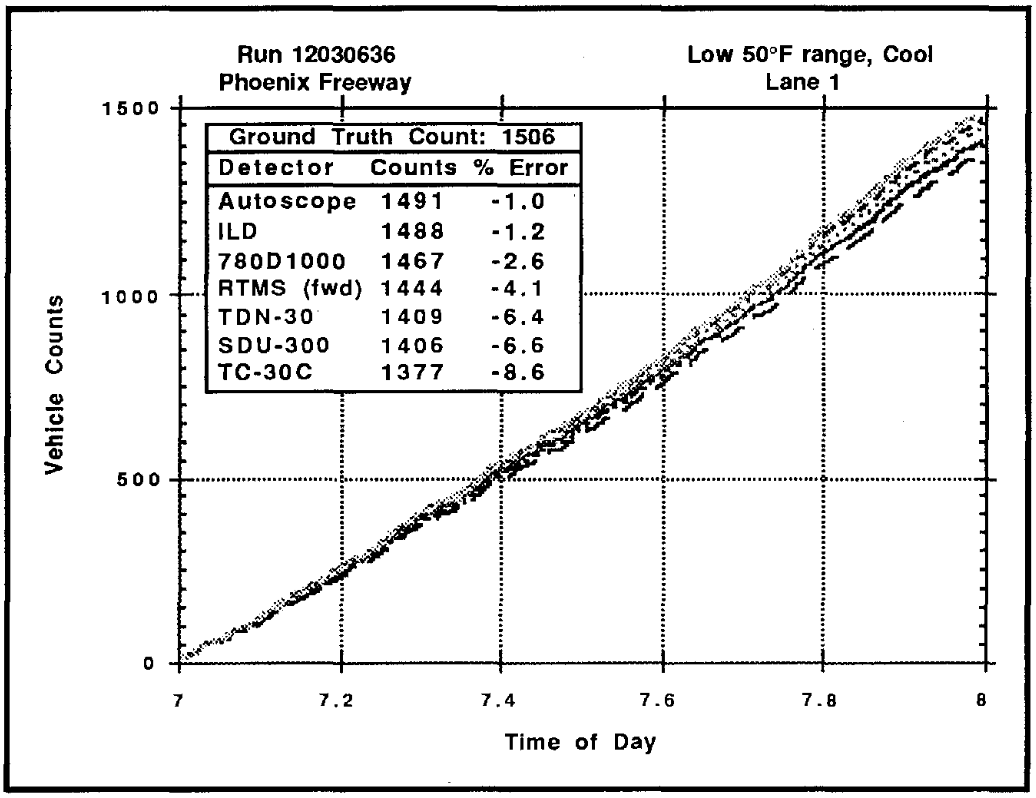
Figure 37. Comparison of Vehicle Counts With Ground Truth for Five Detectors in Lane 2 From I-10 Arizona Freeway Site

Run 12030636

The weather during this session included clear skies and temperatures in the low to mid 50°F range (approximately 10 to 13°C).

This run was ground truthed from 7:00 to 8:00 a.m. Detector count outputs from seven selected detectors were compared against these ground truth values.

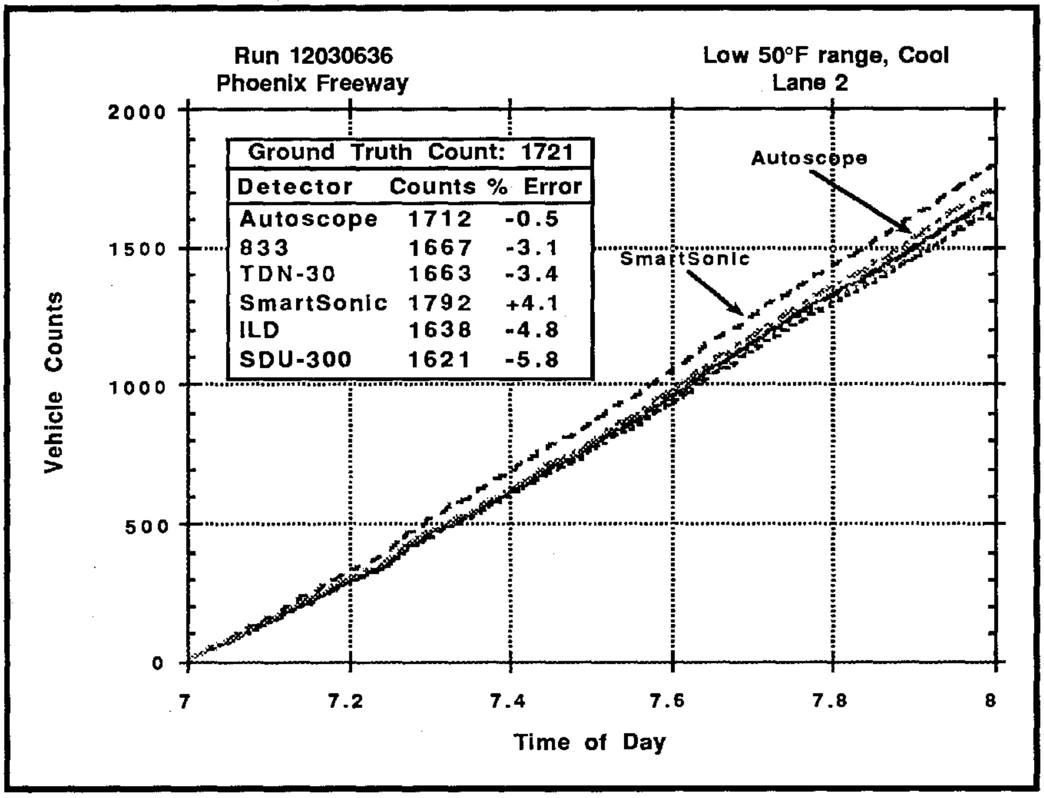
The most accurate detector in lane 1 was the Autoscope 2003 VIP, followed closely by the inductive loop. These two devices undercounted by 1 and 1.2 percent, respectively. The laser radar undercounted by 2.6 percent. The remaining four detectors shown in Figure 38 all undercounted: the forward-looking RTMS undercounted by 4.1 percent and the TDN-30, SDU-300, and TC-30C undercounted by 6.4, 6.6, and 8.6 percent, respectively.



°C = 5(°F-32)/9

Figure 38. Comparison of Vehicle Counts With Ground Truth for Seven Detectors in Lane 1 From Arizona Freeway Site

The lane 2 results for six detectors are illustrated in Figure 39. The Autoscope 2003 was the most accurate detector in terms of count with an undercount of 0.5 percent. The other detectors had errors greater than 3 percent, With the 833 pasive infrared detector coming in second best With 3.1 percent. Of the remaining units, only the SmartSonic passive acoustic array overcounted.



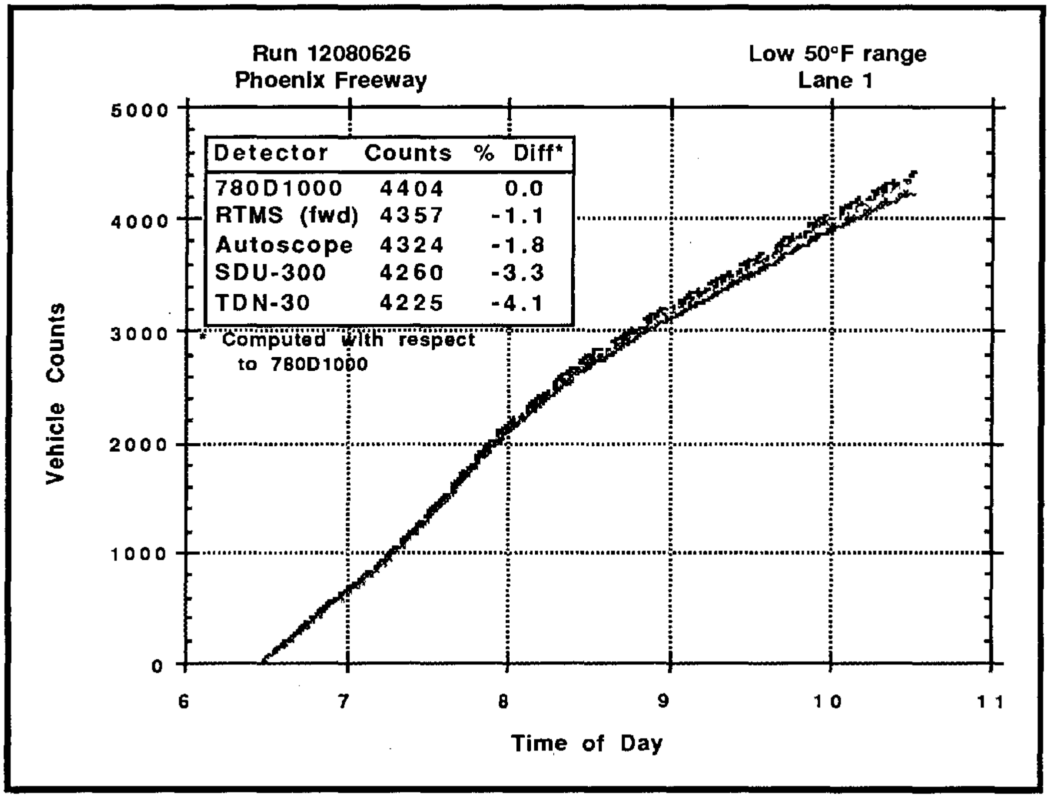
°C = 5(°F-32)/9

Figure 39. Comparison of Vehicle Counts With Ground Truth for Six Detectors in Lane 2 From I-10 Arizona Freeway Site

Run 12080626

This early morning run lasted approximately 4 hours and was conducted in cool, clear weather.

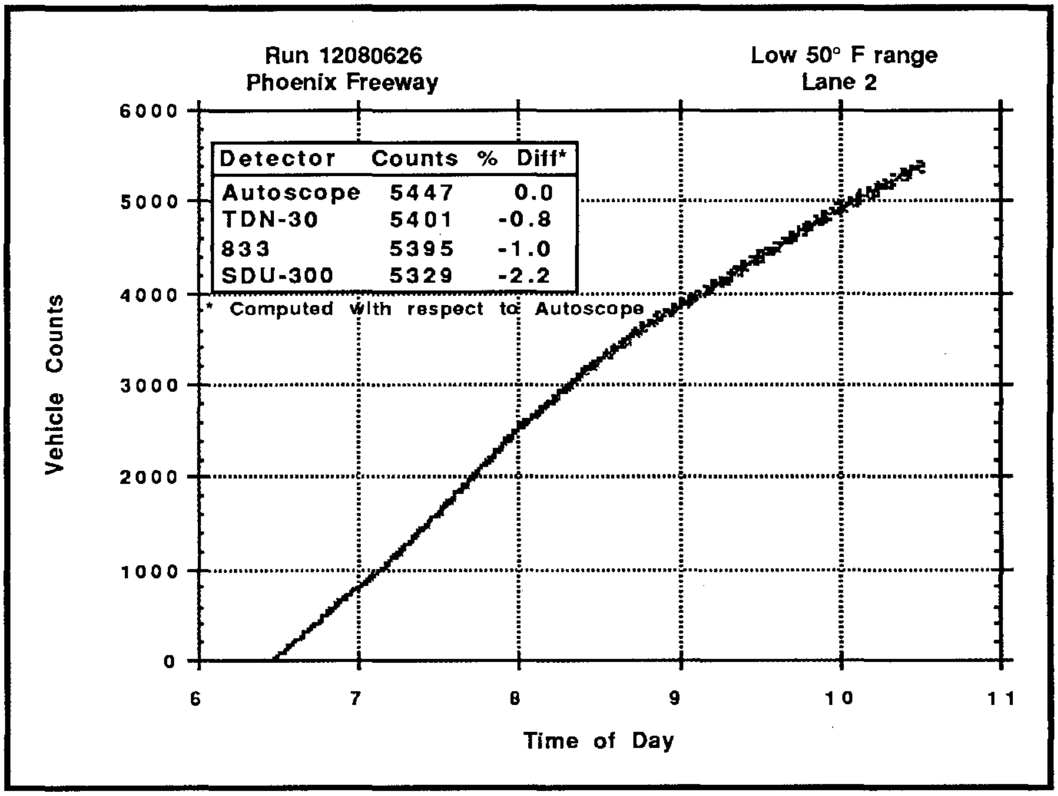
Figure 40 shows the comparison of vehicle counts for five detectors in lane 1. The ouput from the 780D1000 laser radar was used as the reference against which the outputs from the other lane 1 detectors were measured. The forward-looking RTMS and the Autoscope 2003 VIP measured 1.1 and 1.8 percent fewer vehicles, respectively, than the laser radar. The Sumitomo SDU-300 ultrasonic detector and the Whelen TDN-30 microwave Doppler unit registered 3.3 and 4.1 percent fewer counts than the reference.



°C = 5(°F-32)/9

Figure 40. Comparison of Vehicle Counts From Five Detectors in Lane 1 From I-10 Arizona Freeway Site

The lane 2 results in Figure 41 were computed using the output from the Autoscope 2003 VIP as the reference. Four detector outputs are shown. They include, in addition to the Autoscope, the TDN-30 microwave Doppler detector, the 833 passive infrared detector, and the SDU-300 ultrasonic unit. After a 4-hour period of vehicle count accumulation, the TDN-30 registered 0.8 percent fewer counts than the Autoscope, while the 833 registered 1 percent fewer. The SDU-300 responded to 2.2 percent fewer vehicles than did the reference Autoscope.



°C = 5(°F-32)/9

Figure 41. Comparison of Vehicle Counts From Four Detectors in Lane 2 From I-10 Arizona Freeway Site

Run 12081534

Figure 42 contains results from four detectors versus ground truth in lane 1. The best performing detector over the 1-hour interval from 5:30 to 6:30 p.m. was the laser radar at 2.2 percent under the ground truth count. The loop results during this run were unreliable as the apparent crosstalk caused a variety of performance problems. The remaining three plots in Figure 42 represent the forward-looking RTMS, the SDU-300 ultrasonic detector, and the Autoscope VIP, undercounting at 3.5, 4.4, and 6.1 percent, respectively.

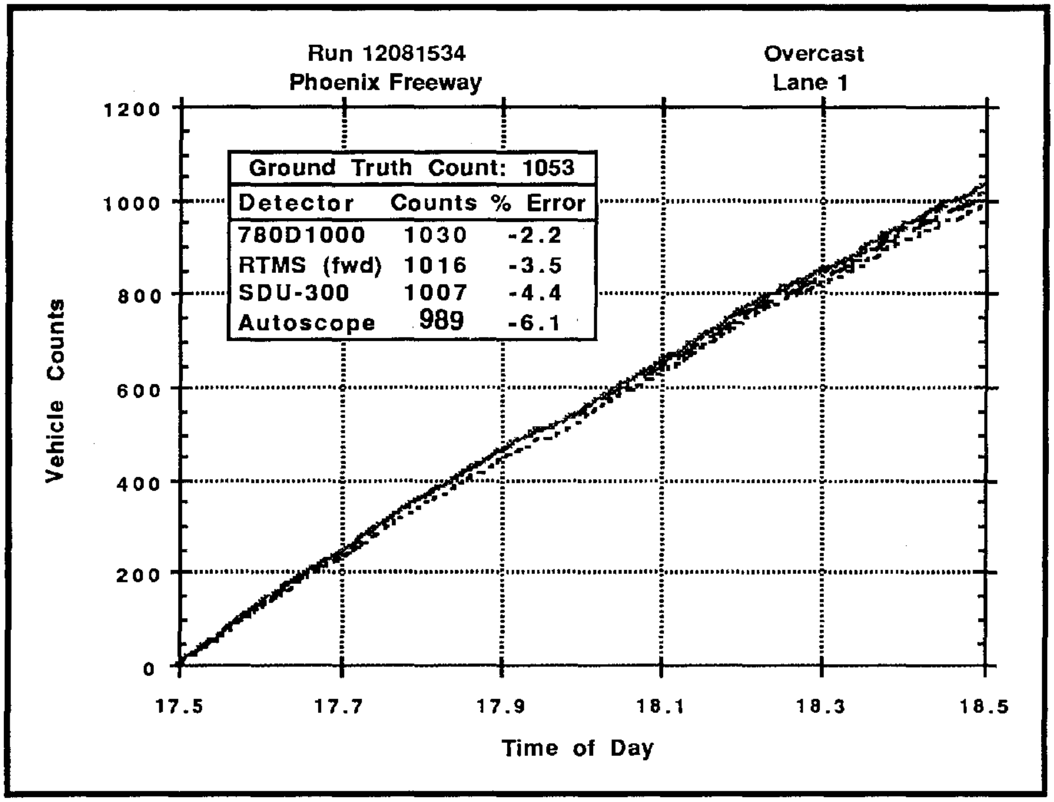


Figure 42. Comparison of Vehicle Counts With Ground Truth for Four Detectors in Lane 1 From the I-10 Arizona Freeway Site

Figure 43 shows the outputs from five detectors in lane 2. Again, the degraded loop results were of little value, and the best performers were the TDN-30 microwave Doppler detector at 1.1 percent under the ground truth value, and the Autoscope 2003 VIP, which undercounted by 1.2 percent. The 833 passive IR device and the SDU-300 ultrasonic detector undercounted by 2.1 and 2.8 percent, respectively, while the SmartSonic acoustic detector continued its tendency to overcount, in this instance by 6.7 percent.

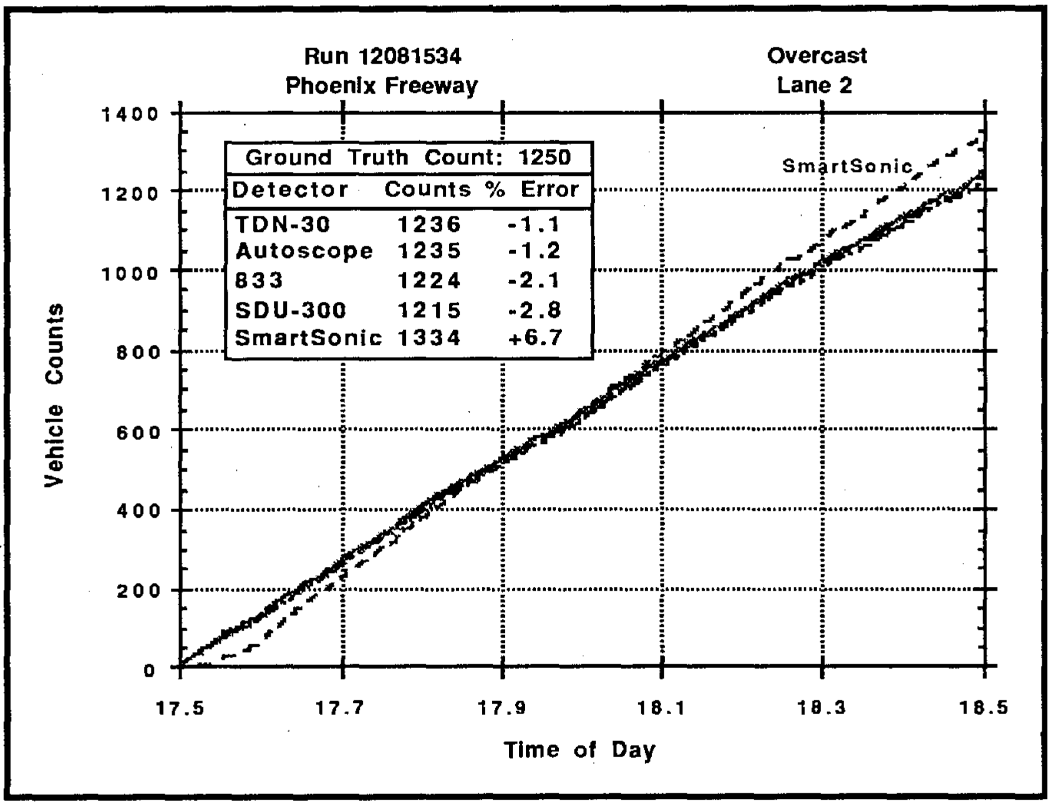
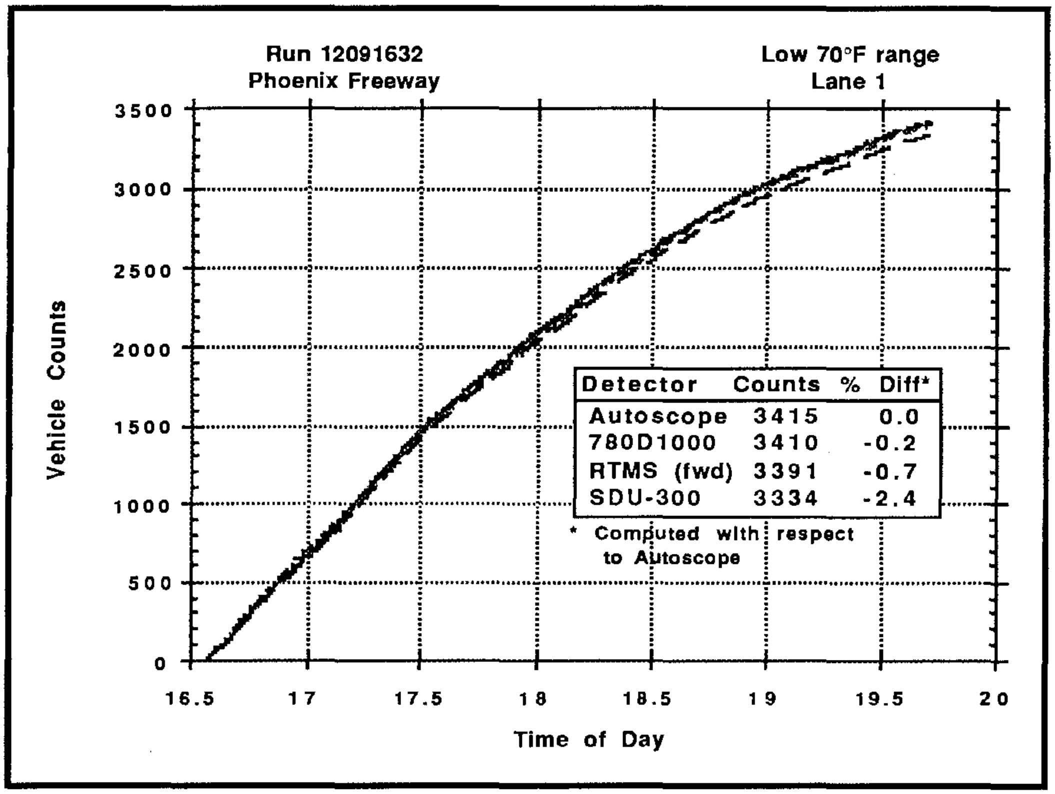


Figure 43. Comparison of Vehicle Counts With Ground Truth for Five Detectors in Lane 2 From the I-10 Arizona Freeway Site

Run 12091632

This run lasted for 3+ hours, and was conducted under normal evening traffic conditions. The weather was warm and clear.

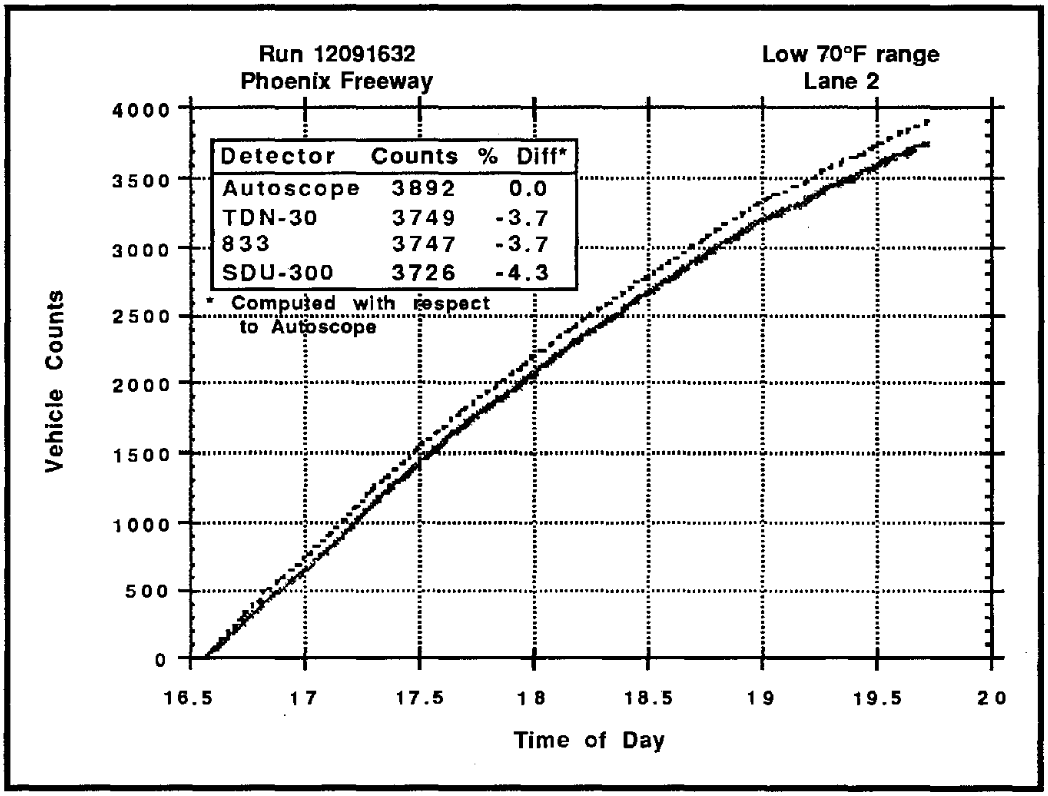
Figure 44 shows the outputs from four detectors in lane 1. The Autoscope 2003 VIP was selected as the reference detector by virtue of its performance in similar conditions during runs that compared its results against ground truth. The Autoscope counts were closely followed by the laser radar, With 0.2 percent fewer counts, and the forward-looking RTMS microwave radar, which responded to 0.7 percent fewer events. The final plot in Figure 44 shows the SDU-300 ultrasonic unit at 2.4 percent behind the Autoscope results.



°C = 5(°F-32)/9

Figure 44. Comparison of Vehicle Counts From Four Detectors in Lane 1 From the I-10 Arizona Freeway Site

The plots displayed in Figure 45 represent four detectors in lane 2 of the Phoenix freeway site. The Autoscope 2003 result was again used as the reference value, with the TDN-30 microwave Doppler detector, the 833 passive infrared detector, and the SDU-300 ultrasonic unit counting 3.7, 3.7, and 4.3 percent fewer events, respectively.



°C = 5(°F-32)/9

Figure 45. Comparison of Vehicle Counts From Four Detectors in Lane 2 From the I-10 Arizona Freeway Site

7. RESULTS FROM PHOENIX 1994 FREEWAY RUNS

The I-10 Phoenix freeway site was revisited during the summer of 1994 in order to evaluate the performance of the detectors in a dry, high-temperature environment. The layout of the detectors was substantially the same as that for the earlier Phoenix 1993 tests. The layouts and other pertinent setup information is provided in Section 9 of the Task L final report.

Comparison of TDN-30 Speeds With Probe Vehicle Observations

Over an approximate 3-week period, drive-throughs were made on the instrumented lanes during the normal test runs using a probe vehicle. The vehicle was identifiable in the database through the use of the Detector Systems Loop Comm Model 600A vehicle transmitter in conjunction with Model 613-SS inductive loop detectors. The passage of the probe vehicle over the instrumented loop initiated a vehicle identification pulse from the 600A transmitter that was recorded by the data logger. This unique vehicle ID pulse allowed the analyst to correlate the output of an individual detector with the passage of a specific vehicle.

Notations were made for each drive-through, detailing which lane was being traversed and the speed of the vehicle as read from the probe vehicle's speedometer. Although some error was certainly introduced due to the possible imprecision of the vehicle's speedometer and the uncertainty associated with having a human observer record the information from the instrument panel, this method gives a good indication of the vehicle speed when traffic conditions allowed for constant-velocity travel. The accuracy of the speed readings was estimated to be ±2 mi/h (±3.2 km/h). The use of different probe vehicles reduced the likelihood of introducing bias errors due to the faulty calibration of a particular speedometer.

Many advanced detectors provide speed and other traffic parameters averaged over some integration interval. Performing this speed comparison required a detector capable of outputting speeds on a per vehicle basis in order to correlate a specific event with the speed information provided by the loop detector. The unit selected for comparison was the TDN-30 microwave Doppler detector. This device provided speeds for individual vehicles via an RS-232 serial interface.

Both lanes 1 and 2 were instrumented with TDN-30s. Table 4 lists the speed outputs from the TDN-30 and the readings recorded by the operator of the probe vehicle.

The specification for the TDN-30 states that speed readings shall be ±3 mi/h (±4.8 km/h) or less on a per vehicle basis. Examination of the results from the lane 1 detector shows compliance only 50 percent of the time when compared to the observations recorded by the driver of the probe vehicle. However, the *average* observed speed error over all the lane 1 drive-throughs was computed to be 4.1 percent, which equates to an error of 2.7 mi/h (4.3 km/h) computed using a 65-mi/h (104.6-km/h) speed. The detector monitoring lane 2 fared better in the drive-throughs, meeting the ±3-mi/h (±4.8-km/h) criteria 85 percent of the time over 40 recorded probe vehicle passages. The average speed error for the lane 2 unit, based on a 65-mi/h (104.6-km/h) speed, was 1.6 mi/h (2.6 km/h).

No lane 1 speeds were recorded for the final eight runs of Table 4 because of an electrical failure on the port of the serial interface board that was used to record the serial information from the detector. The lack of data was not due to any failure of the TDN-30 detector itself.

Table 4. Comparison of Whelen TDN-30 Reported Speeds With Recorded Speedometer Observations

		Lane 1			Lane 2	
Run #	Speedometer Reading (mi/h)	M4b Speed (mi/h)	Observed Speed Error (%)	Speedometer Reading (mi/h)	M4a Speed (mi/h)	Observed Speed Error (%)
07141602				60	64	6.67
				65	67	3.08
07150446	60	62	3.33	60	64	6.67
				60	61	1.67
07190448	65	68	4.62	60	62	3.33
07191613	60	64	6.67	60	61	1.67
	65	70	7.69			
07200447	61	65	6.56	60	63	5.00
	60	65	8.33	60	62	3.33
07201659	65	69	6.15	65	62	-4.62
	65	65	0.00	65	67	3.08
07210438	60	60	0.00	60	64	6.67
	65	68	4.62	65	69	6.15
07211619	60	64	6.67	60	62	3.33
				65	68	4.62
07220441	65	70	7.69	65	69	6.15
	65	69	6.15	60	63	5.00
07251606	65	63	-3.08	60	63	5.00
	60	64	6.67	65	61	-6.15
07260501	65	69	6.15	65	64	-1.54
	65	67	3.08	65	64	-1.54
07261543	65	62	-4.62	66	68	3.03
				65	67	3.08
07270434	65	67	3.08	65	65	0.00
	65	67	3.08	65	66	1.54
08011613				65	68	4.62
				60	61	1.67
08020502				60	62	3.33
				65	67	3.08
08021550				60	61	1.67
				65	64	-1.54
08030437				65	66	1.54
				65	65	0.00
08031611				65	67	3.08
				65	65	0.00
08040435				65	65	0.00
				60	62	3.33
08041552				65	67	3.08
				65	68	4.62
08050438				65	67	3.08
				65	66	1.54
	1266	1318	4.11	2526	2587	2.41

1 mi/h = 1.6 km/h

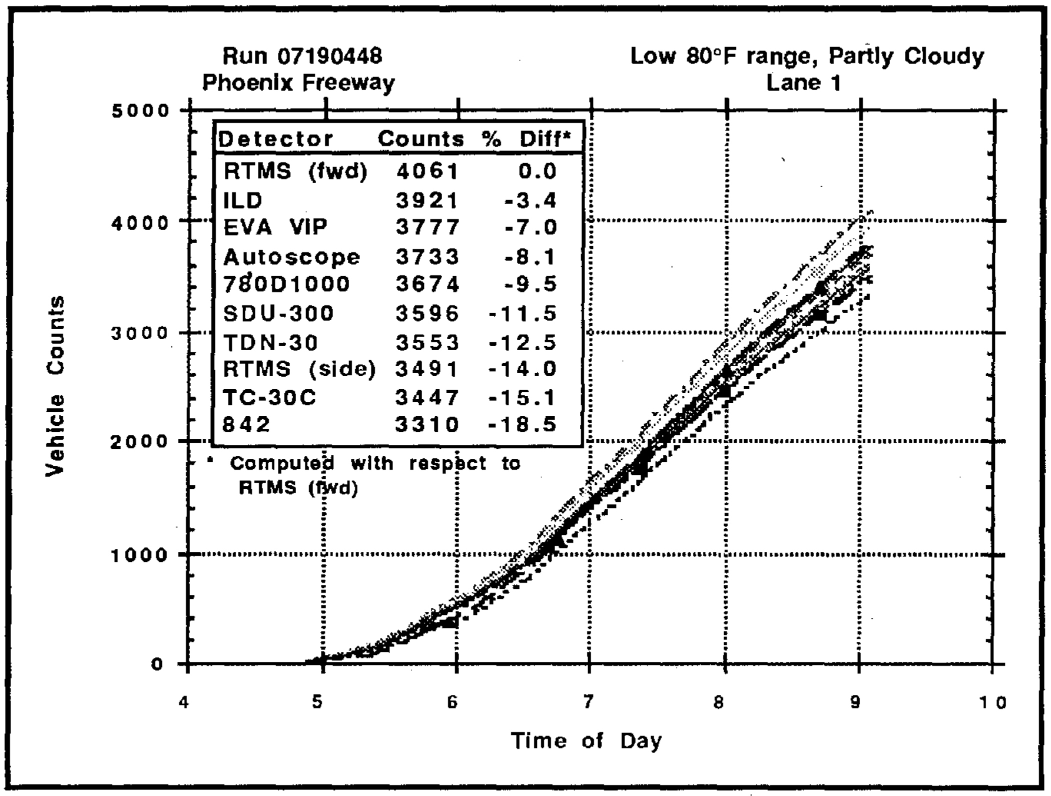
Results From Specific Runs

Run 07190448

This run of some 4+ hours was conducted in the early morning hours, with light clouds evident and the temperature hovering around the low 80°F range (around 28°C).

Figure 46 represents the outputs from 10 detectors monitoring traffic in lane 1. The forward-looking RTMS was chosen as the reference detector for this session based on its performance in the ground truth runs. The RTMS was usually among the most accurate count detectors in lane 1 during the Phoenix '94 tests, but count errors greater than 2 percent were sometimes observed. Recall that the figures showing percent difference information compare the outputs from detectors against a reference value from a detector selected as the standard for that run. These numbers do not represent absolute performance compared to ground truth values.

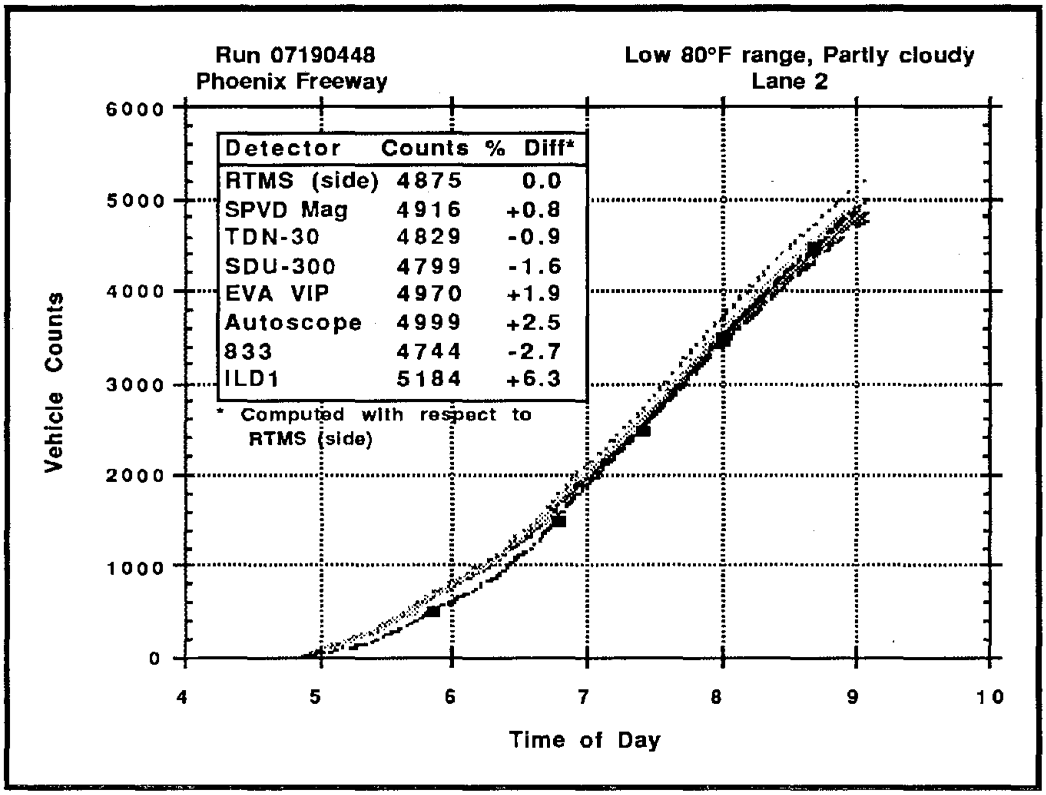
The inductive loop result came the closest to the forward-looking RTMS, but was lower by 3.4 percent. The next two detectors in accuracy were both video image processors, the EVA and the Autoscope 2003. These units registered 7.0 and 8.1 percent fewer counts than the RTMS, respectively. The laser radar reported 9.5 percent fewer counts than the reference, while the remaining five detectors represented in Figure 46 all undercounted With double-digit percent differences.



°C = 5(°F-32)/9

Figure 46. Comparison of Vehicle Counts From 10 Detectors in Lane 1 From the I-10 Arizona Freeway Site

The curves of Figure 47 represent the outputs from eight detectors in lane 2 of the Phoenix I-10 freeway site. The side-looking RTMS microwave radar was determined to be the most accurate detector in terms of counts in lane 2. The SPVD magnetometer counted 0.8 percent more vehicles than did the RTMS, while the TDN-30 microwave Doppler detector reported 0.9 percent fewer counts. After these came the SDU-300 ultrasonic detector, which registered 1.6 percent fewer counts than the reference RTMS unit. The EVA VIP continued to display the same anomaly seen throughout these tests. The unit begins the morning session undercounting, then proceeds to overcount for the remainder of the session. This made the performance appear better than it actually was. The remaining three detectors represented in Figure 47 are the Autoscope 2003 VIP, the model 833 passive infrared detector, and the inductive loop. The loops were plagued With difficulties throughout the Phoenix tests due to a crosstalk problem.



°C = 5(°F-32)/9

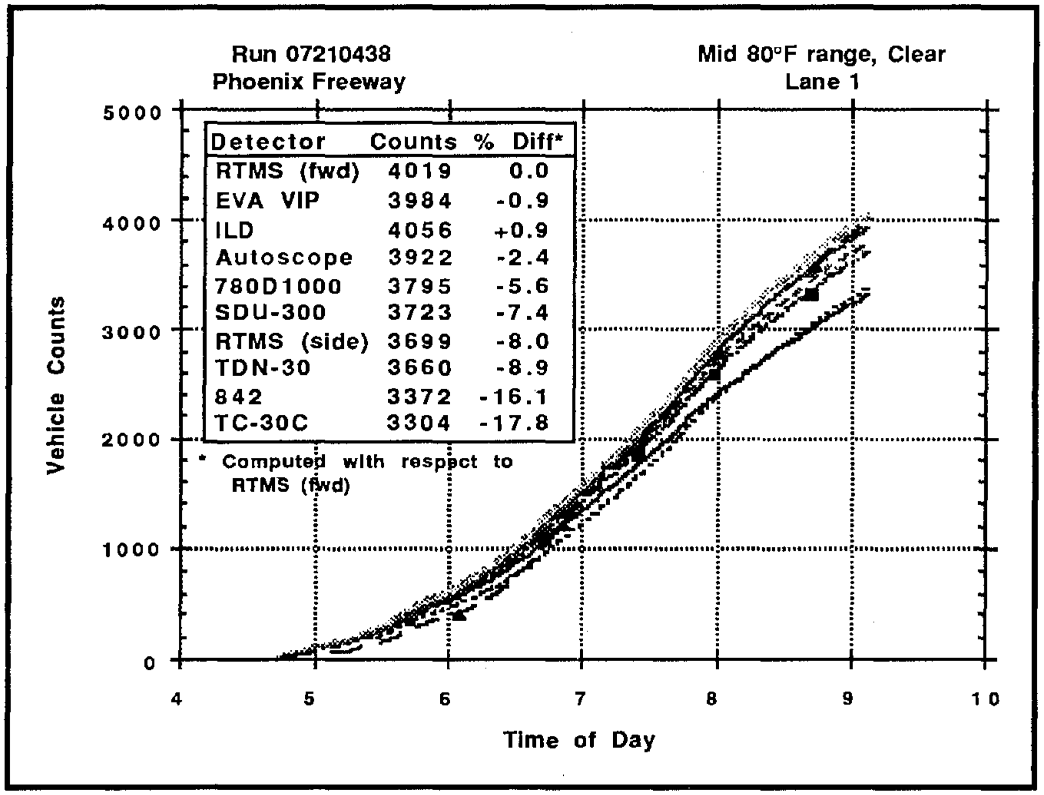
Figure 47. Comparison of Vehicle Counts From Eight Detectors in Lane 2 From the I-10 Arizona Freeway Site

Run 07210438

This early morning session ran for approximately 4.5 hours, encompassing both light pre-dawn traffic and heavier traffic during the morning rush hour. The weather was dry and clear.

Figure 48 shows count comparison plots for 10 detectors monitoring events in lane 1. The forward-looking RTMS true-presence microwave radar was selected as the reference detector for this run. Following the RTMS in accuracy are the EVA VIP, which undercounted, and the inductive loop, which overcounted. Both registered relative differences of 0.9 percent. The EVA result requires further explanation. The difference of 0.9 percent is misleading because the EVA began the run undercounting, then overcounted for the remainder of the session. The net effect was for the undercount and overcount to "cancel out" and thus yield a result that overstates the short-term accuracy of the device. This phenomenon was observed frequently during this series of tests and is believed to be associated with the EVA's difficulty in making seamless dark-to-light and light-to-dark transitions.

The remaining detector results represented in the plots of Figure 48 all resulted in undercounts With the Autoscope 2003 VIP and laser radar showing the best performance of those devices in the back of the pack.

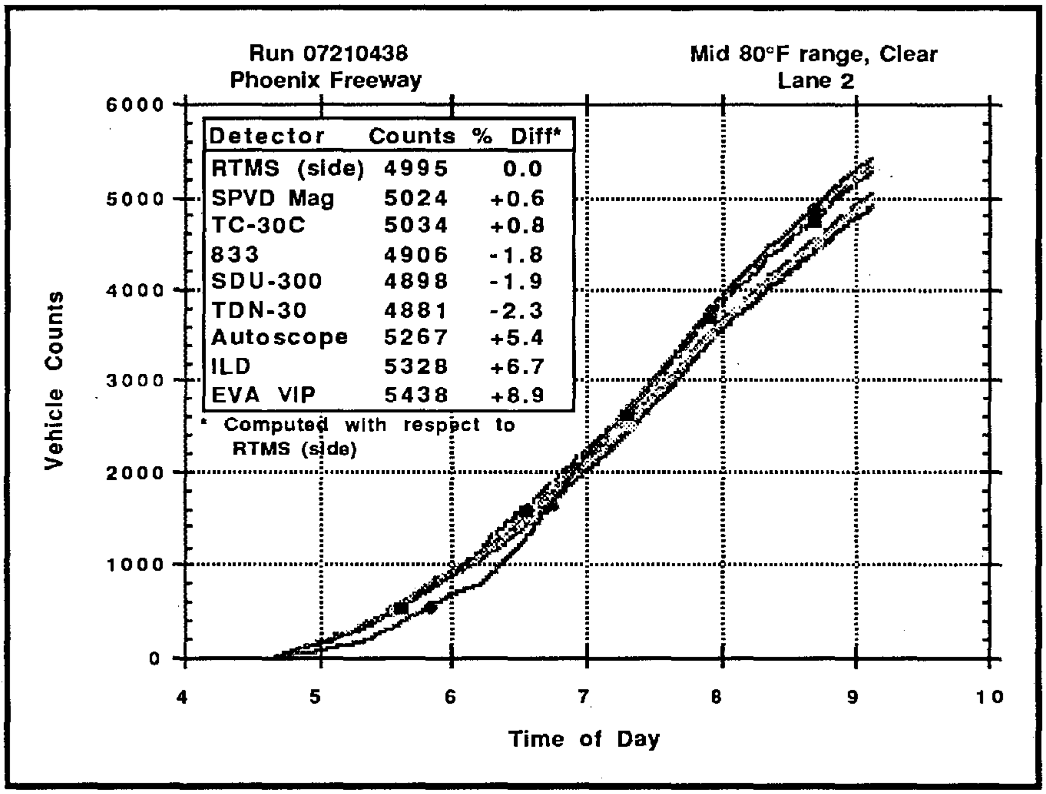


Detector	Counts	% Diff*
RTMS (fwd)	4019	0.0
EVA VIP	3984	-0.9
ILD	4056	+0.9
Autoscope	3922	-2.4
780D1000	3795	-5.6
SDU-300	3723	-7.4
RTMS (side)	3699	-8.0
TDN-30	3660	-8.9
842	3372	-16.1
TC-30C	3304	-17.8

°C = 5(°F-32)/9

Figure 48. Comparison of Vehicle Counts From 10 Detectors in Lane 1 From the I-10 Arizona Freeway Site

Figure 49 shows plots representing nine detectors in lane 2. The side-looking RTMS microwave radar was determined to be the most reliably accurate detector under these weather and traffic conditions. Relative to the referenced RTMS results, the SPVD magnetometer demonstrated the best count accuracy followed by the TC-30C ultrasonic detector. These units registered overcounts of 0.6 and 0.8 percent, respectively. The 833 passive infrared detector and the SDU-300 ultrasonic device registered undercounts of 1.8 and 1.9 percent, respectively, while the TDN-30 microwave Doppler detector was close behind with an undercount of 2.3 percent. The remaining three detectors registered overcounts with respect to the RTMS side-looking unit. They were the Autoscope 2003 VIP at 5.4 percent, the inductive loop at 6.7 percent, and the EVA VIP at 8.9 percent.



°C = 5(°F-32)/9

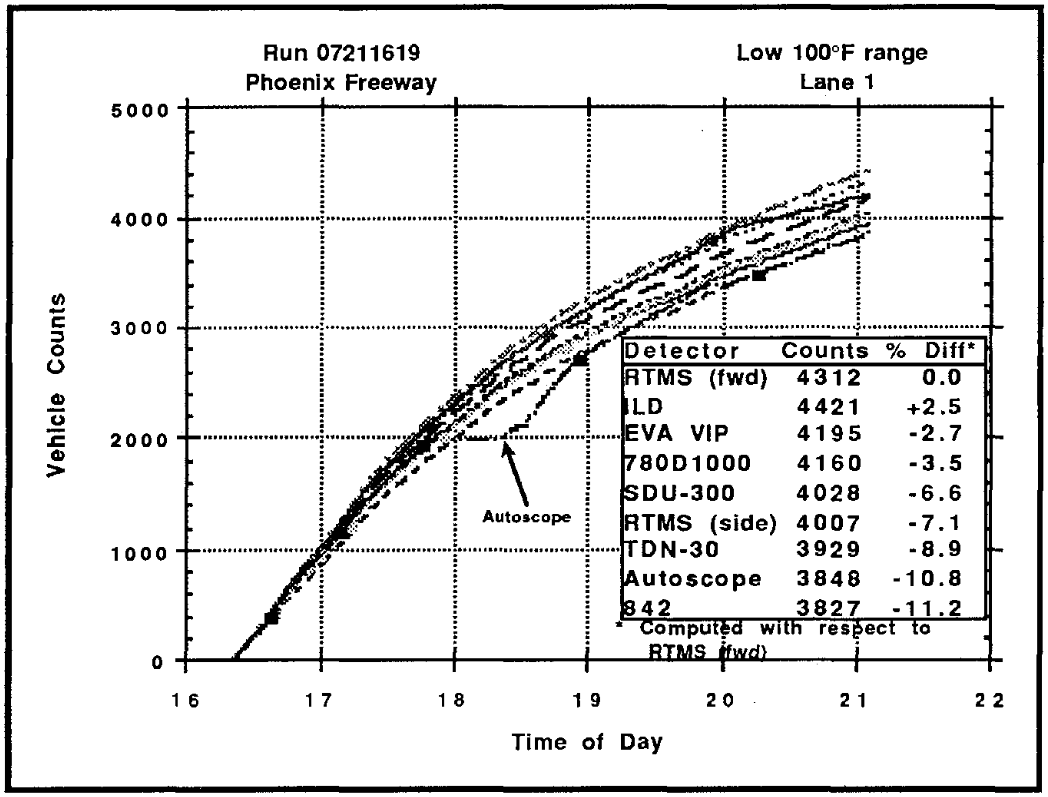
Figure 49. Comparison of Vehicle Counts From Nine Detectors in Lane 2 From the I-10 Arizona Freeway Site

Run 07211619

This run, lasting nearly 4 hours, was conducted in the late afternoon and early evening of a hot, dry day.

Nine detectors in lane 1 are represented in Figure 50. The forward-looking RTMS microwave radar was used as the reference detector, and all of the detectors represented in Figure 50 undercounted with the exception of the crosstalk-plagued inductive loops. The loop represented in the figure overcounted by 2.5 percent, while the EVA VIP ended the session with an undercount of 2.7 percent. Again, the EVA showed difficulty making the light-to-dark background transition when the ambient lighting changed. The unit seemed to track the RTMS quite well until shortly before 8:00 p.m., when the counts began to fall off. Referencing the climatological data in Appendix J of the Task L final report, the time of sunset is given as 7:36 p.m. This suggests that the anomaly experienced by the EVA is probably related to the ambient light condition.

Perhaps the most noticeable anomaly in Figure 50 is associated with the Autoscope 2003 VIP. The lane 1 detections from this VIP seem to drop out entirely at around 5:45 p.m. and do not resume until approximately 6:20 p.m. Once the unit recovered, it appeared to operate normally. Compounding an understanding of the anomaly is the fact that the same unit monitoring the adjacent lane experienced no such difficulty. The reason for this anomaly is not known. It would have been interesting to have had access to the device's serial output in order to correlate the information contained in the data string that was computed using the Autoscope's pulse outputs.



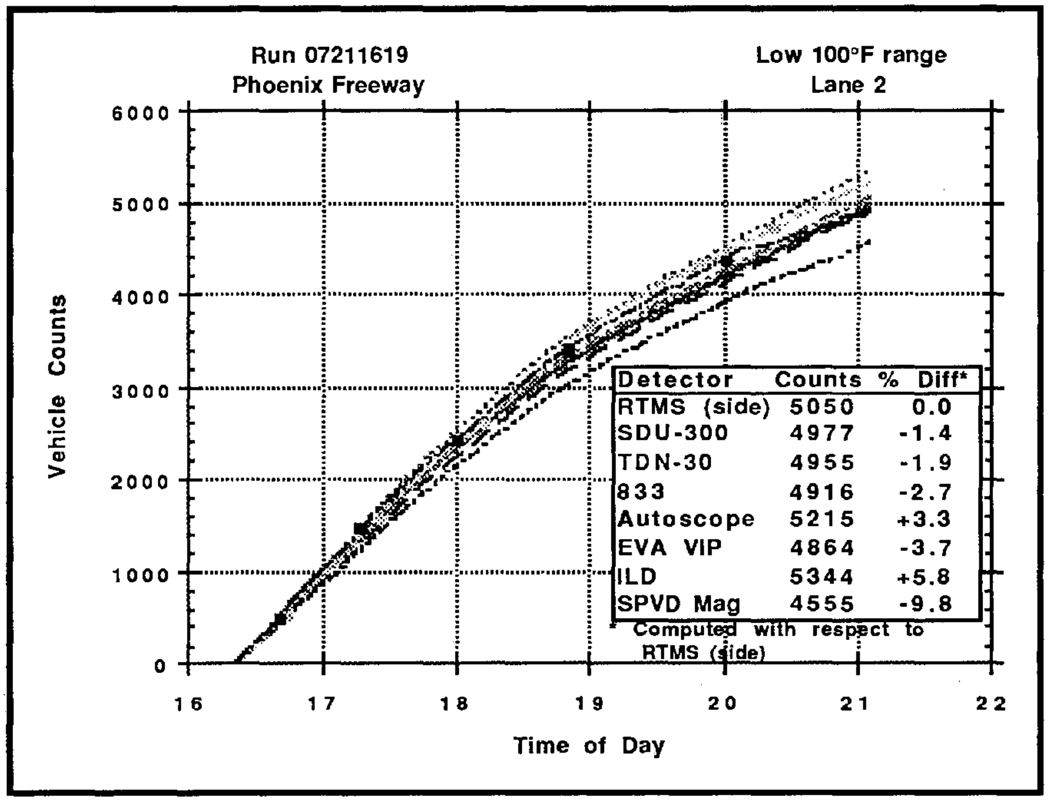
Detector	Counts	% Diff*
RTMS (fwd)	4312	0.0
ILD	4421	+2.5
EVA VIP	4195	-2.7
780D1000	4160	-3.5
SDU-300	4028	-6.6
RTMS (side)	4007	-7.1
TDN-30	3929	-8.9
Autoscope	3848	-10.8
842	3827	-11.2

* Computed with respect to RTMS (fwd)

°C = 5(°F-32)/9

Figure 50. Comparison of Vehicle Counts From Nine Detectors in Lane 1 From the I-10 Arizona Freeway Site

Figure 51 shows the results from eight detectors in lane 2. The side-looking RTMS microwave radar was again used as the reference detector for lane 2 based on earlier ground truth results. The three detectors with the next best accuracies all experienced undercounts. These were the SDU-300, the TDN-30, and the 833, measuring 1.4, 1.9, and 2.7 percent undercount, respectively. The Autoscope 2003 VIP overcounted by 3.3 percent, while the EVA VIP undercounted by 3.7 percent. The inductive loop over-counted by 5.8 percent, while the SPVD magnetometer registered 9.8 percent lower than the reference detector.



°C = 5(°F-32)/9

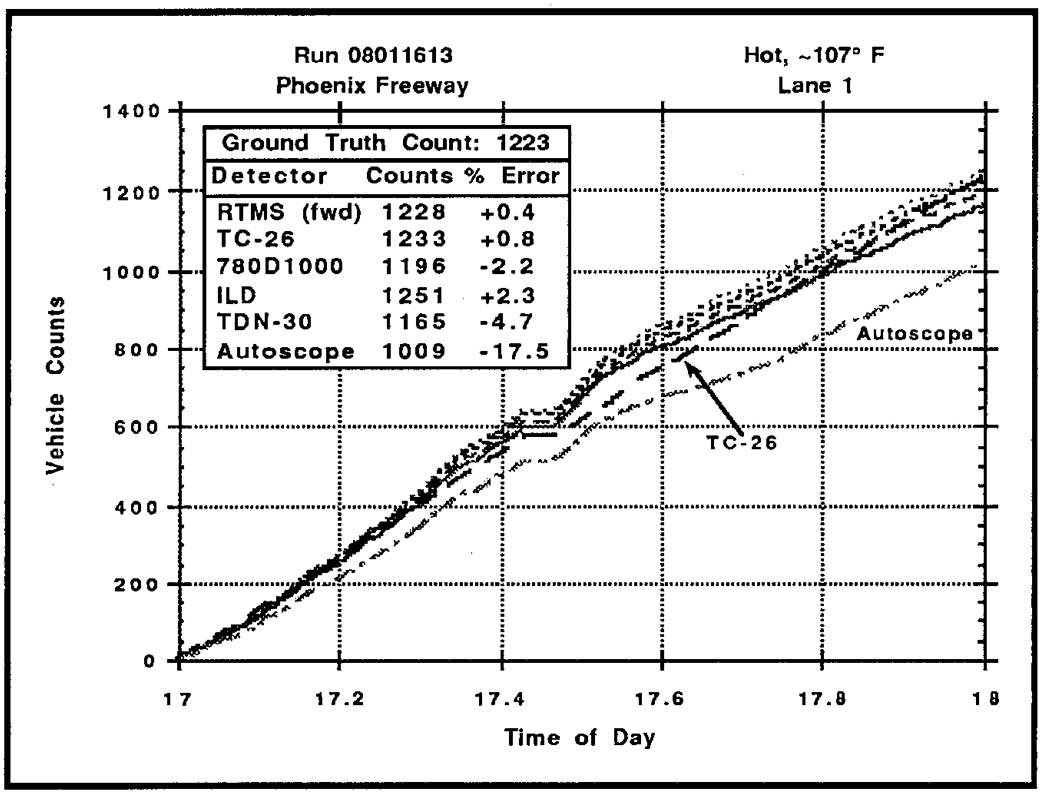
Figure 51. Comparison of Vehicle Counts From Eight Detectors in Lane 2 From the I-10 Arizona Freeway Site

Run 08011613

This run was conducted during the late afternoon and early evening hours of a hot, dry day. This session was ground truthed for the 1-hour period between 5:00 and 6:00 p.m.

The outputs from six detectors in lane 1 are shown in Figure 52 for the 1-hour ground truth period. Of the six detectors represented in the figure, the forward-looking RTMS provided the best results. The device registered an overcount of 0.4 percent compared to the total number of vehicles counted manually from the video imagery. The TC-26 responded with an overcount of 0.8 percent, but this total is misleading. The unit appeared to undercount for the first three-quarters of an hour and then proceeded to overcount.

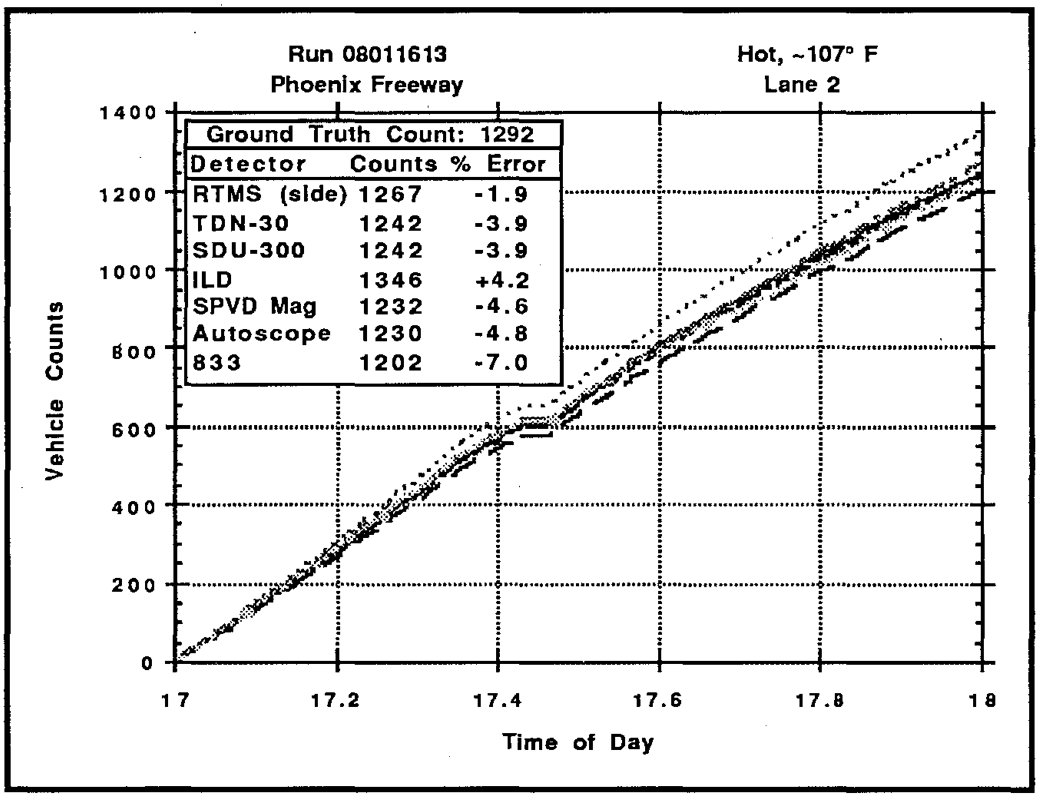
The laser radar undercounted by 2.2 percent, while the inductive loop registered an overcount of 2.3 percent. The TDN-30 reponded with an undercount of 4.7 percent, and the Autoscope 2003 VIP undercounted by 17.5 percent.



°C = 5(°F-32)/9

Figure 52. Comparison of Vehicle Counts With Ground Truth for Six Detectors in Lane 1 From the I-10 Arizona Freeway Site

The side-looking RTMS provided the best count accuracy in lane 2 as shown in Figure 53. The unit registered an undercount of 1.9 percent, while the TDN-30 and the SDU-300 each undercounted by 3.9 percent. The inductive loop overcounted by 4.2 percent, while the final three detectors, the SPVD magnetometer, the Autoscope 2003 VIP, and the Eltec 833 passive infrared device all undercounted.



°C = 5(°F-32)/9

Figure 53. Comparison of Vehicle Counts With Ground Truth for Seven Detectors in Lane 2 From the I-10 Arizona Freeway Site

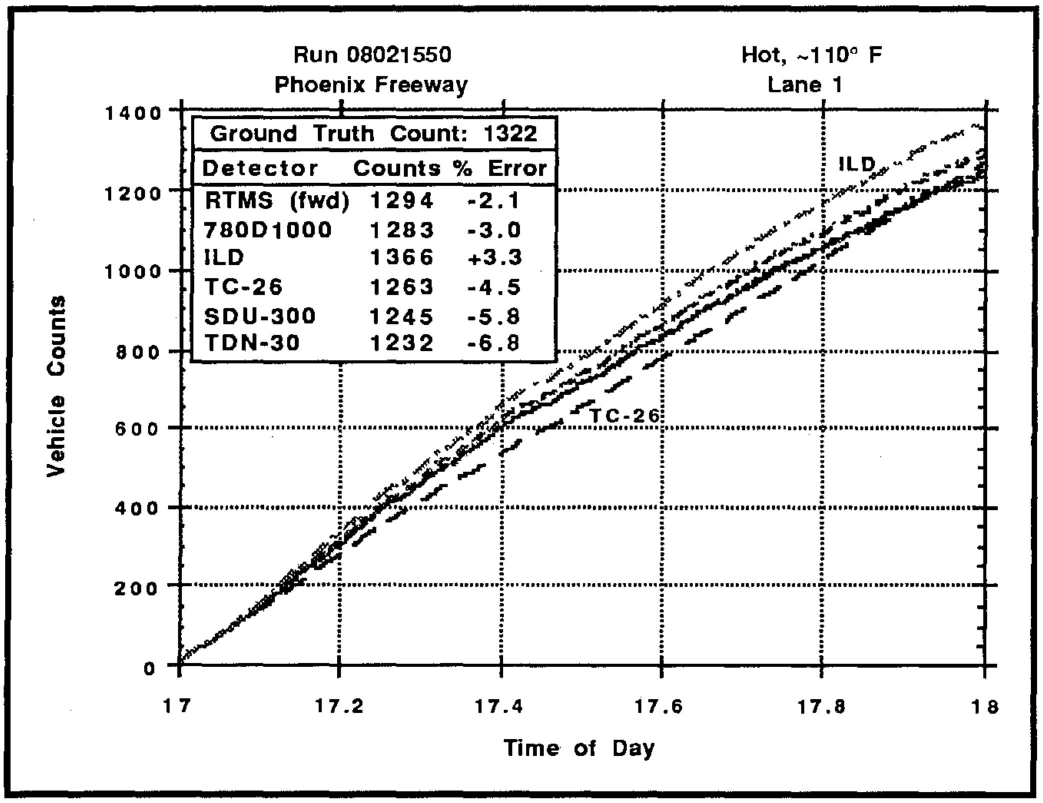
Run 08021550

This late afternoon run was conducted in extremely hot and dry conditions. The session was ground truthed in post-processing from 5:00 to 6:00 p.m.

The six outputs displayed in Figure 54 represent results from detectors monitoring lane 1. The best performing unit during the 1-hour ground truth interval was the forward-looking RTMS microwave radar, which undercounted by 2.1 percent. The laser radar undercounted by 3 percent, while the inductive loop registered a 3.3 percent overcount. The field was rounded out by the TC-26 microwave Doppler unit, the SDU-300 ultrasonic detector, and the TDN-30 microwave Doppler device.

The TC-26 undercounted for the first part of the run, and then seemingly began to overcount during the latter portion. This was a common occurrence for this detector due mainly to two factors. The wide detection beam output by this device made it difficult to confine it to a single lane when mounted at the heights and viewing angles typical of these installations. from the footprint geometry calculations given in Appendix F of the Task L final report, the width of the detection beam for a unit positioned 20 feet (6.1 m) high with a 70 degree angle of incidence (with respect to nadir) is 16.4 feet (5.0 m). This is wider than most traffic lanes. This causes overcounts due to the unwanted detection of vehicles in adjacent lanes of traffic.

The detector, as configured in the *Detection Technology for IVHS* field tests, also had a long built-in electronic hold time. This has the effect of missing vehicle detections during periods of heavy traffic due to the entry of a second vehicle into the detector's sensing area prior to the falling edge of the pulse generated by the first vehicle. With fast-moving, closely spaced vehicles, several may pass through the zone while registering only a single count. This causes the unit to undercount and dominates the results during heavy traffic conditions. When the volume lightens, the overcounting due to the large beamwidth becomes the dominant effect.

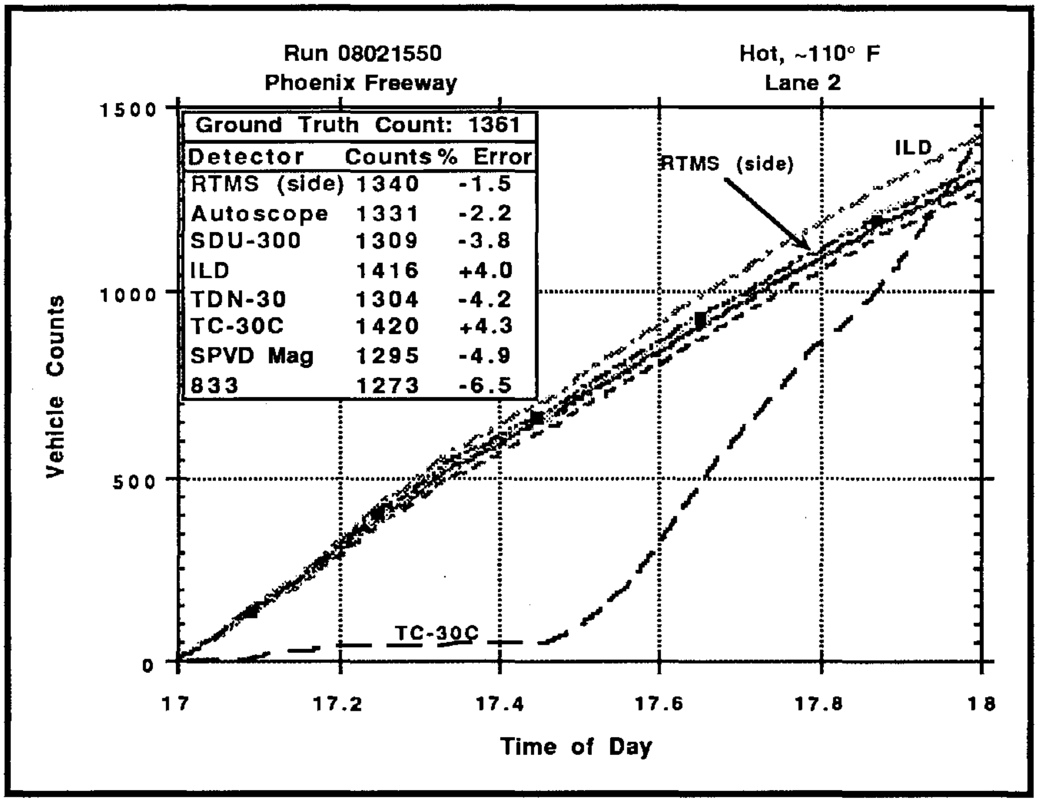


°C = 5(°F-32)/9

Figure 54. Comparison of Vehicle Counts With Ground Truth for Six Detectors in Lane 1 From the I-10 Arizona Freeway Site

Figure 55 shows the results from eight lane 2 detectors for the 1-hour ground truth period. The top performer in lane 2 was the side-looking RTMS, which registered an undercount of 1.5 percent. The Autoscope 2003 VIP and the SDU-300 ultrasonic detector responded with undercounts of 2.2 and 3.8 percent, respectively. The inductive loop overcounted by 4 percent, while the TDN-30 microwave Doppler detector undercounted by 4.2 percent. The TC-30C ultrasonic device registered an overcount of 4.3 percent over the interval, but an examination of the plot reveals that this number does not tell the entire story.

The TC-30C barely responds at all for the first one-half hour, then begins to overcount dramatically during the latter part of the hour. The net result is an overcount of 4.3 percent, but the plot can hardly be considered to be representative of the traffic flow over the interval. Positions seven and eight are filled by the SPVD magnetometer, which undercounted by 4.9 percent, and the 833 passive infrared detector, which undercounted by 6.5 percent.



°C = 5(°F-32)/9

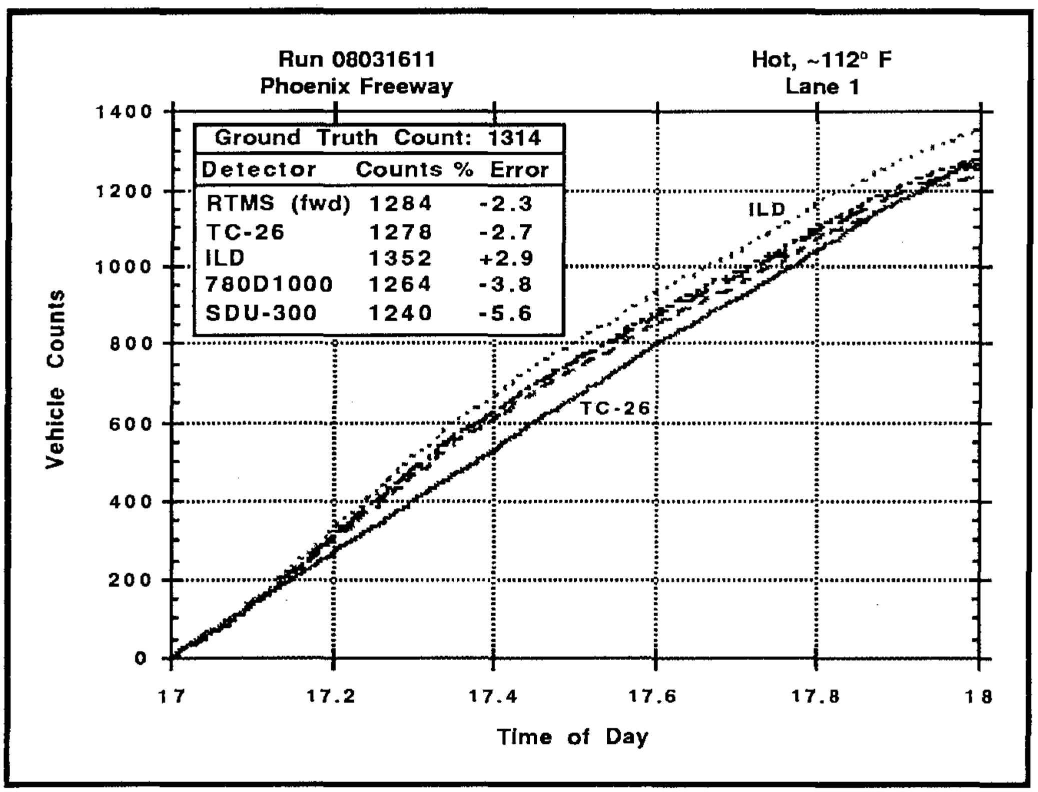
Figure 55. Comparison of Vehicle Counts With Ground Truth for Eight Detectors in Lane 2 From the I-10 Arizona Freeway Site

Run 08031611

This run was conducted on a day where the high temperature was measured at 113°F (45°C). The traffic during the 1-hour ground truth interval between 5:00 and 6:00 p.m. was moderate.

Figure 56 represents outputs from five lane 1 detectors over the 1-hour ground truth interval. The results, while not accurate enough to support many of the traffic parameter specifications listed in Section 2 of the Task L final report, do not seem to be influenced by the high temperature in a way that is readily apparent.

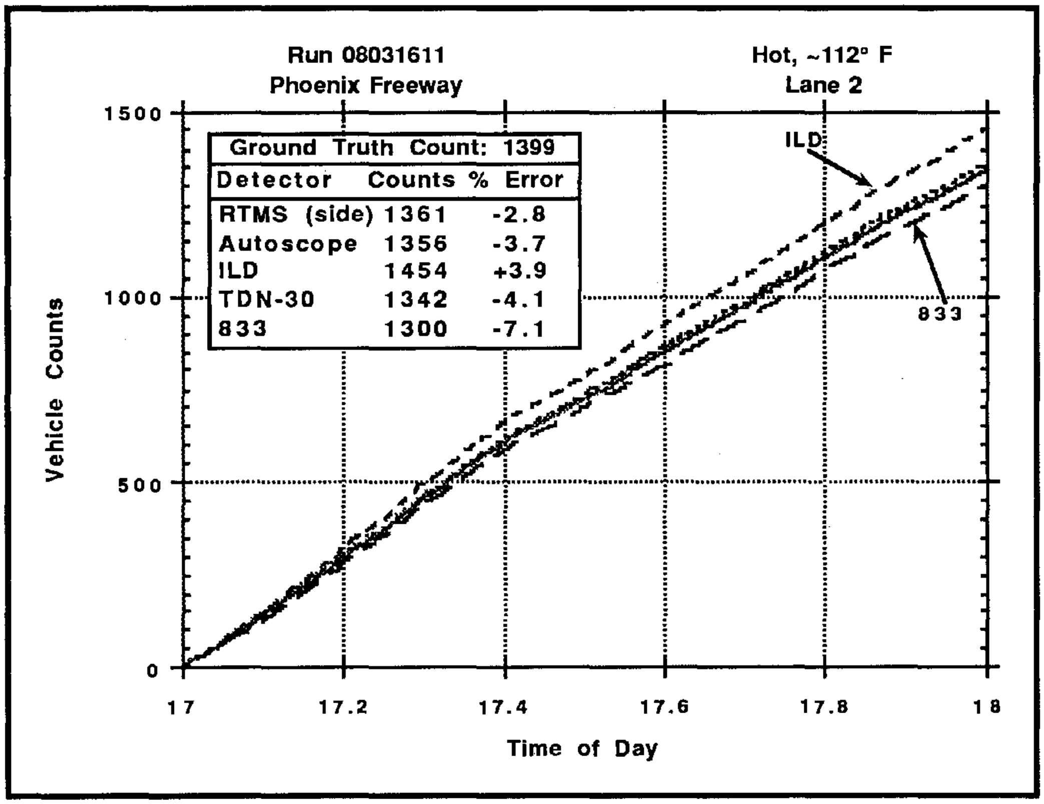
The best performer was once again the forward-looking RTMS microwave radar, which undercounted by 2.3 percent. The TC-26 reported an undercount of 2.7 percent, but once again this is a misleading result. Just as observed during the prior day's run over the same 5:00 to 6:00 p.m. interval (Run 08021550), the TC-26 undercounts for the first part of the hour and then overcounts for the remainder. These results tend to cancel each other out, erroneously minimizing the percent error computed at the end of the hour. The inductive loop continued to overcount, registering 2.9 percent more detections than were observed during the evaluation of the video imagery. The laser radar responded with an undercount of 3.8 percent, while the SDU-300 registered an undercount of 5.6 percent.



°C = 5(°F-32)/9

Figure 56. Comparison of Vehicle Counts With Ground Truth for Five Detectors in Lane 1 From the I-10 Arizona Freeway Site

Figure 57 shows the results from five detectors in lane 2 over the same 1-hour ground truth interval. The side-looking RTMS was the most accurate detector in terms of vehicle counts in lane 2, registering an undercount of 2.8 percent. The Autoscope 2003 VIP undercounted by 3.7 percent, the inductive loop registered a 3.9 percent overcount, the TDN-30 undercounted by 4.1 percent, and the 833 undercounted by 7.1 percent.



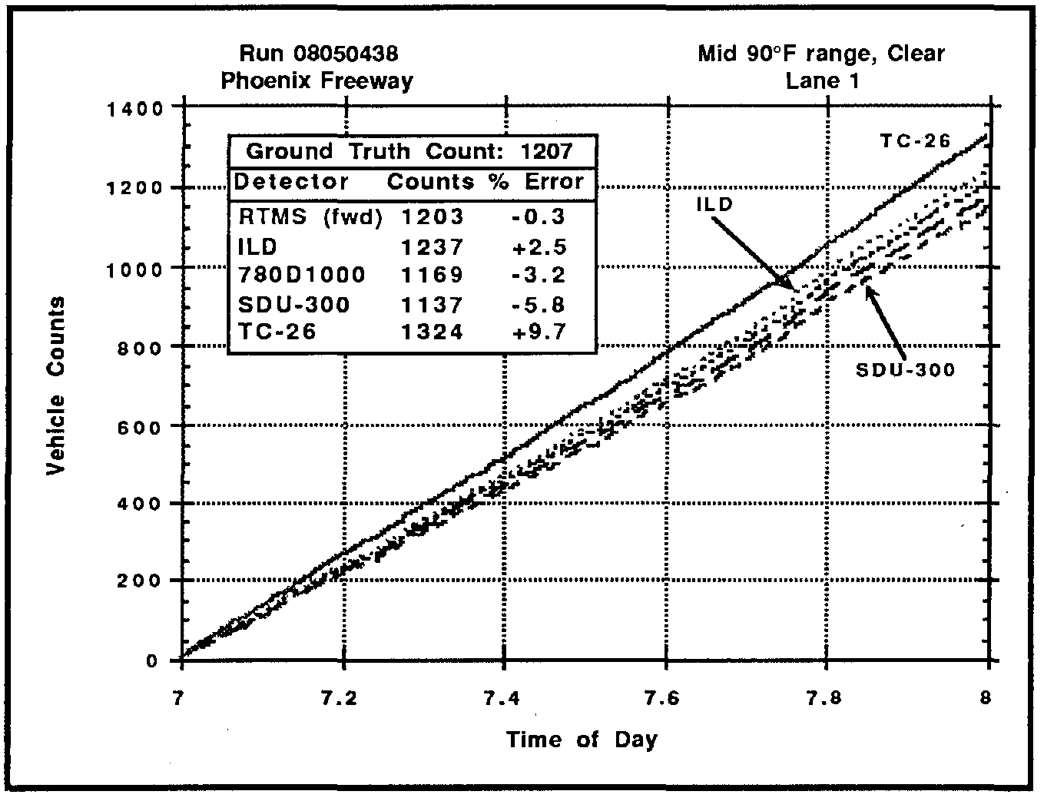
°C = 5(°F-32)/9

Figure 57. Comparison of Vehicle Counts With Ground Truth for Five Detectors in Lane 2 From the I-10 Arizona Freeway Site

Run 08050438

This early morning run was conducted during moderate traffic conditions and ground truthed between 7:00 and 8:00 a.m. Even at such an early hour, the temperature was in the mid 90°F range (around 35°C).

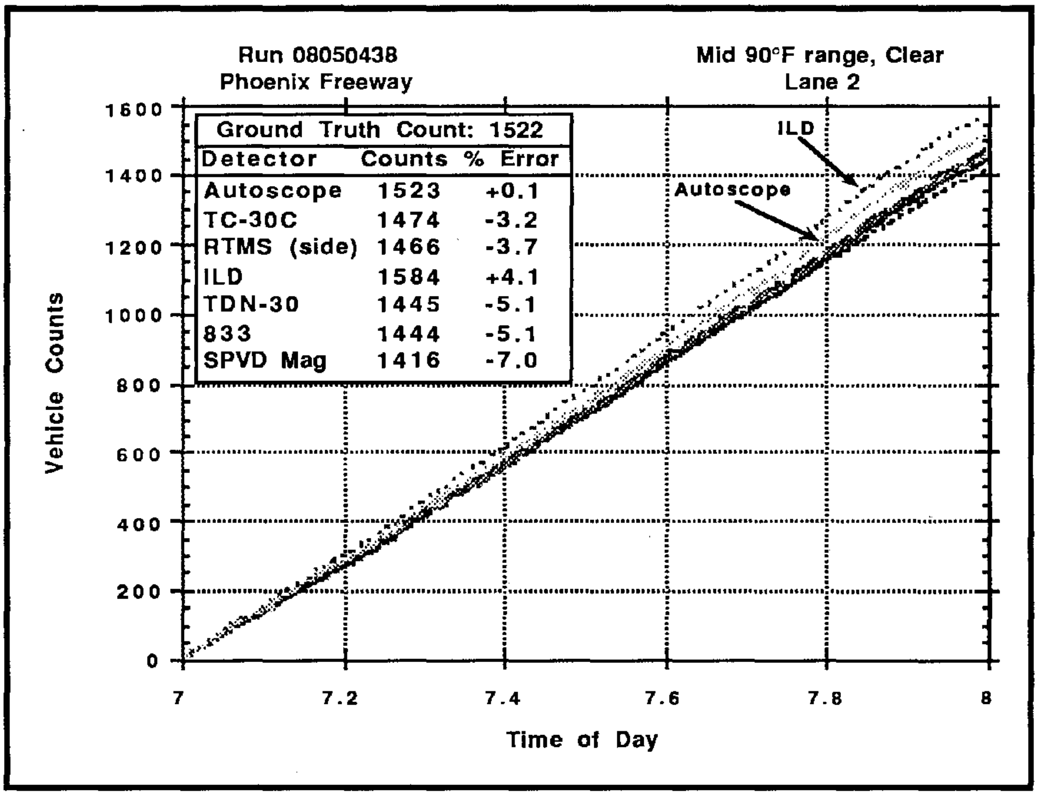
Figure 58 shows the results for five detectors in lane 1. The forward-looking RTMS microwave radar registered an undercount of a mere four vehicles, corresponding to an error of -0.3 percent. The inductive loop continued to overcount, this time by 2.5 percent. The laser radar and the SDU-300 ultrasonic unit registered undercounts of 3.2 and 5.8 percent, respectively, while the TC-26 responded With an overcount of 9.7 percent.



°C = 5(°F-32)/9

Figure 58. Comparison of Vehicle Counts With Ground Truth for Five Detectors in Lane 1 From the I-10 Arizona Freeway Site

The seven curves represented in Figure 59 cover the same 1-hour period from 7:00 to 8:00 a.m., but show the results from detectors in lane 2. The best performance was from the Autoscope 2003 VIP, which tallied a single count higher than the manually recorded ground truth obtained from the video imagery. The TC-30C ultrasonic detector and the side-looking RTMS undercounted by 3.2 and 3.7 percent, respectively. The inductive loop overcounted by 4.1 percent, while the TDN-30 microwave Doppler detector and the Model 833 passive infrared device both recorded undercounts of 5.1 percent. The SPVD magnetometer undercounted by 7 percent.



°C = 5(°F-32)/9

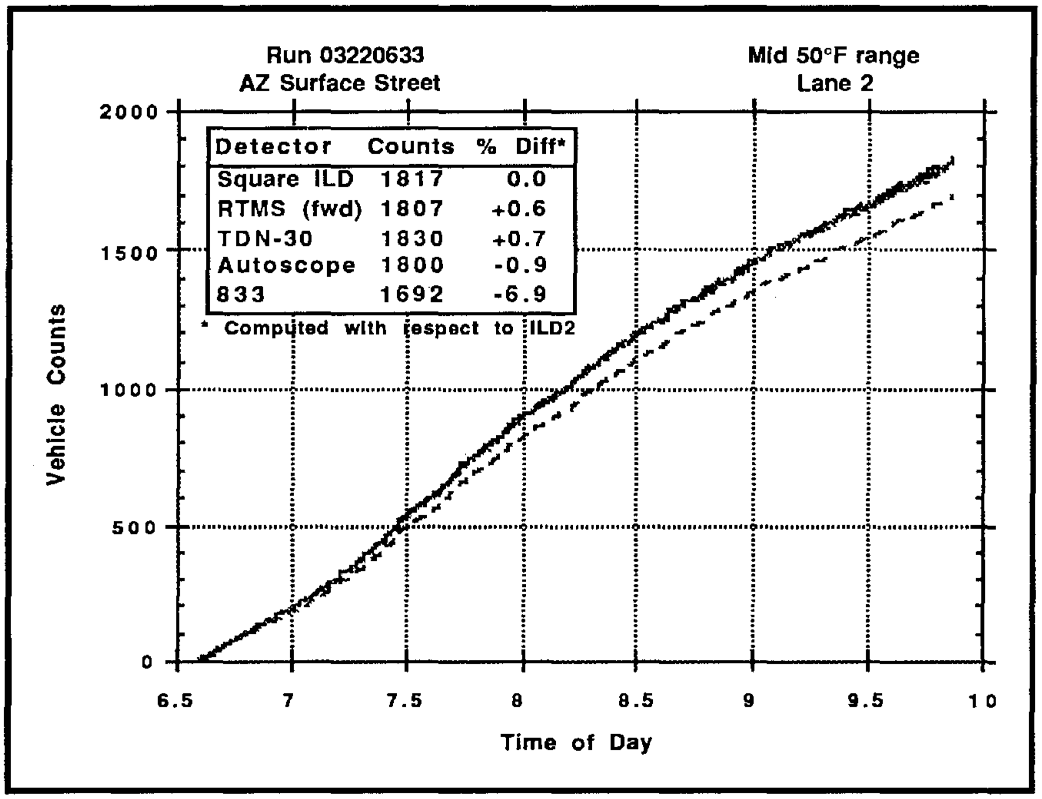
Figure 59. Comparison of Vehicle Counts With Ground Truth for Seven Detectors in Lane 2 From I-10 Arizona Freeway Site

8. RESULTS FROM TUCSON SURFACE STREET RUNS

Run 03220633

Results from five detectors in the middle traffic lane (lane 2) are given in Figure 60. These outputs have been filtered by running them through a FORTRAN program that omitted the counts recorded during the signal's north-south red phase. This reduced the anomalies encountered when vehicles make left and right turns and sweep through multiple lanes when completing their turning movements.

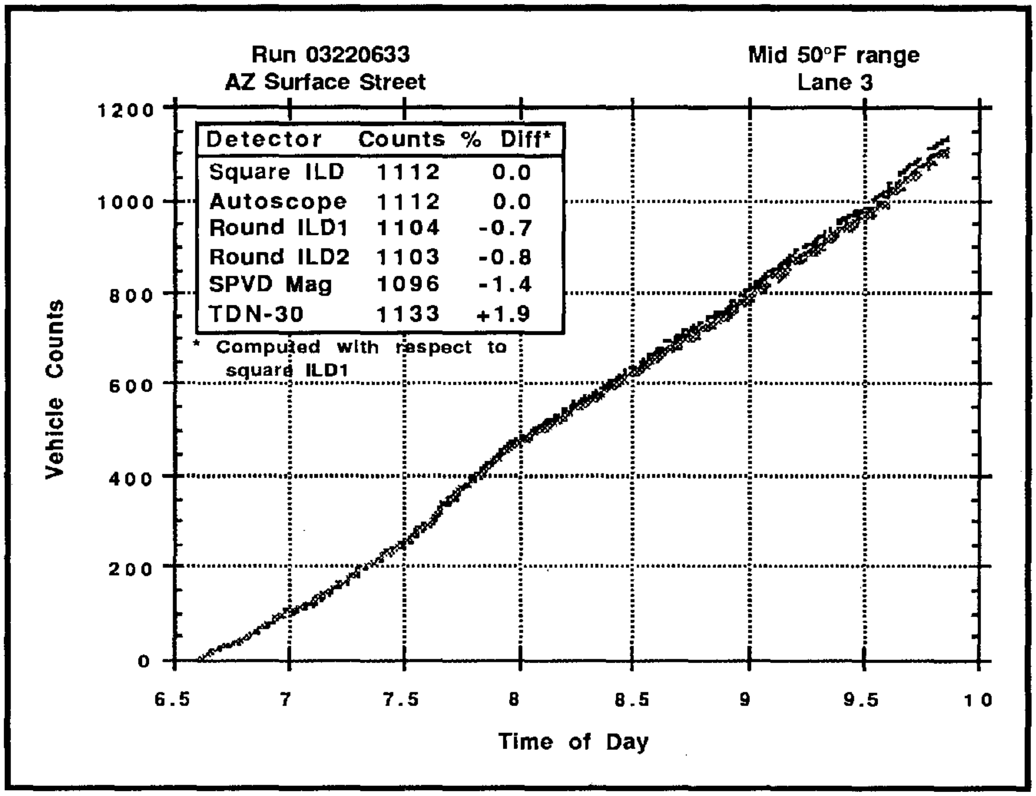
The counts from the second inductive loop in lane 2 were used as the reference value against which the other detector outputs were compared. Three detector outputs, the forward-looking RTMS microwave radar, the TDN-30 microwave Doppler detector, and the Autoscope 2003 VIP, all yielded count results that were within 1 percent of the ILD value after their counts were filtered through the FORTRAN program.



°C = 5(°F-32)/9

Figure 60. Comparison of Vehicle Counts From Five Detectors in Lane 2 From the Arizona Surface Street Site

The results from the lane 3 outputs shown in Figure 61 are closely grouped. The Autoscope 2003 count agrees exactly with the reference count from ILD1 (ILD2 was found to be the most accurate detector in lane 2). The two round inductive loops were each within 1 percent of the square ILD value. The SPVD magnetometer undercounted by 1.4 percent with respect to the loop, while the TDN-30 microwave unit overcounted by 1.9 percent. The close grouping of the three loop outputs from the same lane is a good indicator that the software filtering routine is working well.

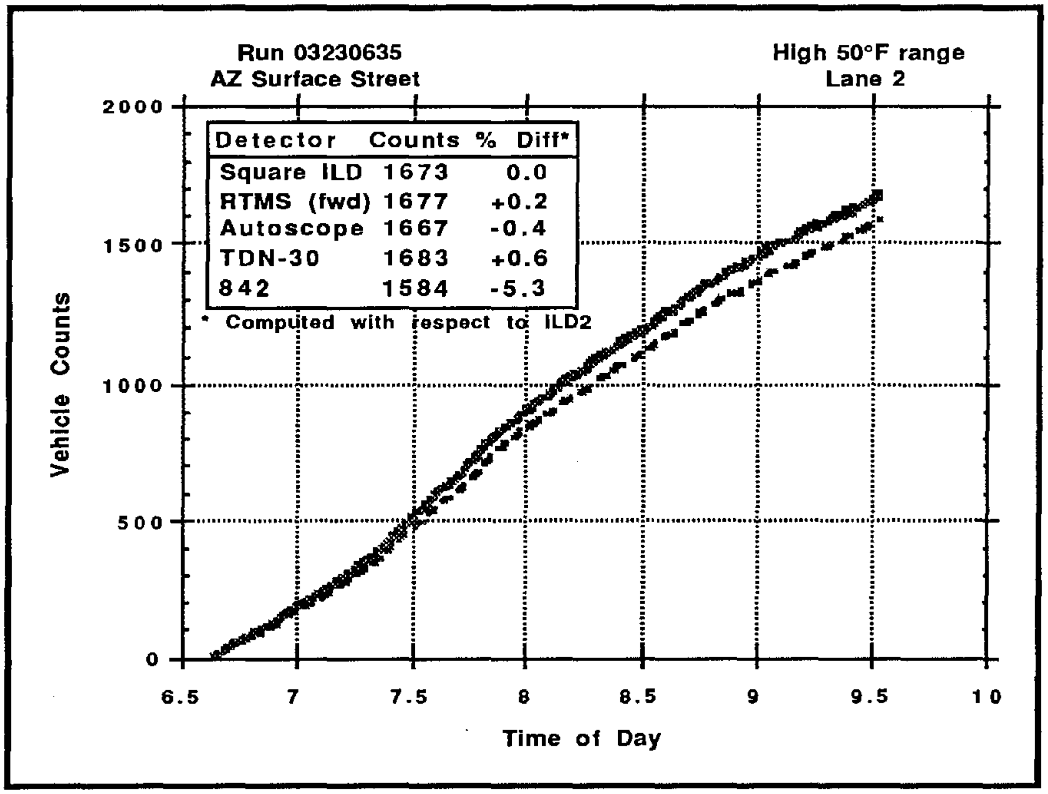


°C = 5(°F-32)/9

Figure 61. Comparison of Vehicle Counts From Six Detectors in Lane 3 From the Arizona Surface Street Site

Run 03230635

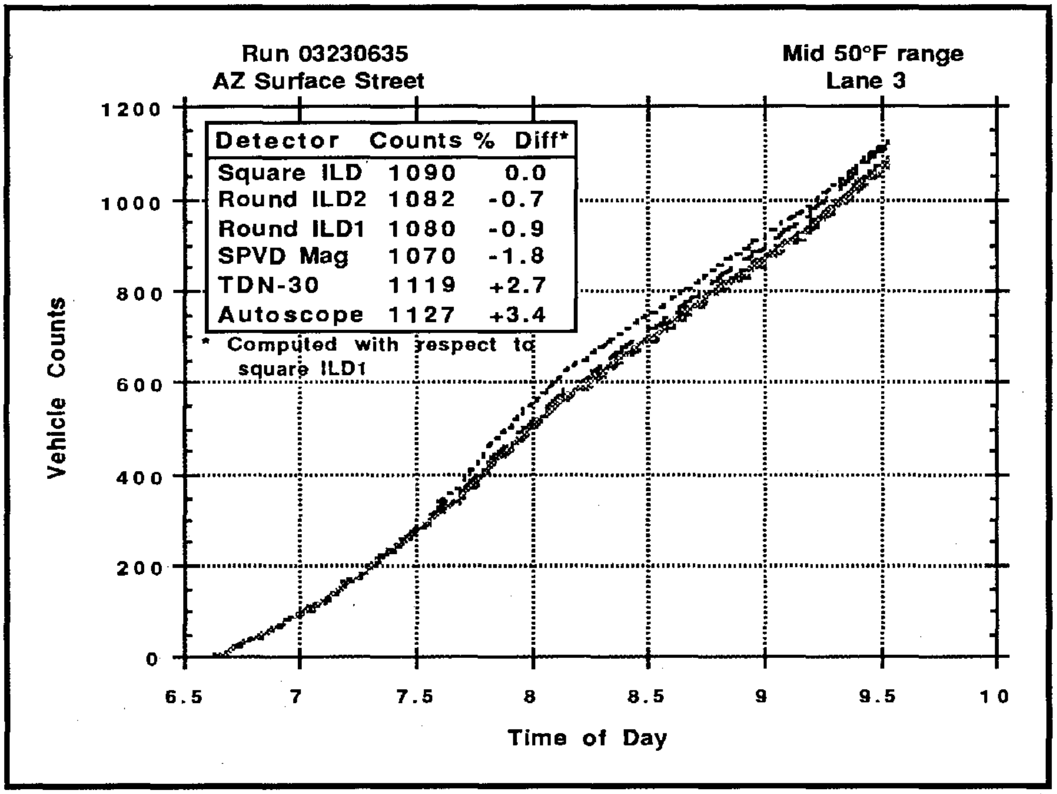
Figure 62 shows a tight grouping for four of the five lane 2 detectors plotted. The forward-looking RTMS true-presence microwave radar, the Autoscope 2003 VIP, and the TDN-30 microwave Doppler detector all provided outputs that were within 0.6 percent of the baseline inductive loop count. The Model 842 passive infrared detector undercounted by 5.3 percent with respect to the inductive loop.



°C = 5(°F-32)/9

Figure 62. Comparison of Vehicle Counts From Five Detectors in Lane 2 From the Arizona Surface Street Site

The lane 3 filtered count results of Figure 63 show the outputs from the data plots from the three loops agreeing within 1 percent of the value reported by the baseline square loop value. The SPVD magnetometer undercounted by 1.8 percent with respect to the loop reference, while the TDN-30 and Autoscope overcounted by 2.7 and 3.4 percent, respectively.



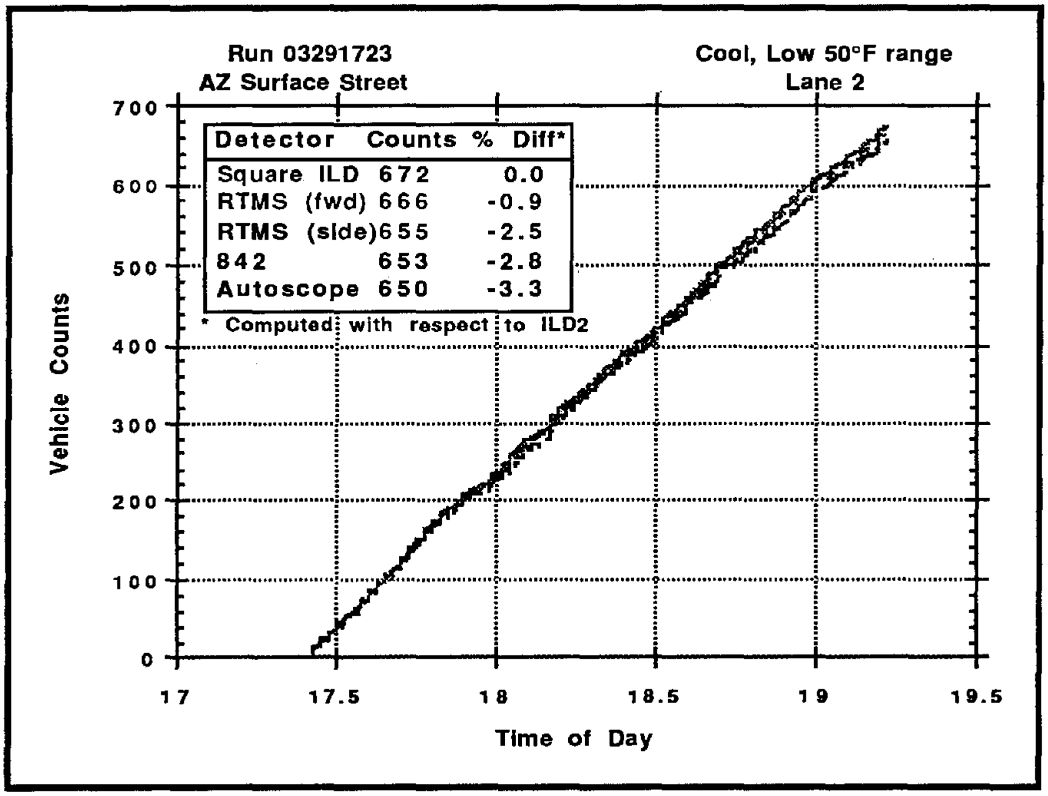
°C = 5(°F-32)/9

Figure 63. Comparison of Vehicle Counts From Six Detectors in Lane 3 From the Arizona Surface Street Site

Run 03291723

This run was conducted over a nearly 2-hour period. The weather was cool, with the temperature in the low 50°F range (around 11°C).

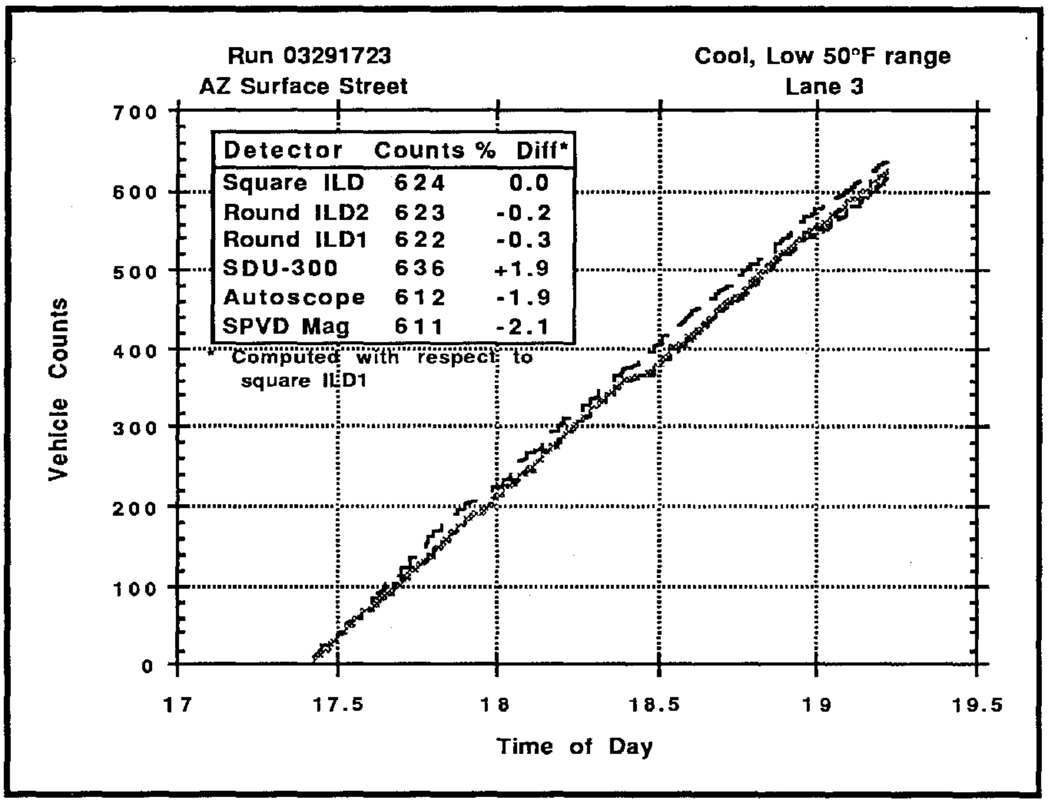
The filtered counts from five detectors in lane 2 are provided in Figure 64. This nearly 2-hour period of light traffic shows the forward-looking RTMS microwave radar as the closest to the reference inductive loop value with an undercount of 0.9 percent. The side-looking RTMS unit reported an undercount of 2.5 percent, while the Model 842 infrared detector and the Autoscope 2003 VIP reported undercounts of 2.8 and 3.3 percent, respectively.



°C = 5(°F-32)/9

Figure 64. Comparison of Vehicle Counts From Five Detectors in Lane 2 From the Arizona Surface Street Site

The six lane 3 detectors represented in Figure 65 show typically close agreement between the three displayed inductive loops, which were all within 0.3 percent of each other. The SDU-300 ultrasonic detector and the Autoscope 2003 VIP were both off by 1.9 percent, with the former overcounting and the latter undercounting. The SPVD magnetometer reported 2.1 percent fewer counts than the reference ILD value.



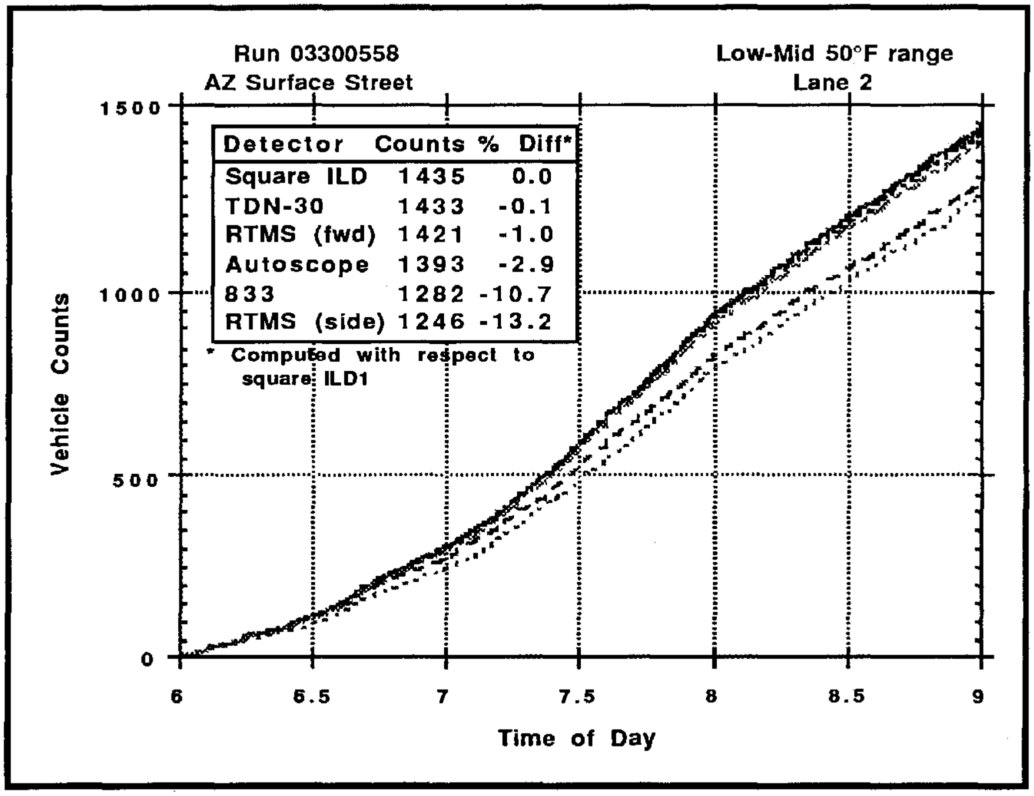
°C = 5(°F-32)/9

Figure 65. Comparison of Vehicle Counts From Six Detectors in Lane 3 From the Arizona Surface Street Site

Run 03300558

This 3-hour, early morning run was conducted in cool temperatures, ranging from the low to mid 50°F range (around 11 to 13°C).

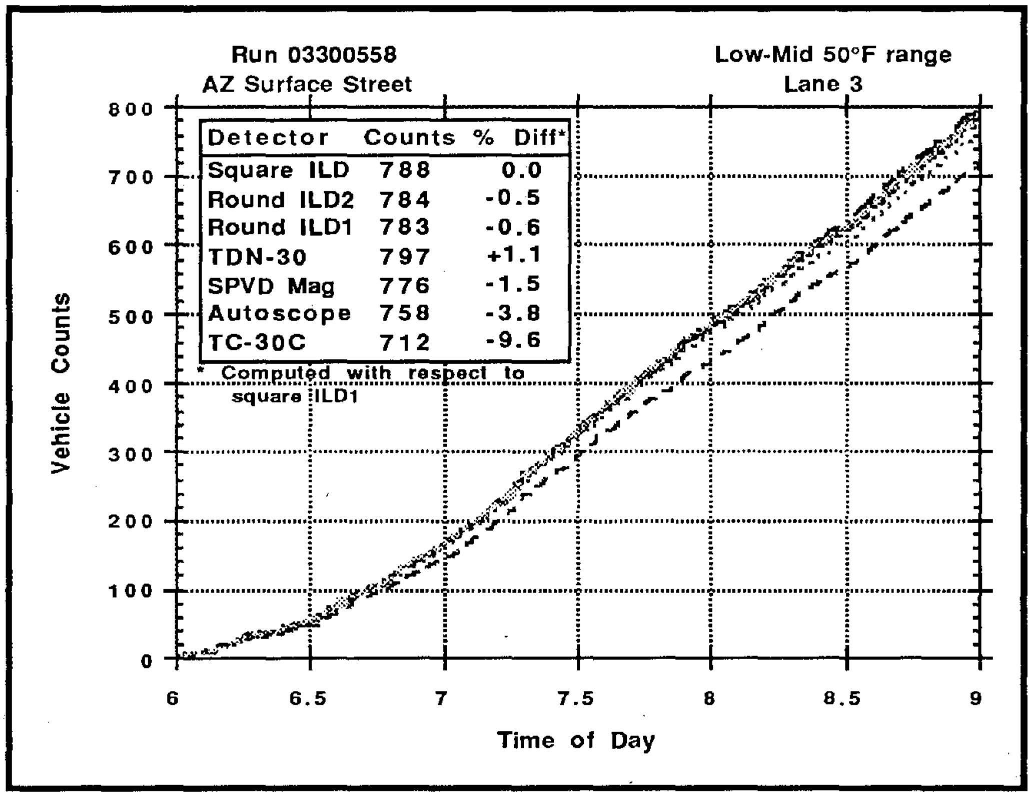
Figure 66 shows plots for six detectors observing traffic in lane 2. As usual, the percent differences were computed using the inductive loop count as the reference value. The TDN-30 microwave Doppler detector reported a difference of only two counts with respect to the inductive loop, while the forward-looking RTMS showed a 1 percent undercount. The Autoscope 2003 VIP was low by 2.9 percent, while the 833 infrared unit and the side-looking RTMS both reported double-digit undercounts.



°C = 5(°F-32)/9

Figure 66. Comparison of Vehicle Counts From Six Detectors in Lane 2 From the Arizona Surface Street Site

Figure 67 shows filtered results from seven detectors representing five different technologies. The three displayed inductive loops showed agreement to within 0.6 percent of one another. The TDN-30, SPVD magnetometer, Autoscope 2003, and TC-30C ultrasonic detector followed in order of decreasing accuracy with respect to the counts recorded by the reference loop. The TDN-30 overcounted by 1.1 percent and the SPVD, Autoscope, and TC-30C undercounted by 1.5, 3.8, and 9.6 percent, respectively.



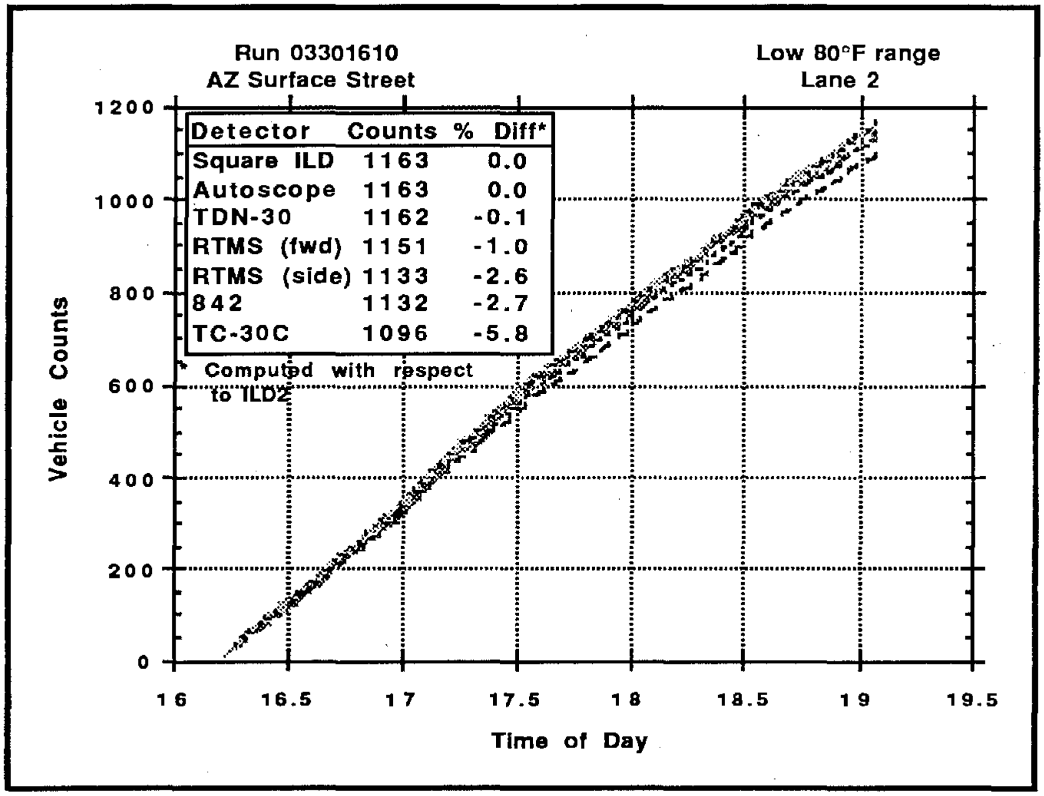
°C = 5(°F-32)/9

Figure 67. Comparison of Vehicle Counts From Seven Detectors in Lane 3 From the Arizona Surface Street Site

Run 03301610

This nearly 3-hour afternoon run took place during pleasant 80°F (26.7°C) weather.

Figure 68 shows close agreement between three of the seven detector outputs in lane 2. The inductive loop and Autoscope 2003 totals agreed exactly, while the count from the TDN-30 lagged by a single count. The forward-looking RTMS microwave radar undercounted by 1 percent with respect to the inductive loop reference, while the side-looking RTMS, 842 infrared detector, and TC-30C ultrasonic unit undercounted by 2.6, 2.7, and 5.8 percent, respectively.



°C = 5(°F-32)/9

Figure 68. Comparison of Vehicle Counts From Seven Detectors in Lane 2 From the Arizona Surface Street Site

Figure 69 shows the filtered count outputs from seven detectors monitoring lane 3. The first square inductive loop is again used as the reference against which the other percent differences are computed. The three inductive loops again lead the way, With the TDN-30 showing a 1 percent overcount with respect to the referenced loop. The SPVD magnetometer showed an undercount of 3 percent, while the Autoscope 2003 and the TC-30C both registered an undercount of 5 percent.

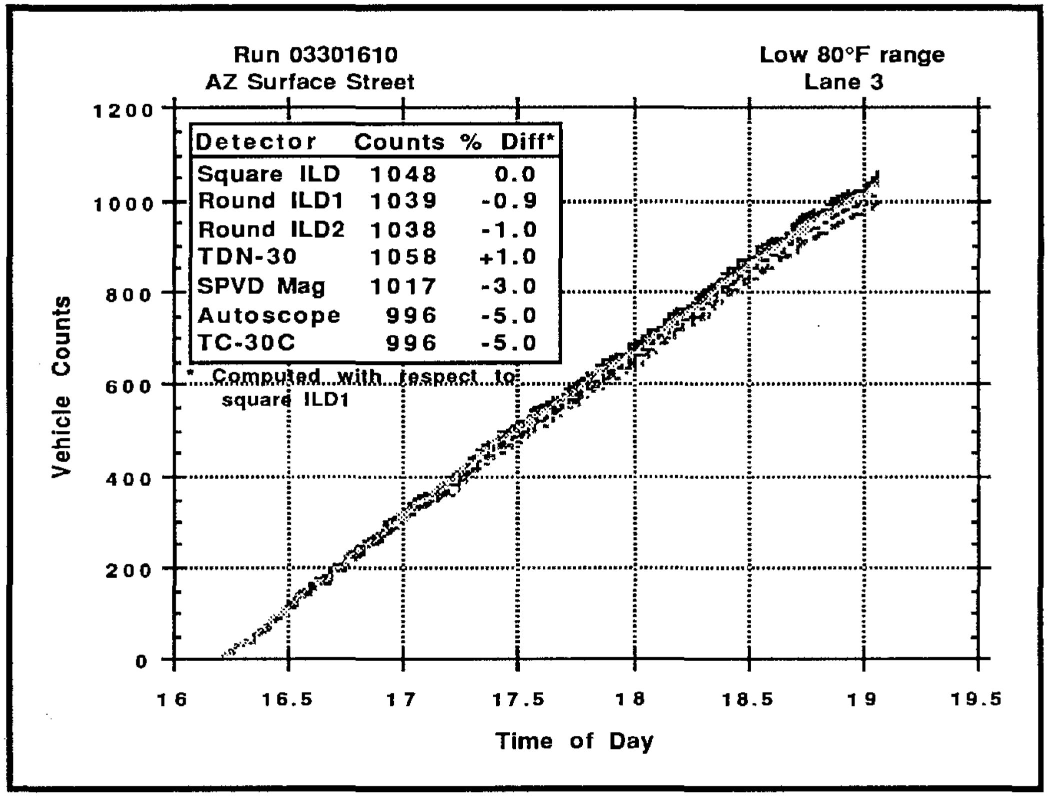
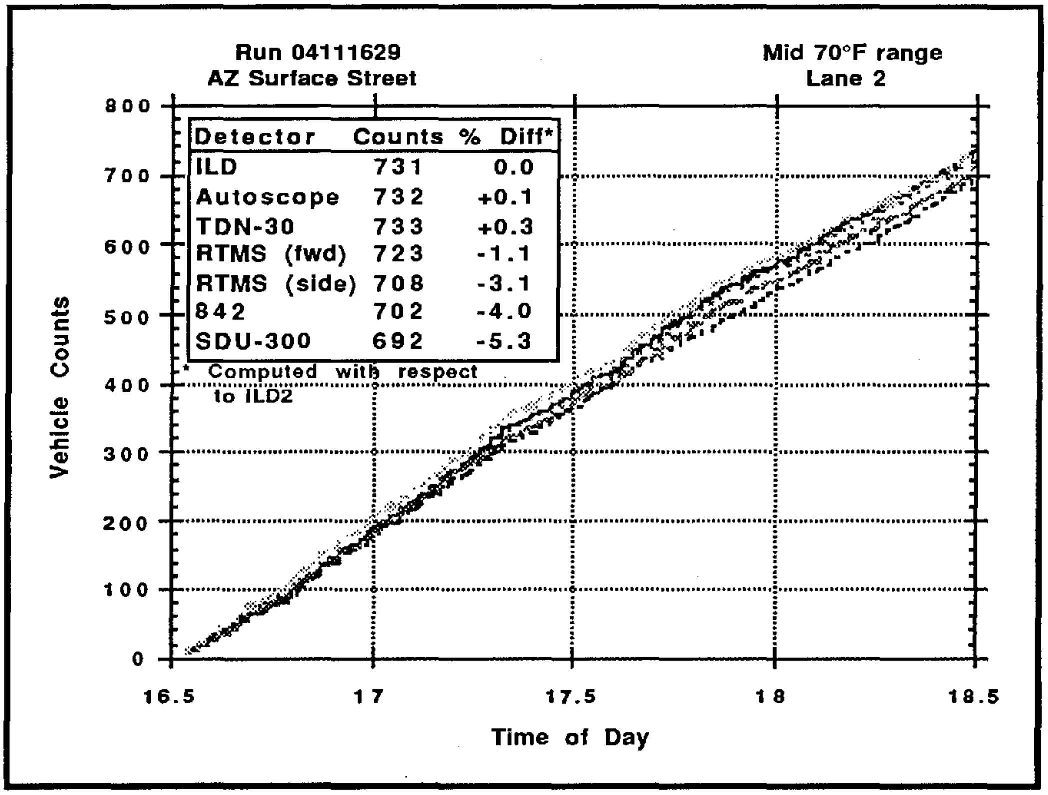


Figure 69. Comparison of Vehicle Counts From Seven Detectors in Lane 3 From the Arizona Surface Street Site

Run 04111629

This session was conducted during a pleasant mid 70°F (around 24°C) temperature over a duration of approximately 2 hours.

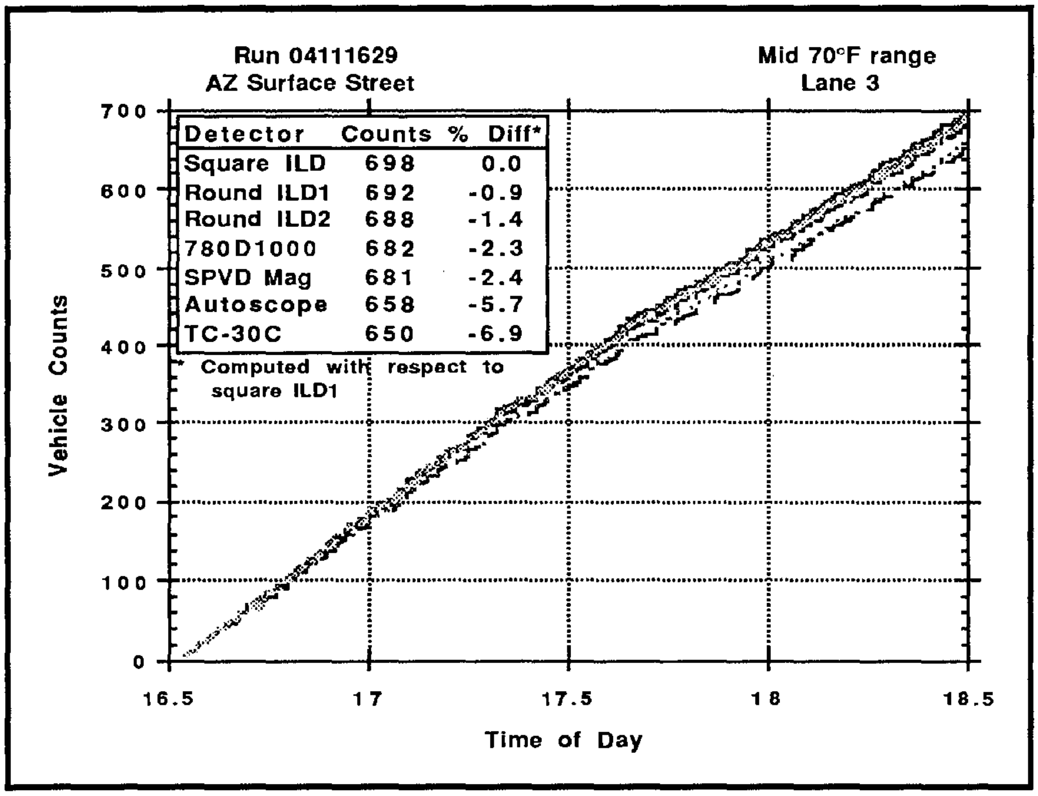
Figure 70 shows outputs from seven detectors viewing lane 2. The Autoscope 2003 VIP and the TDN-30 microwave Doppler detector registered 0.1 and 0.3 percent overcounts, respectively, compared to the square ILD. The forward-looking RTMS undercounted by 1.1 percent, while the side-looking RTMS reported a 3.1 percent undercount. The 842 infrared detector and the SDU-300 ultrasonic detector had undercounts of 4 and 5.3 percent, respectively.



°C = 5(°F-32)/9

Figure 70. Comparison of Vehicle Counts From Seven Detectors in Lane 2 From the Arizona Surface Street Site

The outputs from seven detectors in lane 3 are represented in Figure 71. The gaps between the three inductive loops were uncharacteristically large, with a spread of 1.4 percent between the three outputs. Still, the inductive loops occupy the top three spots with respect to count accuracy. Following the loops were the laser radar and SPVD magnetometer at 2.3 and 2.4 percent undercount, respectively. The Autoscope reported an undercount of 5.7 percent, and the TC-30C reported an undercount of 6.9 percent.



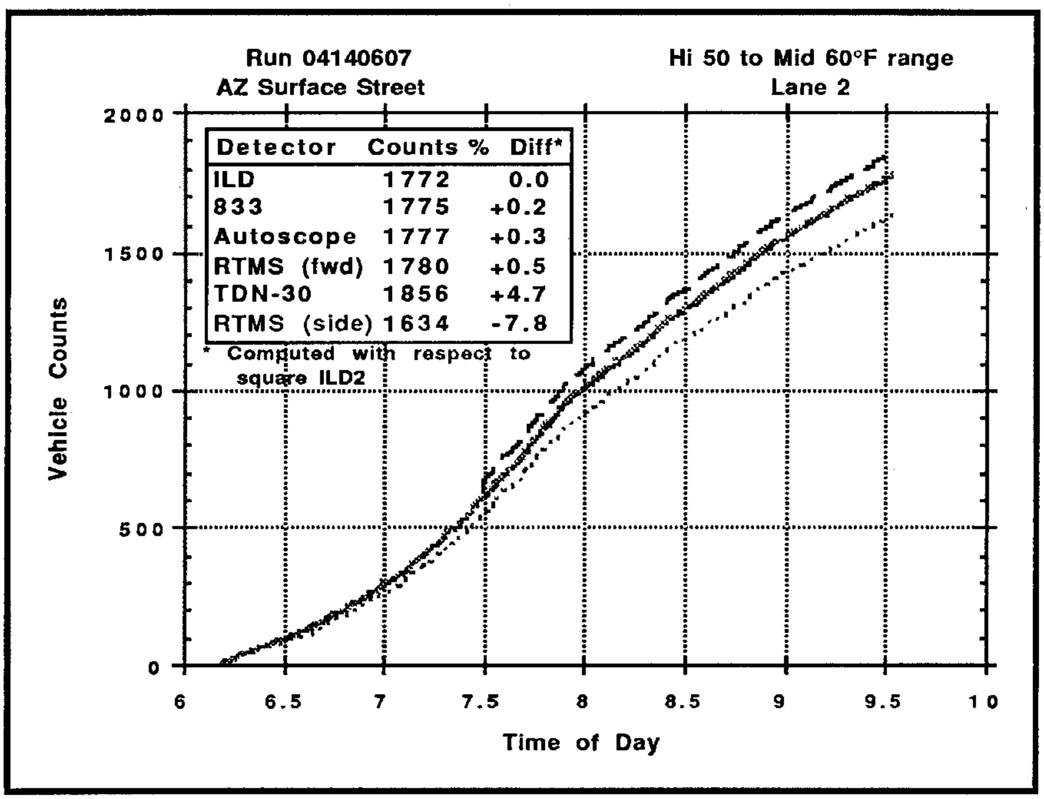
°C = 5(°F-32)/9

Figure 71. Comparison of Vehicle Counts From Seven Detectors in Lane 3 From the Arizona Surface Street Site

Run 04140607

This early morning run was more than 3 hours in duration and occurred amid temperatures in the high 50 to mid 60°F (around 14 to 19°C) range.

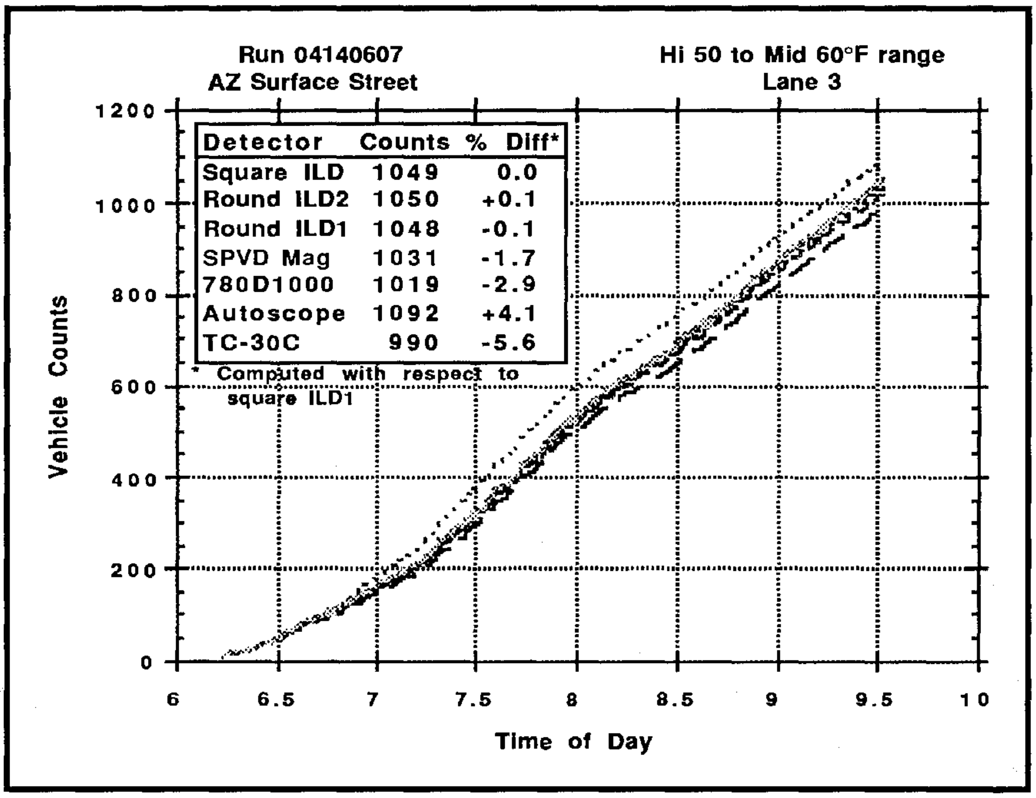
Figure 72 represents the outputs from six detectors in lane 2. The 833, the Autoscope 2003 VIP, and the forward-looking RTMS microwave radar all fell within 0.5 percent of the reference loop value. These four curves are flanked by the plots representing the TDN-30, which overcounted by 4.7 percent, and the side-looking RTMS, which undercounted by 7.8 percent. The TDN-30 overcount appears to commence around 7:30 a.m., when the curve takes a sudden jump upward. Until this time, the unit's output seemed to be tracking the others nicely.



°C = 5(°F-32)/9

Figure 72. Comparison of Vehicle Counts for Six Detectors in Lane 2 From the Arizona Surface Street Site

The seven curves comprising Figure 73 find the two round loops in agreement with the square reference loop, each Within a single count. The SPVD magnetometer read 1.7 percent lower than the reference detector, while the laser radar undercounted by 2.9 percent. The Autoscope 2003 VIP registered an overcount of 4.1 percent and the TC-30C turned in a typical undercount of 5.6 percent.



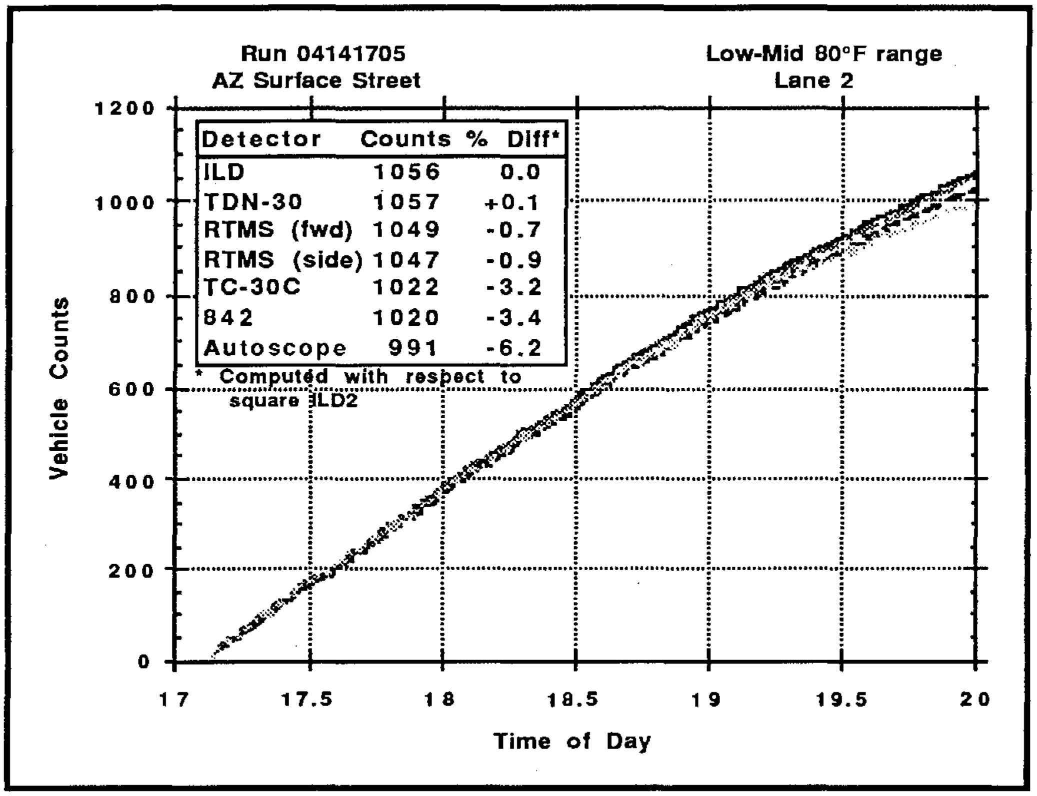
°C = 5(°F-32)/9

Figure 73. Comparison of Vehicle Counts From Seven Detectors in Lane 3 From the Arizona Surface Street Site

Run 04141705

This evening run lasted slightly less than 3 hours and the temperature hovered in the low to mid 80°F (around 27 to 30°C) range.

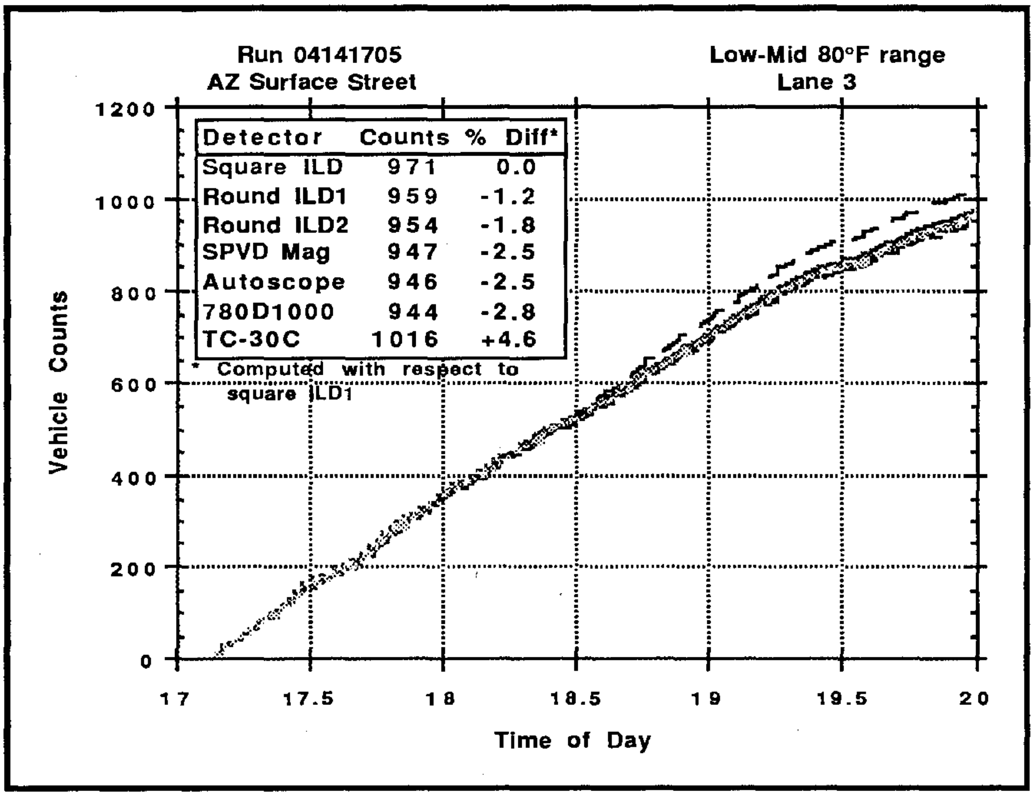
The lane 2 count results are given in Figure 74 for seven detectors. The best performing were the TDN-30 and forward- and side-looking RTMS. These reported differences from the reference detector of less than 1 percent. The TC-30C, 842, and Autoscope undercounted with respect to the reference loop, yielding percent differences of 3.2, 3.4, and 6.2, respectively.



°C = 5(°F-32)/9

Figure 74. Comparison of Vehicle Counts From Seven Detectors in Lane 2 From the Arizona Surface Street Site

Figure 75 shows the filtered count comparisons for seven detectors monitoring lane 3. The first square loop was again used as the reference against which the other detector outputs were compared. No other unit reported counts to within 1 percent of the reference value. The closest were the pair of round loops located farther down the lane, which showed undercounts of 1.2 and 1.8 percent, respectively. The SPVD magnetometer and the Autoscope 2003 VIP both registered 2.5 percent fewer counts than the square loop, while the TC-30C ultrasonic detector overcounted by 4.6 percent.



°C = 5(°F-32)/9

Figure 75. Comparison of Vehicle Counts From Seven Detectors in Lane 3 From the Arizona Surface Street Site

9. CONCLUSIONS

Table 5 contains vehicle count accuracy results compiled over the 30 selected runs that were compared to ground truth values during the program. Some detectors appear in multiple columns. These entries represent cases where multiple units were employed or a single unit monitored multiple lanes. Blank cells represent instances in which no data were obtained due to no fault of the detector (e.g., the device was not fielded during that run or the setup was known to be sub-optimal in some way). Cells With asterisks represent instances in which no results were obtained due to detector failure or instances in which extremely poor results were attributed to detector malfunction. These asterisks are important in that they provide information relating to the reliability of the detectors.

Arithmetic means and standard deviations were computed for the percent count accuracies contained in Table 5. Together, these two results provide an indication of how well each detector performed over the broad range of weather and traffic conditions represented by these 30 runs. The mean is the average value obtained over all of the runs in which results were reported for that particular detector, while the standard deviation gives an indication of how far from the mean value a count result is likely to be. This implies that all runs were weighted equally. Therefore, a run in which 100 vehicles were counted during ground truthing carries the same weighting in the Table 5 mean and standard deviation computations as a run in which 2000 vehicles were counted.

To normalize the results with respect to the number of vehicles counted, cumulative count accuracies were computed and are shown in Table 6. Vehicle counts for each listed detector were summed over all the reported values listed in Table 5. Likewise, the ground truth counts for the appropriate traffic lanes were summed for each run in which a value was reported for that detector. Cumulative count accuracies were calculated using the detector and ground truth totals.

The most consistently accurate detector in terms of count was the inductive loop. The non-weighted means (from Table 5) from the two ILDs reflected overcounts of 0.8 and 0.4 percent, respectively, while the standard deviations of 2.6 and 3.1 percent were among the tighter groupings seen. Even then, the numbers were inflated by the Phoenix freeway results, where improper installation led to crosstalk problems, and the Minnesota surface street tests, where frequent lane changes coupled with light traffic conditions could lead to overly exaggerated count errors.

Recomputing these results without the influence of the Minneapolis street and Phoenix freeway data yields a mean of -0.20 percent and a standard deviation of 0.83 percent for ILD1, and a mean of -0.01 percent with a 1 percent standard deviation for ILD2. These results indicate that the inductive loops meet even the most stringent of the vehicle flow error specifications listed in Chapter 2 of the Task L final report. Following the loops in count accuracy, with results in the 1 to 2 percent category, were the forward-looking RTMS and one of the Autoscope 2003 lane outputs. The next most accurate detectors in terms of count, were those with accuracies in the 3 percent to 7 percent range. These included the TDN-30, the second Autoscope 2003 lane output, TC-30C, SDU-300, SPVD magnetometer, side-looking RTMS, and the 833. The detectors exhibiting the poorest count accuracies were the 842, SmartSonic, and TC-26. The large errors in this group were due in part to built-in large hold times and designs that were not optimized for the service they experienced during the field evaluations.

Table 5. Count Accuracy Matrix

Run #	TDN-30(1)	TDN-30(2)	A'scope (1)	A'scope (2)	ILD(1)	ILD(2)	TC-30C	SDU-300(1)	SDU-300(2)	SPVD MAG	RTMS (fwd)	RTMS (side)	833	842	SS-1	TC-26	780D 1000
01281601	-1.9		-0.1	-2.8	+0.6	-0.6	-10.5						*			*	
02101610	+0.2		+0.5	-1.8	+0.6	-0.3	-1.1	-7.6					*			*	
02110625	-0.3		-0.3	-1.8	+0.2	-0.6	-1.6	-2.5					-23.4			*	
03081153	*	+0.7	+2.4	-15.9	+4.7	+2.8	+17.3			-0.7	+3.4		*			*	
03091019	+13.9	+0.0	-1.2	-1.3	+7.3	+1.9	*			+0.0	+0.9		-4.4			*	
03101343	-2.9	-4.0	-0.5	-2.1	+1.2	+1.0	+13.1			-19.2	+9.3		+16.4			+12.1	
03120842	+0.0	+1.3	+14.3	-20.1	+3.8	+2.5	*	-18.9		+1.3	+8.2		*			*	
07150617	*	-6.2	-2.1	+0.1	+0.2	+2.4	*	-4.0	-3.0	-6.8	-2.7	-1.9	*			-17.5	
07151610	*	-4.1	-0.6	-0.1	-0.2	+0.9	*	-3.5	-1.5	-6.0	+9.8	-2.7	*			+48.6	
07201429	*	-4.2	-1.8	-2.7	+0.3	+0.2	*	-2.2	-1.1	-7.4	+0.5	-8.0	*			+19.8	
07210613	*	-5.5	-1.9	-1.5	-0.1	+0.2	*	-6.5	-4.4	-15.4	-3.2	-7.5	*			-31.5	
07230615	*	-6.0	-2.9	-1.3	-0.5	+0.1	*	-5.1	-3.9	-15.8	-1.8	-6.6	*			-26.4	
07231329	*	-0.9	-2.2	-1.5	+0.4	+0.5	*	-2.2	-1.8	-12.0	+0.5	-3.9	*			*	
07280615	*	-4.5	-4.1	-0.4	-0.1	+0.2	*	-7.5	-3.4	-8.0	-0.9	-7.6	*			-19.4	
07291653	*	-6.4	-0.9	-0.6	-0.5	+0.0	*	-4.7	-2.1	-5.8	-0.7	+14.5	*			+32.1	
08261617	-0.2				+0.0	+0.2	*						+8.9	+0.1		-13.3	
09071553	-1.5				-1.5	-1.7	*	+5.5			+0.2		-7.1	-3.9		-9.8	
09141730	-1.7				-2.4	-1.6	*	-1.6			+2.4		+8.2	-25.6		+9.9	
11090822	-8.5	-1.4			+2.1	-8.6	-7.1	-4.1	-2.3	-0.1			+0.9	-21.3		*	-9.3
11221359	-8.2	-2.6	-11.0	+0.1	-6.8	*	+2.9	-9.4	-3.8	-2.7	-6.2		-4.1	*	+20.8	-46.5	-5.5
11230648	-4.6	-2.2	-4.0	-0.2	-0.5	*	-1.7	-11.0	-3.9	+5.6	-2.4		-2.4	*	+10.5	-47.0	-2.0
12021502	-4.8	-2.8	-4.8	-0.8	-1.2	-5.9	-7.5	-5.5	-2.0	*	-2.9		-3.1	*	+14.3	-45.1	-2.2
12030636	-6.4	-3.4	-1.0	-0.5	-1.2	-4.8	-8.6	-6.6	-5.8	*	-4.1		-3.1	*	+4.1	-47.5	-2.6
12081534	-7.3	-1.1	-6.1	-1.2	*	*	-12.6	-4.4	-2.8	*	-3.5		-2.1	*	+6.7	-22.8	-2.2
07281536	-12.6	-3.3	-3.6	+0.5	+3.2	+2.9	-18.1	-0.9	-1.8	*	+1.2	-0.4	-2.8	-12.5		*	-1.2
08011603	-4.7	-3.9	-17.5	-4.8	+2.3	+4.2	*	-5.1	-3.9	-4.6	+0.4	-1.9	-7.0	-12.9		+0.8	-2.2
08021550	-6.8	-4.2	-17.3	-2.2	+3.3	+4.0	+4.3	-5.8	-3.8	-4.8	-2.1	-1.5	-6.5	-12.0		-4.5	-3.0
08031611	-7.6	-4.1	-19.6	-3.1	+2.9	+3.9	*	-5.6	-4.8	*	-2.3	-2.7	-7.1	-10.7		-2.7	-3.8
08041552	-8.1	-4.9	-6.8	-4.5	+2.6	+3.4	*	-5.7	-4.7	-3.8	-2.8	+0.1	-5.4	-11.1		-2.8	-3.1
08050438	-7.5	-5.1	-1.7	+0.1	+2.5	+4.1	-24.7	-5.8	-4.5	-7.0	-0.3	-3.7	-5.1	-13.8		+9.7	-3.1
MEAN:	-3.9	-3.3	-3.6	-2.7	+0.8	+0.4	-4.0	-5.2	-3.3	-6.0	+0.0	-2.4	-2.7	-12.4	+11.3	-9.7	-3.4
STDEV:	5.4	2.1	6.8	4.7	2.6	3.1	11.3	4.2	1.3	6.3	4.0	5.6	8.2	7.4	6.6	26.5	2.2

Table 6. Cumulative Count Accuracies

	TDN-30(1)	TDN-30(2)	A'scope (1)	A'scope (2)	ILD(1)	ILD(2)	TC-30C	SDU-300(1)	SDU-300(2)	SPVD MAG	RTMS (fwd)	RTMS (side)	833	842	SS-1	TC-26	780D 1000
Cumulative Accuracy:	-4.3	-3.8	-4.7	-1.6	+0.1	+0.1	-5.4	-5.0	-3.5	-6.6	-1.1	-3.3	-4.2	-12.2	+11.3	-15.4	-3.3

☆U.S. GOVERNMENT PRINTING OFFICE: 1996 - 418-103/65718