Evaluation of Prototype Automatic Truck Rollover Warning Systems

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Federal Highway Administration

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

FOREWORD

This report will be of interest to highway engineers and administrators responsible for the safety of trucks on freeway ramps. This report presents the evaluation of three prototype automatic truck rollover warning systems that were installed on ramps on the Capital Beltway in the Washington, D.C. area. Two systems were installed on ramps in Virginia, and one system was installed on a ramp in Maryland.

The systems were operational for 3 years, and data were collected on the effect the system had on slowing trucks, the accuracy of the sensors in measuring truck characteristics, as well as the operational and maintenance problems experienced with the systems. Plans and specifications for the installation of these systems are available from the Federal Highway Administration, HSR-30.

Sufficient copies of this report are being distributed to provide a minimum of two copies to each FHWA regional office and six copies to each Division office. Four of the Division office copies should be sent to their State highway agency by the division.

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

NOTICE

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16. Abstract

Three operating prototype Automatic Truck Rollover Warning Systems (ATRWS) installed on the Capital Beltway in Maryland and Virginia were evaluated for 3 years. The general objectives of this evaluation were to assess how the ATRWS performed and to determine its cost-effectiveness. More specifically, the requirements of this project were to:

1. Evaluate the performance and maintenance requirements of the system components.
2. Evaluate the effect of the ATRWS on speed reduction of detected trucks traveling at or near their rollover speed or maximum safe speed.
3. Evaluate any improvements in safety resulting from the systems.
4. Prepare appropriate user and maintenance manuals, and update the design and specifications.

The project also called for system maintenance and operational support to the two States and periodic calibration of the system components. The following tasks were followed to accomplish the evaluation objectives:

1. Task A System Evaluation Plan.
2. Task B Calibration Tests — Weight, Speed, Classification, and Fiber-Optic Sign Activation Analysis.
3. Task C Provide System Maintenance — Design Plans vs. As-Built, and Operational Maintenance.
4. Task D System Evaluation — Speed Reduction Analysis.

17. Key Words

Truck, rollover, detection, warning, accident, prevention, exit ramp, prototype, evaluation.

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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)

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1. INTRODUCTION

BACKGROUND

Truck accidents on urban freeways occur more frequently at interchanges — particularly on curved exit ramps — than at any other location. In fact, trucks overturning on exit ramps at interstate interchanges account for 5 out of every 100 fatal accidents.(1) Truck rollover accidents can be very costly in urban areas, because these accidents usually result in fatalities and injuries, vehicle and roadway damage, and traffic delays. Losses are even greater when trucks carrying combustible or hazardous cargo are involved.

An earlier Federal Highway Administration (FHWA) study examined the feasibility of deploying an automatic system that would warn drivers of trucks susceptible to rollover.(2) That study identified that existing detection and information systems could be integrated to provide a system that would give early warning of a possible overturn and advise the truck driver to reduce speed. As a result of this feasibility study, three systems were designed and installed at three ramps on the Capital Beltway (I-495) in Virginia and Maryland.

This final report presents the results and findings of the evaluation for three prototype Automatic Truck Rollover Warning Systems (ATRWS), located at:

1. I-495W/I-95S in Springfield, Virginia.
2. I-495W/Route 123N in McLean, Virginia.
3. I-495E/I-95N in Beltsville, Maryland.

OBJECTIVES

The general objectives of this evaluation were to assess how the ATRWS performed and to determine its cost-effectiveness. More specifically, the requirements of this project were to:

1. Evaluate the performance and maintenance requirements of the system components.
2. Evaluate the effect of the ATRWS on speed reduction of detected trucks traveling at or near their rollover speed or maximum safe speed.
3. Evaluate any improvements in safety resulting from the systems.
4. Prepare appropriate user and maintenance manuals, and update the design and specifications.

The project also called for system maintenance and operation support to the two States and periodic calibration of the system components. The following tasks were followed to accomplish the evaluation objectives:

1. Task A System Evaluation Plan.

2. Task B Calibration Tests — Weight, Speed, Classification, and Fiber-Optic Sign Activation Analysis.

3. Task C Provide System Maintenance — Design Plans vs. As-Built, and Operational Maintenance.

4. Task D System Evaluation — Speed Reduction Analysis.

5. Task E Preparation of Draft Manuals and Final Report — Updated User and Technical Manuals, and Plans.

This report provides the results of the first four objectives. The user manual and updated design plan (i.e., as-built drawings) and specifications were prepared and submitted to FHWA separately. They are available from FHWA or the contractor.

PROCEDURE

The first task required the development of a system evaluation plan. This plan was submitted to FHWA in February 1994.[(3)] In summary, the plan called for the following:

1. Collection and analysis of accident data to establish if any truck rollover accidents occurred or other accidents that could be attributed to the system.

2. Periodic testing of the system components by having tanker and box tractor trailers of known weight and speed travel over the system several times.

3. Periodic evaluation of the speed changes affected by the system.

4. Collection and analysis of maintenance and operation costs and other requirements for operating the ATRWS.

The periodic testing was to be at 4-month intervals. Unfortunately, only two tests could be conducted for a variety of reasons, including the fact that there were significant periods when the systems were not operating properly, the unavailability of trucks, and some weather constraints. The first evaluation occurred about 4 months after the three systems were installed. The results of that evaluation were documented and reported to the FHWA in April 1995.[(4)] This final report provides the results of the second evaluation, which occurred about 16 months after installation, and the results of the overall evaluation of the system.

CHAPTER 2. DESCRIPTION OF THE AUTOMATIC TRUCK ROLLOVER WARNING SYSTEM

THE ROLLOVER PROCESS

A description of the ATRWS must begin with an understanding of truck rollover. While a detailed discussion of this phenomena can be found in the feasibility report, the following provides a summary.(2)

As a truck travels through a curved ramp, its speed and the ramp's curvature and superelevation cause a level of lateral acceleration on the truck. For each truck and loading condition, there is a maximum value of lateral acceleration beyond which it will roll over. This level of acceleration is called the rollover threshold (RT), and values for various trucks have been determined from static and dynamic tests by the University of Michigan's Transportation Research Institute (UMTRI). UMTRI also has defined the maximum lateral acceleration a truck with a given RT can sustain as:

$$a_{y_{max}} = \frac{RT\text{-}SM}{1.15} \qquad (1)$$

where SM is a safety margin value and 1.15 is a factor accounting for additional lateral acceleration due to steering fluctuation during the turn.

The maximum lateral acceleration is also related to curve geometrics and speed by the following equation:

$$a_{y_{max}} = \frac{V^2_{max}}{R(g * e)} \qquad (2)$$

where e is superelevation, g is gravity, and V is speed. Thus the maximum rollover threshold speed (V_{max}) is derived from these two equations, which becomes one of the parameters to decide if the truck may rollover.

ATRWS DESIGN

The objective of the ATRWS is to identify a truck of a certain type that is traveling towards a curved ramp, whose speed is likely to approach or exceed the rollover threshold speed, and then to warn the driver of the truck to reduce speed prior to reaching the curve. The rollover theshold speed is determined by the truck's weight, rollover threshold factor, and the geometrics of the ramp (superelevation and radius of curve). To accomplish this objective, the following components are used:

1. Two sets of weigh-in-motion (WIM) detectors for each lane on the ramp embedded in the pavement at an appropriate distance before the curved section, which measure the weight and speed of trucks by class. The WIM detectors are piezoelectric sensors.

2. Loop magnetic detectors for each lane on the ramp placed at a sufficient distance before the curved section, which measure the speed of the passing vehicles. Figure 1 shows the installation of both the piezoelectric sensors and loop magnetic detectors for one of the sites.

3. A radar-sensing device located at the second WIM detector for each lane on the ramp, which is able to determine whether a truck has exceeded a pre-set height value. (Tanker trucks, which are lower than box-trailer trucks, have a different rollover threshold factor). Figure 2 shows the height detector.

4. A sign warning system for each lane on the ramp that consists of a static truck rollover warning sign with an advisory speed and a fiber-optic sign that displays the message "TRUCKS REDUCE SPEED" when activated. Figure 3 shows two views of the sign, one when not activated and one when it is activated.

5. A controller that operates the system by processing the input data from the WIM detectors, the speed loop detectors, and height detector in accordance to an algorithm. Figure 4 shows the controller components which includes, the 486 computer controller (enclosed in industrial housing), cellular modem, 24-h inverter/backup battery, loop, and piezo cables terminated at the computer.

Figure 5 shows a full view of the I-495W/I-95S site in Springfield, VA. Figures 6 and 7 are schematic diagrams of the typical installation. Detailed design plans and specifications were prepared and are available.

WIM detection station 1 and 2 are loop-piezo-piezo stations, and provided vehicle weight, vehicle classification, and vehicle speed for all vehicles to the ATRWS controller. Likewise, WIM stations 4 and 5 of the system are also loop-piezo-piezo stations, which provide vehicle weight, vehicle classification, and vehicle speed to the programmable controller. Vehicle height is provided by the height detector, which is placed near WIM station 2 (station 4 for two-lane system) to the controller. The data from WIM stations 1 and 2 and the height detector are analyzed by the ATRWS software to determine if the vehicle would exceed the RT critical speed at the point of curvature. If the ATRWS determines that the vehicle will exceed the critical speed at the point of curvature, given its entry speed, weight, vehicle classification, and ramp geometrics, the ATRWS activates a warning information system, i.e., a readable message on a fiber-optic sign mounted below a static warning sign. Both WIM stations 3 and 6 consist of loop-piezo-loop configurations and are used to measure and record vehicle speed and classification data prior to entering the point of curvature (PC) of the ramp.

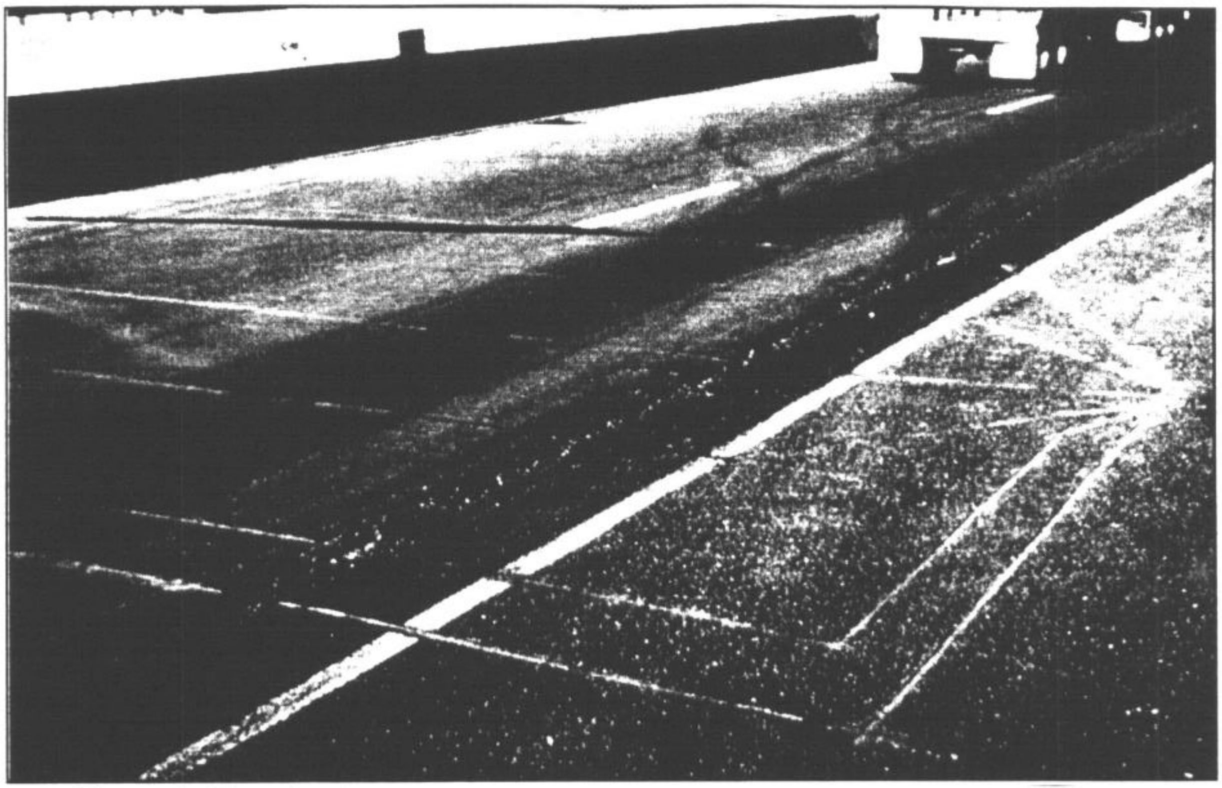


Figure 1. Piezoelectric sensors and loop magnetic detectors embedded in pavement.

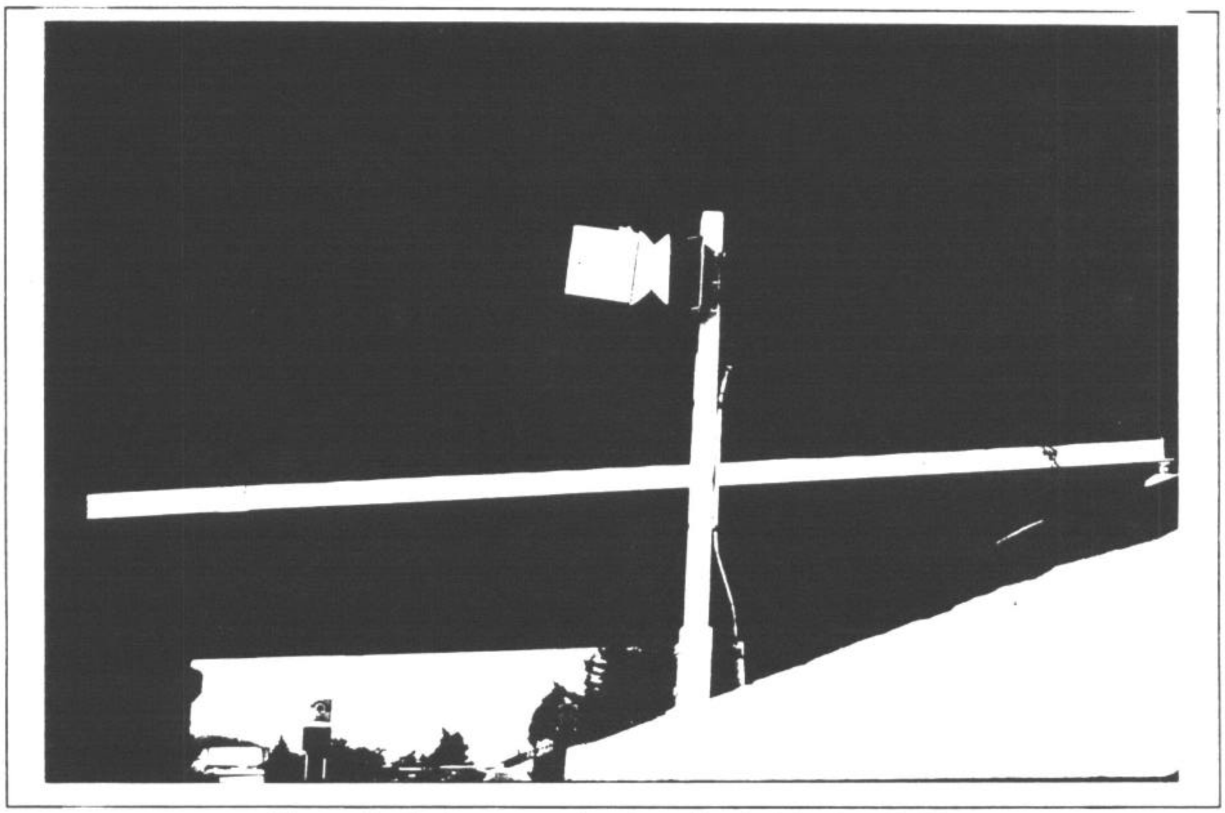
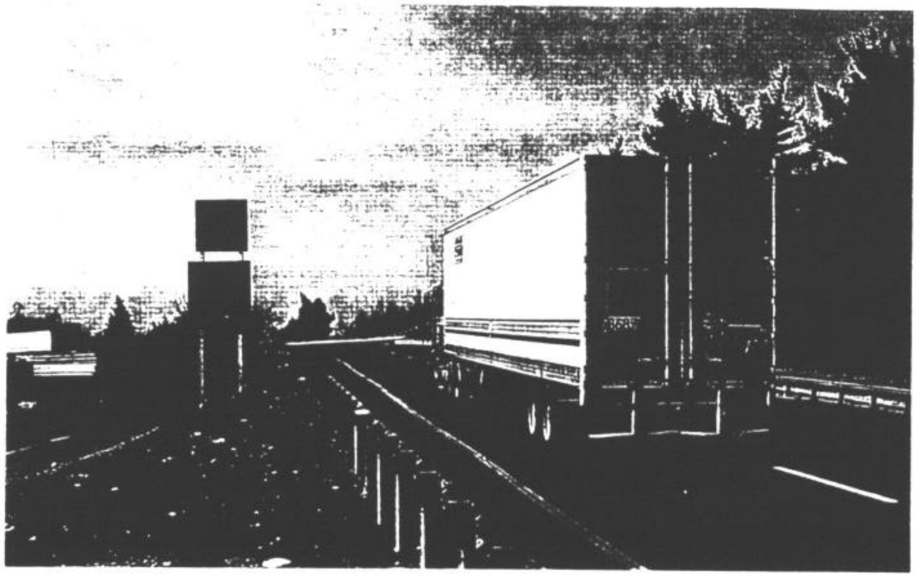


Figure 2. Radar sensor for detecting height threshold.



(a) Fiber-optic sign blank.

(b) Fiber-optic sign activated.
Figure 3. Two views of ATRWS sign system.

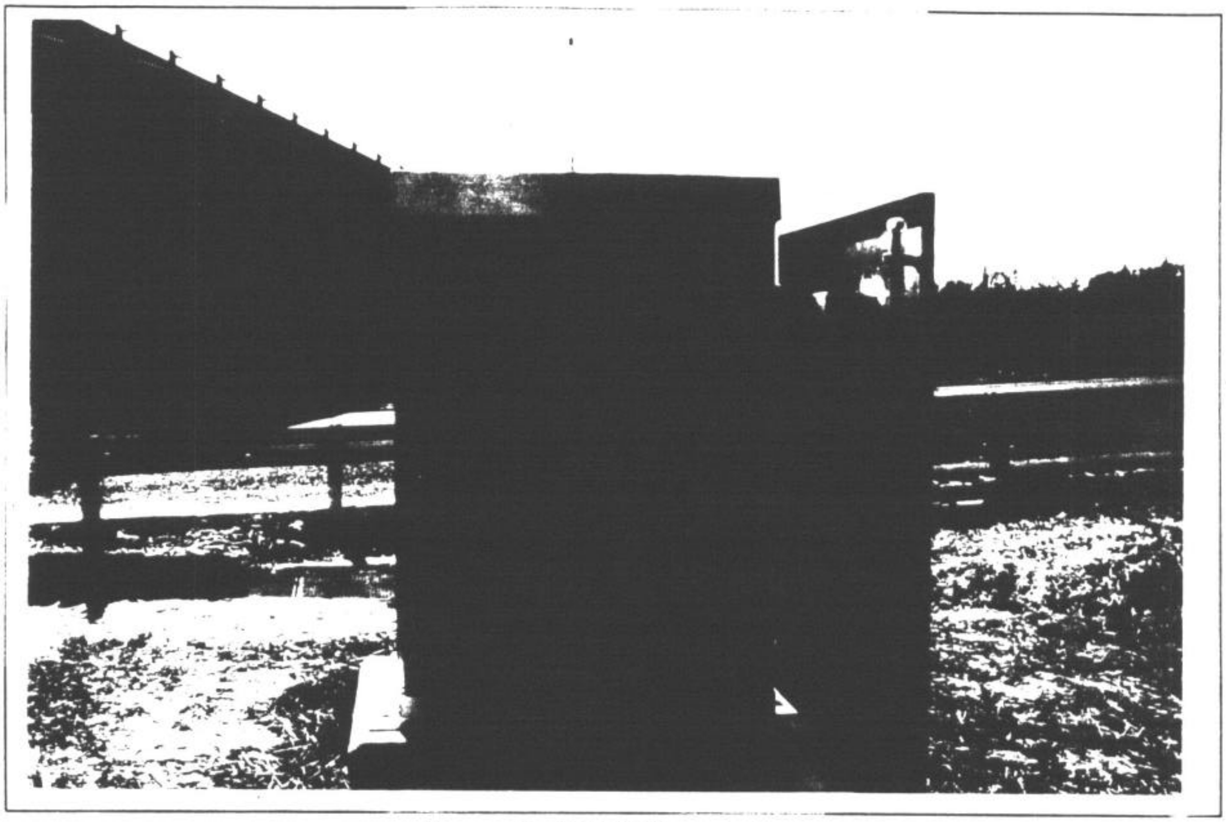


Figure 4. ATRWS controller.

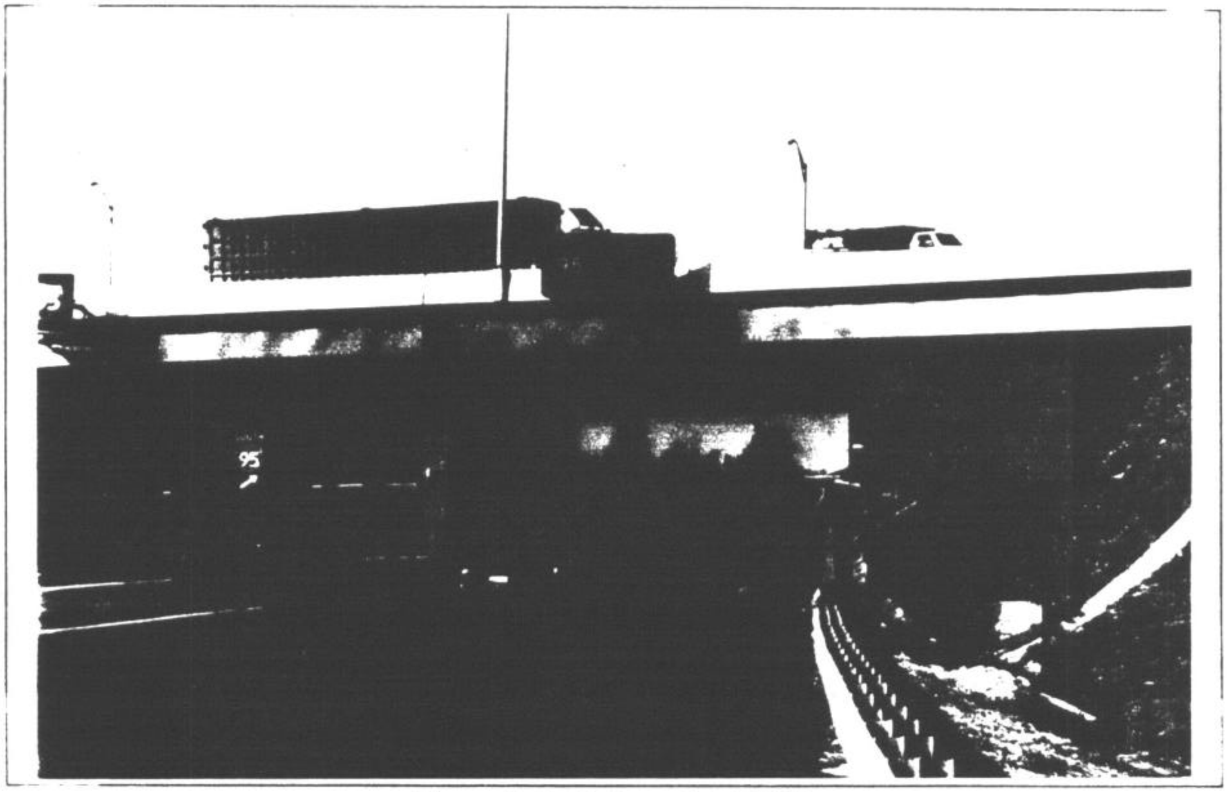
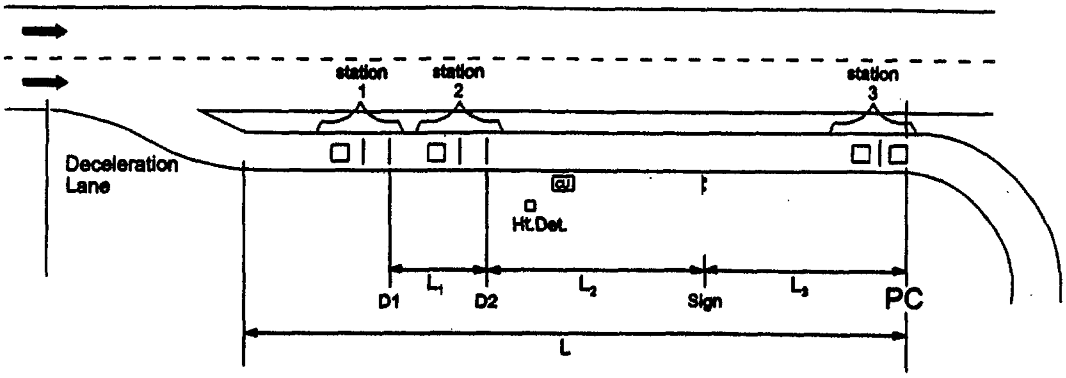


Figure 5. Full view of ATRWS.



CU = Controller Unit.

□ = Height Detector.

⊦ = Warning Sign.

L = Length of ramp deceleration lane.

L_1 = Distance between station 1 and station 2 equals 30.5 m (100 ft).

L_2 = Distance between station 2 and warning sign equals 61.0 m (200.0 ft).

$L_3 = \frac{V_1^2 - V_2^2}{2d}$, where V_1 is the truck speed at station 1, V_2 is the critical ramp speed, and (d) is the deceleration rate. For design purposes, V_1 is the mainline speed limit.

PC = Point of Curvature for ramp.

Figure 6. Typical ATRWS detector placements for one-lane ramp.

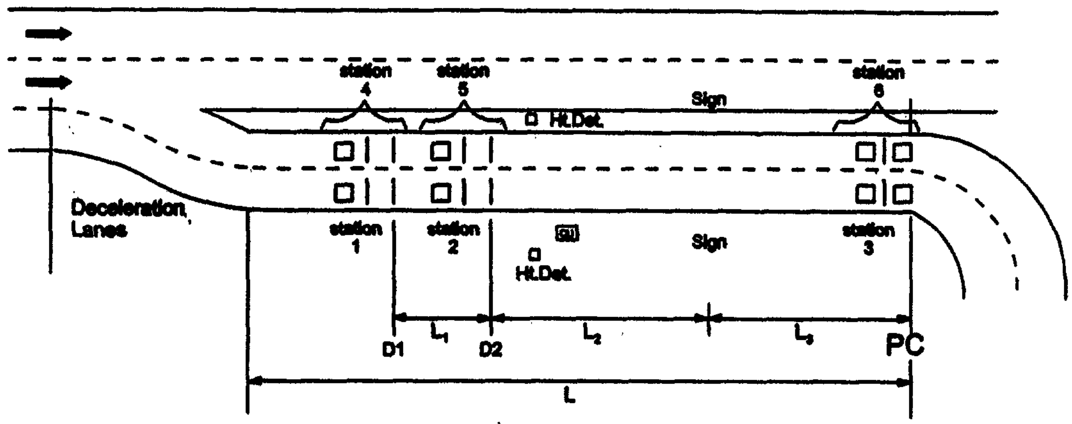


Figure 7. Typical ATRWS detector placements for two-lane ramp.

WIM stations 3 and 6 are both for evaluation purposes to determine the speed reduction of trucks with and without sign activation. The data are stored and are retrievable via remote dial-up modem on conventional telephone and cellular lines.

Both the one-lane and two-lane systems operate in the same manner; therefore, only the operational logic of the one-lane system is described below. See figure 8 for the operational logic flow chart. Both WIM detection stations 1 and 2 provide weight, vehicle classification, and vehicle speed to the programmable controller. If the vehicle is classified as a truck, the two weights will be compared and the heavier weight is used. Also, at WIM station 2, a height detector determines if the truck is less than 3.4 m (11 ft), and if so, classifies it as a tanker truck. Depending upon whether the truck is classified as a tanker or non-tanker, a rollover threshold value will be assigned to it based on its weight using the following data programmed into the controller:

TANKER		NON-TANKER	
Weight Range (lb)	RT	Weight Range (lb)	RT
0 - 10,000	0.65g	0 - 35,000	0.73g
>10,001 - 20,000	0.50g	>35,001 - 50,000	0.60g
>20,001 - 50,000	0.49g	>50,001 - 65,000	0.50g
>50,001 - 70,000	0.34g	>65,001 - 80,000	0.38g
>70,001 - 80,000	0.26g	>80,001 - 100,000	0.36g

1 lb = 0.454 kg

- From station 1 and station 2 detectors, the truck's deceleration (d) is determined from the following equation:

$$d = \frac{V_1^2 - V_2^2}{2L_1} \qquad (3)$$

where V_1 and V_2 are speeds at stations 1 and 2, respectively, and L_1 is the distance between them, established at 30.5 m (100 ft).

- Based on deceleration rate (d) from above, and effective deceleration due to gravity (a_g), resulting from the slope of the road, the likely speed of the truck at the point of curvature is calculated as follows:

$$V_{PC} = \sqrt{V_2^2 - 2 \cdot d \cdot (L_2 + L_3) - 2 \cdot a_g \cdot (L_2 + L_3)} \qquad (4)$$

where $(L_2 + L_3)$ is the distance from the second station to the point of curvature.

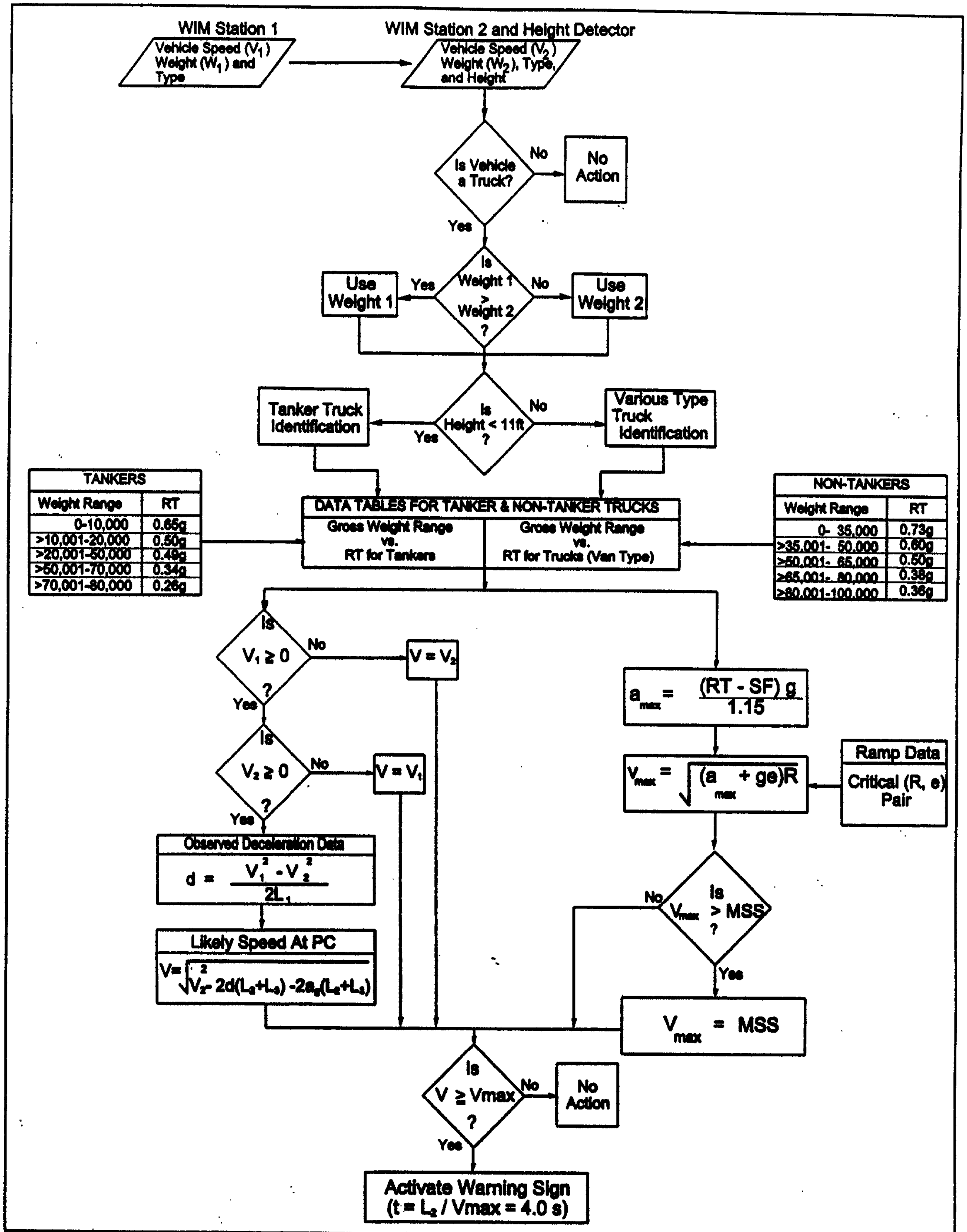


Figure 8. Operational logic for activating the warning system.

- The maximum value of lateral acceleration a_{max} beyond which the truck will roll over is calculated as follows:

$$a_{max} = \frac{(RT - SM)g}{1.15} \quad (5)$$

- The maximum rollover threshold speed (V_{max}) derived from equation 2 is then calculated by the following:

$$V_{max} = \sqrt{(a_{max} + ge)\ R} \quad (6)$$

- The calculated V_{max} is then compared to a maximum safe speed (MSS) of the ramp, which is determined by the user and would normally be set at about 94.4 km/h (40 mi/h). The lower of the two values is used in the next step.

- The likely speed at the PC, calculated previously as V_{PC}, is then compared to the V_{max}. If it is equal to or greater than V_{max}, then the sign is activated.

At WIM station 3, the vehicle speed for the truck is also measured. Data from all stations are recorded and retained in the controller for a specified period. The data can be downloaded to a microcomputer at the controller site or transferred to a microcomputer in a central office over a communication link.

As indicated above, the fiber-optic sign is activated whenever the predicted speed (V_{pred}) at the PC exceeds the estimated rollover threshold speed or the preset maximum safe speed. Both States requested the use of a maximum safe speed advisory warning sign. Because of this requirement, the ATRWS rarely, if ever, activated under the rollover threshold speed options, which normally would be higher than the maximum safe speed. This issue will be discussed later in the report.

3. PERFORMANCE AND MAINTENANCE OF SYSTEM

This chapter presents the findings that determine the performance and maintenance of each ATRWS system. The findings are presented by the following two tasks: (1) Task B Calibration Tests, and (2) Task C Provide System Maintenance.

TASK B CALIBRATION TESTS

This task presents: (1) the data analysis for the second evaluation period, and (2) a comparative analysis for the first evaluation period and the second period, for system detection accuracy, that is, for identifying trucks by type and measuring their speeds, gross weight, and height threshold.

The vehicle record (veh_rcrd) file produced by the ATRWS system was used for this analysis. Veh_rcrd files can be recorded in several durations (i.e., daily, weekly, or monthly), but were collected daily for ease of analysis. This file recorded all vehicles that traveled through the site for each WIM station in graphical and text formats. Figure 9 shows a sample vehicle record (veh_rcrd) file screen printout.

The veh_rcrd file was used in conjunction with the ATRWS analysis software to verify field observations and measurements of the ATRWS system. To fulfill this requirement, the following subtasks were conducted:

1. Calibration tests (after installation) to ensure that all components worked and systems functioned according to their design, and summary (second evaluation period).

2. Evaluation of classification and speed measurements for additional visual observations of different truck types (second evaluation period).

3. Evaluation of fiber-optic sign activation accuracy for visual observations of Class 5 through 11 trucks (second evaluation period).

4. Comparative analysis of the first and second evaluation periods.

To accomplish Tasks 1 to 4, data for two trucks (one tanker trailer and one box trailer) of known weights and speeds that traveled through the systems were evaluated. A laser speed gun was used to measure the speeds of Class 5 through 11 trucks for each WIM station. The evaluation criteria for all ATRWS system gross vehicle weight (GVW) percent error measurements is ±15 percent per the American Society for Testing and Materials (ASTM) Standard E1318-90[5] and recommendations made by VDOT. The speed accuracy criteria for all WIM station measurements is ± 3.2 km/h (2 mi/h). At the time of this study, typical vehicle classification data was not readily available. Hence, a 95-percent confidence level specification for vehicle classification was assumed for analysis of vehicle classification data.

GRAPHICAL FORMAT

```
(5877) LANE WIM 1  TYPE 9  GVW 69.6 kips  LENGTH 72 ft
18-K ESAL 1.416  SPEED 44 mph  MAX GVW 80.0 kips  Tue May 10 11:20:59.90 1994

  4.0          35.1         4.2    15.0
 o----o--------------------o----o---------o
14.6 16.9                13.4 13.8      10.9

(5881) LANE WIM 2  TYPE 9  GVW 84.6 kips  LENGTH 68 ft
18-K ESAL 3.138  SPEED 42 mph  MAX GVW 80.0 kips  Tue May 10 11:21:01.27 1994

  4.0          34.9         4.2    14.9
 *----*--------------------*----*---------*
20.1 17.6                17.0 17.8      12.0

(5894) LANE WIM 3  TYPE 9  GVW 0.0 kips  LENGTH 68 ft
18-K ESAL 0.000  SPEED 39 mph  MAX GVW 80.0 kips  Tue May 10 11:21:10.44 1994

  4.3          36.8         4.4    15.6
 o----o--------------------o----o---------o

Hit any key to resume
```

TABULAR FORMAT

```
(5877) LANE WIM 1  TYPE 9  GVW 69.6 kips  LENGTH 72 ft
18-K ESAL 1.416  SPEED 44 mph  MAX GVW 80.0 kips  Tue May 10 11:20:59.90 1994
    UNIT    SEPARATION    WEIGHT    ALLOWABLE
               (ft)       (kips)      (kips)
     1                     10.9        20.0
     2         15.0        13.8        17.0
     3          4.2        13.4        17.0
     4         35.1        16.9        17.0
     5          4.0        14.6        17.0

(5881) LANE WIM 2  TYPE 9  GVW 84.6 kips  LENGTH 68 ft
18-K ESAL 3.138  SPEED 42 mph  MAX GVW 80.0 kips  Tue May 10 11:21:01.27 1994
    UNIT    SEPARATION    WEIGHT    ALLOWABLE
               (ft)       (kips)      (kips)
     1*     OVER GVW       12.0        20.0
     2*        14.9        17.8        17.0
     3*         4.2        17.0        17.0
     4*        34.9        17.6        17.0
     5*         4.0        20.1        17.0
Hit any key to resume
Vehicle Display Resumed

(5894) LANE WIM 3  TYPE 9  GVW 0.0 kips  LENGTH 68 ft
18-K ESAL 0.000  SPEED 39 mph  MAX GVW 80.0 kips  Tue May 10 11:21:10.44 1994
    UNIT    SEPARATION    ALLOWABLE
               (ft)        (kips)
     1                      20.0
     2         15.6         17.0
     3          4.4         17.0
     4         36.8         17.0
     5          4.3         17.0
Hit any key to resume
```

Figure 9. Sample vehicle record (veh_rcrd) file screen printout in graphical and tabular formats.

Calibration Tests Results for Second Evaluation Period

The purpose of this analysis was to compare actual Class 9, five-axle tanker and box truck: (1) GVW, (2) speed, and (3) classification to those recorded by the ATRWS system. One Class 9 five-axle tanker and box truck was used for this analysis. Each driver was instructed to drive the truck through each lane of each site as many times as possible within the allowable time frame. Statistical analysis was conducted for only those runs that were 100 percent identified. The effectiveness of conducting and completing this analysis was contingent upon the ability to schedule trucks through a trucking association, which was logistically a problem throughout this study.

A sample of the data results reported in this section is shown in appendix A for only the Springfield ATRWS. The results of the three measures of effectiveness previously mentioned are presented for each site.

Actual GVW vs. Measured GVW

Carriers were requested to load their trucks to 75-percent capacity. Their GVW was measured using a static scale at the carrier's location or at a static scale near the Springfield site. The known weights from the static scale were used to compare against the weight measured by the ATRWS. The results for each site follow.

Springfield Site

Calibration tests for the tanker truck were conducted on April 25, 1995, and July 17, 1996. Calibration tests were conducted on May 24, 1995, and July 17, 1996, for the box truck. Calibration runs were not conducted for WIM station 1 and 2 (right travel lane, lane 1) for tanker and box trucks on April 25, 1995, due to severe pavement deterioration. Calibration runs conducted on July 17, 1996, were for right and left lanes for tanker and box truck.

Table 1 summarizes the data results by showing the number of times the truck's measurement was within the ±15 percent GVW specification (first number), the number of valid truck runs (second number), followed by the percentage of trucks within the specification. WIM stations 1 and 2 for the second evaluation were not operating properly due to pavement deterioration. As seen by the data in the table, the reliability of each WIM station of the ATRWS varied from 43 percent to 100 percent.

Table 1. Number and percentage of truck runs with measured weights within specification at the Springfield ATRWS site.

Truck Trailer Type	Evaluation Period	Lane 1		Lane 2	
		WIM Station		WIM Station	
		1	2	4	5
Tanker	April 1995	ND	ND	8/9(89)	6/8(75)
	July 1996	4/9(44)	9/9(100)	3/7(43)	7/7(100)
Box	May 1995	ND	ND	4/7(57)	2/2(100)
	July 1996	9/9(100)	4/8(50)	4/9(44)	9/9(100)
Note: ND = No data X/Y(XX), where X = # passing specification, Y = # of valid runs, and XX = percent					

McLean Site

Calibration tests for the tanker truck were conducted on April 25, 1995, and July 16, 1996. Calibration tests were conducted on May 24, 1995, only for the box truck. Interchange construction and realignment caused this site to be without power for several months (September 10, 1995, to April 30, 1996). This action reduced the amount of time available to conduct an additional evaluation.

Table 2 summarizes the results by showing the same statistics noted for table 1. As seen by the data in table 2, the reliability of each WIM station of the ATRWS varied from 0 percent to 56 percent.

Table 2. Number and percentage of truck runs with measured weights within specification at the McLean ATRWS site.

Truck Trailer Type	Evaluation Period	Lane 1	
		WIM Station	
		1	2
Tanker	April 1995	5/9(56)	0/9(0)
	July 1996	4/13(31)	6/16(38)
Box	May 1995	1/5(20)	0/7(0)
Note: ND = No data X/Y(XX), where X = # passing specification, Y = # of valid runs, and XX = percent			

Beltsville Site

Calibration tests for the tanker truck were conducted on May 11, 1995, and October 3, 1996. Calibration tests were conducted on May 25, 1995, only for the box truck. However, no results were recorded since calibration runs were cancelled in the field due to piezo sensor failure.

Table 3 summarizes the results by showing the same statistics noted in table 1. As seen by the data in table 3, the reliability of each WIM station of the ATRWS varied from 0 percent to 100 percent.

Table 3. Number and percentage of truck runs with measured weights within specification at the Beltsville ATRWS site.

Truck Trailer Type	Evaluation Period	Lane 1		Lane 2	
		WIM Station		WIM Station	
		1	2	4	5
Tanker	May 1995	0/3(0)	0/3(0)	0/8(0)	0/6(0)
	October 1996	5/6(83)	1/14(7)	10/12(83)	12/12(100)

Note: ND = No data
X/Y(XX), where X = # passing specification, Y = # of valid runs, and XX = percent

Weight Calibration Analysis Summary

It is concluded that all ATRWS system WIM stations accurately measured both the tanker and box trucks' GVW within specifications, with the exception of WIM stations 1 and 2 tanker truck measurement at the Springfield site and WIM station 5 box truck measurement at the Beltsville site. The Virginia GVW measurement errors were attributed to pavement deterioration. The Maryland site GVW measurement errors were attributed to drivers not traveling completely in their lane.

It is also concluded from this analysis that comparing statically weighed trucks to ATRWS GVW-measured trucks is an effective method for analyzing the results of the WIM stations. However, it is very difficult to find static weigh stations in close proximity to most WIM stations. Therefore, it is recommended that one of several possible alternative methods be used. A study published recently in *Transportation Research Record 1364* provides an effective and expedient way to validate weigh-in-motion station GVW measuring accuracies.[6] In the study, researchers from the Minnesota Department of Transportation (MNDOT) found that they could determine WIM station accuracy by comparing the measured GVW's of 5,000 trucks to the distribution graph of a statically weighed truck as a baseline. MNDOT found that if a graph of the average distribution of GVW's for the 5,000 truck population matches the baseline population (i.e., within a 4-percent systematic WIM error), that it would be considered an accurate WIM station. When this procedure is used and a particular WIM station is shown by graphical data to have a higher than 4 percent error for Class 9 five-axle trucks, ATRWS technicians will be advised to adjust calibration parameters from the host computer located at VDOT and the Maryland State Highway Administration (MDSHA).

Actual Speed vs. Measured Speed

The drivers of the test trucks were instructed by the evaluator to travel at various speeds, communicated to them via transceivers. These speeds were used as the actual speed for the comparisons, which are reported for each site below.

Springfield Site

Table 4 summarizes the data results for this analysis by showing the number of times when the truck's measured speed was within the ± 3.2 km/h (2 mi/h) specification (first number), the number of valid truck runs (second number), followed by the percentage of trucks with measured speeds within the specification. WIM stations 1 and 2 for the second evaluation were not operating properly due to pavement deterioration. As seen by the data in table 4, the reliability of measured speeds by system was more accurate than weight measurements, varying from 71 percent to 100 percent.

Table 4. Number and percentage of truck runs with measured speeds within specification at the Springfield ATRWS site.

Truck Trailer Type	Evaluation Period	Lane 1		Lane 2	
		WIM Station		WIM Station	
		1	2	4	5
Tanker	April 1995	ND	ND	9/9(100)	8/8(100)
	July 1996	7/9(78)	7/9(78)	5/7(71)	5/7(71)
Box	May 1995	ND	ND	7/7(100)	2/2(100)
	July 1996	7/8(88)	7/8(88)	7/9(78)	9/9(100)

Note: ND = No data
X/Y(XX), where X = # passing specification, Y = # of valid runs, and XX = percent

McLean Site

Calibration tests for the tanker truck were conducted on April 25, 1995, and July 16, 1996. Calibration tests were conducted on May 24, 1995, only for the box truck.

Table 5 summarizes the results by showing the same statistics as table 4. As seen by the data in table 5, the reliability of each WIM station of the ATRWS varied from 40 to 100 percent.

Table 5. Number and percentage of truck runs with measured speeds within specification at the McLean ATRWS site.

Truck Trailer Type	Evaluation Period	Lane 1	
		WIM Station	
		1	2
Tanker	April 1995	9/9(100)	8/9(89)
	July 1996	12/13(92)	15/16(94)
Box	May 1995	2/5(40)	8/8(100)

Note: ND = No data
X/Y(XX), where X = # passing specification, Y = # of valid runs, and XX = percent

Beltsville Site

Calibration tests for the tanker truck were conducted on May 11, 1995, and October 3, 1996. Calibration tests were conducted on May 25, 1995, only for the box truck.

Table 6 summarizes the data results by showing the same statistics mentioned previously in table 5. As seen by the data in table 6, the reliability of each WIM station of the ATRWS was 100 percent.

Table 6. Number and percentage of truck runs with measured speeds within specification at the Beltsville ATRWS site.

Truck Trailer Type	Evaluation Period	Lane 1		Lane 2	
		WIM Station		WIM Station	
		1	2	4	5
Tanker	May 1995	3/3(100)	3/3(100)	8/8(100)	6/6(100)
	October 1996	6/6(100)	14/14(100)	12/12(100)	12/12(100)

Note: ND = No data
X/Y(XX), where X = # passing specification, Y = # of valid runs, and XX = percent

Speed Calibration Analysis Summary

In summary, all three ATRWS system site speed measurements were within the ±3.2 km/h (2 mi/h) specification, with the exception of the box truck runs for WIM stations 1 and 2 at the Springfield site. For this site, it is not known whether the system did not measure the speed correctly or whether the driver did not maintain the indicated speed. More data related to the accuracy of the ATRWS in measuring speed are presented later.

Actual Classification vs. Measured Classification

The ATRWS identifies the truck classification by determining the number and spacing of axles. The accuracy of the system for this variable was compared to the known classification of both trucks. The results for each site are reported below.

Springfield Site

Table 7 summarizes the data results by showing the number of times the truck's measured classification was within the 95-percent specification (first number), the number of valid truck runs (second number), followed by the percentage of trucks within the specification. WIM stations 1 and 2 for the second evaluation were not operating properly due to pavement deterioration. As seen by the data in table 7, the reliability of measured classifications by system was typically more accurate than weight measurements with the exception of the tanker runs for July 17, 1996.

Table 7. Number and percentage of truck runs with measured classifications within specification at the Springfield ATRWS site.

Truck Trailer Type	Evaluation Period	Lane 1		Lane 2	
		WIM Station		WIM Station	
		1	2	4	5
Tanker	April 1995	ND	ND	9/9(100)	8/8(100)
	July 1996	3/9(33)	3/9(33)	3/7(43)	3/7(43)
Box	May 1995	ND	ND	4/7(57)	2/2(100)
	July 1996	8/8(100)	7/8(88)	7/9(78)	9/9(100)

Note: ND = No data
X/Y(XX), where X = # passing specification, Y = # of valid runs, and XX = percent

McLean Site

Calibration tests for the tanker truck were conducted on April 25, 1995, and July 16, 1996. Calibration tests were conducted on May 24, 1995, only for the box truck.

Table 8 summarizes the results by showing the same statistics noted in table 7. As seen by the data in table 8, the reliability of each WIM station of the ATRWS varied from 69 to 100 percent.

Table 8. Number and percentage of truck runs with measured classifications within specification at the McLean ATRWS site.

Truck Trailer Type	Evaluation Period	Lane 1 WIM Station	
		1	2
Tanker	April 1995	9/9(100)	9/9(100)
	July 1996	9/13(69)	12/16(75)
Box	May 1995	5/5(100)	7/7(100)

Note: ND = No data
X/Y(XX), where X = # passing specification, Y = # of valid runs, and XX = percent

Beltsville Site

Calibration tests for the tanker truck were conducted on May 11, 1995, and October 3, 1996. Calibration tests were conducted on May 25, 1995, only for the box truck.

Table 9 summarizes the data results by showing the same previously mentioned statistics. As seen by the data in table 9, the reliability of each WIM station of the ATRWS was more accurate for the tanker compared to the two other sites, ranging from 83 to 100 percent accurate.

Table 9. Number and percentage of truck runs with measured classifications within specification at the Beltsville ATRWS site.

Truck Trailer Type	Evaluation Period	Lane 1 WIM Station		Lane 2 WIM Station	
		1	2	4	5
Tanker	May 1995	3/3(100)	3/3(100)	8/8(100)	6/6(100)
	October 1996	5/6(83)	13/14(93)	12/12(100)	12/12(100)

Note: ND = No data
X/Y(XX), where X = # passing specification, Y = # of valid runs, and XX = percent

Classification Calibration Analysis Summary

In summary, it was concluded that the ATRWS performance for identifying truck classifications was accurate for all three sites. However, it was determined that pavement deterioration does in fact compromise the classification accuracy of the systems, especially for tanker trucks, and in some cases the box truck. A final analysis of the systems classification accuracy will include the results of additional truck classification runs discussed later in this report.

Evaluation of Classification Measurements of Different Truck Types

The purpose of this part of the evaluation was to determine the accuracy of the detectors of the ATRWS for identifying additional Class 5 through 11 trucks per Scheme F of the FHWA Truck Classification. Appendix B presents a sample of the truck classification data results for each WIM station for one of the three ATRWS sites. Table 10 summarizes the results by showing the number of times the truck's measured classification was within the 95-percent specification (first number), the number of valid truck runs (second number), followed by the percentage of trucks within the specification.

Table 10. Number and percentage of additional measured truck classifications within the specification for all three ATRWS sites.

ATRWS Site	Evaluation Period	Lane 1			Lane 2		
		WIM Station			WIM Station		
		1	2	3	4	5	6
Springfield	August 23 & 27, 1996	50/50(100)	51/51(100)	43/43(100)	48/48(100)	51/51(100)	47/47(100)
McLean	August 22-23, 1996	26/26(100)	27/27(100)	27/27(100)			
Beltsville	November 19 & 21, 1996	ND	ND	46/46(100)	54/54(100)	45/48(94)	37/37(100)

Note: ND = No data
X/Y(XX), where X = # passing specification, Y = # of valid runs, and XX = percent

At the time of this study, there were no set industry-wide classification accuracy standards for systems such as these. Thus, a 95-percent confidence level was arbitrarily selected. In summary, all three ATRWS systems accurately classified all the Class 5 through 11 trucks above the 95 percent specification. As shown in table 10, all measurements exceeded the specifications at all three sites.

Evaluation of Speed Measurements of Different Truck Types

The purpose of this part of the evaluation was to determine the accuracy of the detectors of the ATRWS to measure the speed of additional trucks (Class 5 through 11 trucks). The design specification of the ATRWS was to measure the truck speed within ±3.2 km/h (2 mi/h). To accomplish this evaluation, the speed measured by the ATRWS was compared to that measured by a laser speed gun. Although the laser speed gun used in this task was subject to the cosine effect, it was relatively insignificant because of the small angle between the target and the speed gun. (The apparent measured speed of a target will be decreased from its actual speed, depending on the angle between the laser gun and the direction of traffic. For example, angles of less than 8° have an error of under 1 percent, and angles of 14° have a 3-percent error.) Table 11 summarizes the speed gun cosine angle for each weigh-in-motion station for three sites. For this study, all cosine angles were less than 8°. Therefore, all measured speeds by speed gun were considered actual speeds within a 1-percent error.

Table 11. Speed gun cosine angle of each WIM station for ATRWS speed analysis.

ATRWS Site	Speed gun angle (degrees) per WIM station					
	1	2	3	4	5	6
Springfield	2.7	3.2	2.5	2.7	3.2	2.5
McLean	2.0	1.2	1.0			
Beltsville	2.9	2.9	2.1	1.4	1.4	0.4

The detailed results of this analysis for each site are shown in a series of tables in appendix B. The overall results are summarized in table 12. The data shows that at 8 of 13 WIM stations, the detectors measured the speed within the ± 3.2 km/h (2 mi/h) specification for at least 90 percent of the measurements. Because of the accurate speed findings during the calibration part of the evaluation, the speed inaccuracies of the McLean ATRWS are attributed to the targeting and recording speeds of trucks by the laser gun technician. Also, it is believed that all the lower percent accuracies found for all WIM station 3 speed measurements were primarily due to the laser gun operator "locking onto" trucks at greater distances for WIM stations 3 and 6.

Evaluation of Fiber-Optic Sign Activation Accuracy

Visual observations of fiber-optic sign activations were conducted for the Springfield and McLean sites on October 1, and August 22 and 23, 1996, and the Beltsville site on October 4, 1996. This subtask was analyzed based on a 95-percent confidence level specification for ATRWS fiber-optic sign activations. Visual observations were compared to those of the system veh_rcrd and/or dot_txt files. In this analysis, it was essential that WIM station 2 was accurately matched to WIM station 3, and likewise for WIM station 5 and WIM station 6. In some cases, the WIM station 3 record number in dot_txt file appeared to be incorrectly matched to WIM

Table 12. Number of additional measured truck speeds within the specification for all three ATRWS sites.

Lane	WIM Station	ATRWS Site		
		Springfield	McLean	Beltsville
1	1	98(50)	81(26)	ND
	2	94(51)	74(27)	ND
	3	95(43)	56(27)	98(46)
2	4	90(48)	N/A	98(54)
	5	73(51)	N/A	94(48)
	6	79(47)	N/A	92(37)
Average All		88(290)	70(80)	96(185)

Notes: XX(YY)= XX Percent of Total Trucks measured (YY).

ND = No Data — Speed data was collected; however, inoperable piezo sensors caused ATRWS to misclassify and/or not record trucks in veh_rcrd file. Consequently, there was no ATRWS data to compare to field data for WIM stations 1 and 2.

N/A = Not Applicable — one-lane ramp, therefore only three WIM stations. Also, primarily Class 5 through 6 trucks were used due to the lack of Class 7 and above trucks using this ATRWS site.

station 2. Therefore, only dot_txt records that matched WIM stations 2 and 3 and WIM stations 5 and 6 within 25 record numbers were used as criteria for a valid dot_txt file record.

A sample of the detailed results of this analysis for the Springfield ATRWS site is shown in appendix C, with a summary of each site discussed below.

Springfield Site

Fiber-Optic Sign Lane 1 - It was observed that trucks activated this sign 56 out of 79 observations. However, an analysis could only be conducted for 26 out of the 79 (33 percent) (activation and non-activation) observations. For the 26 confirmed observations, 20 out of 26 trucks activated the sign. The review of the dot_txt file showed that 19 out of 20 (95 percent) fiber-optic sign activations were correct. After reviewing dot_txt files, it was confirmed that 6 out of 6 (100 percent) trucks did not activate sign. A review of the vehicle record (veh_rcrd) file confirmed all the dot_txt file truck records were used in this analysis. Only vehicle records that were 100-percent identified were used in this analysis as shown in appendix C. The 53 unconfirmed field observations were due to two reasons: (1) inherent ATRWS problem that causes records to not be stored in dot_txt file when there is no matching truck record between WIM stations 2 and 3, or WIM station 3 being totally missed by the system, and (2) incorrect downloading of file to host computer system software not storing records because WIM station 3 was missed and/or not matched correctly. However, these unconfirmed field observations were stored in the veh_rcrd file. The equipment manufacturer is currently working on system software to rectify WIM station 3 not matching and/or missed by the system.

Fiber-Optic Sign Lane 2 - It was observed in the field that trucks activated this sign for 55 out of 71 observations. All 71 observations could not be confirmed for the same reasons as lane 1. However, 66 out of 71 (93 percent) of the unconfirmed field observations were stored in the veh_rcrd file.

McLean Site

Fiber-Optic Sign Lane 1 - It was observed that trucks activated this sign 42 out of 58 observations. The review of the dot_txt file showed that 41 out of 42 (98 percent) fiber-optic sign activations were correct. After reviewing dot_txt files, it was confirmed that 14 out of 16 (90 percent) trucks did not activate sign. A review of the vehicle record (veh_rcrd) file confirmed all the dot_txt file truck records used in this analysis.

Beltsville Site

Fiber-Optic Sign Lane 1 - It was observed in the field that trucks activated this sign 64 out of 79 observations. All 79 observations could not be confirmed for the same reasons that applied to lane 2 of the Springfield system. These unconfirmed field observations were not stored in the veh_rcrd file. None of these 79 observations are shown in appendix C.

Fiber-Optic Sign Lane 2 - This sign activated 53 out of 54 observations. After reviewing the dot_txt file, 53 out of 53 fiber-optic sign activations were confirmed. After reviewing dot_txt files, it was confirmed that 1 out of 1 trucks did not activate sign. A review of the vehicle record (veh_rcrd) file confirmed all the dot_txt file truck records were used in this analysis.

Fiber-Optic Sign Activation Summary

In summary, three of the five lanes met the ATRWS 95-percent specification for activation and inactivation. The results of the fiber-optic sign activation are summarized in table 13. Upon investigation, however, it was discovered that ATRWS software programing does not allow vehicle records to be stored in the dot_txt file when WIM station 3 and 5 are missed and/or incorrectly matched. Therefore, lane 2 of the Springfield site and lane 1 of the Beltsville site were not analyzed for this second evaluation period.

Table 13. Fiber-optic sign activation accuracy (second evaluation period).

ATRWS Site	Lane No.	Sign Activation Percent Accuracy	Sign In-Activation Percent Accuracy
Springfield	1	95(20)	100(6)
	2	ND	ND
McLean	1	98(42)	90(16)
Beltsville	1	ND	ND
	2	100(53)	100(1)

Notes: XX(YY) = XX Percent of Total Trucks measured (YY).

ND = No Data — Speed data were collected; however, inoperable piezo sensors caused ATRWS to misclassify and/or not record WIM 3 or WIM 6 in the dot_txt file. Consequently, there was no ATRWS data to compare to field data for WIM stations 1 and 2.

Comparative Analysis of the First and Second Evaluation Periods for Task B Calibration

This section presents a comparative analysis of the findings from the first and second evaluation of the GVW, speed, classification, and fiber-optic sign activation measures. These analyses are presented in tables 14 through 24 that follow.

Table 14. Springfield ATRWS first and second evaluation calibration summary comparisons for weight and speed accuracy (tanker truck).

WIM #	GVW % Accuracy		Speed % Accuracy	
	First Evaluation Period	Second Evaluation Period	First Evaluation Period	Second Evaluation Period
WIM 1	56	44	100	71
WIM 2	44	100	100	78
WIM 4	89	66*	100	86***
WIM 5	100	87**	100	86***

* This percentage is the average of two different calibration days. The percent accuracies were 89 and 43 percent.

** This percentage is the average of two different calibration days. The percent accuracies were 73 and 100 percent.

*** This percentage is the average of two different calibration days. The percent accuracies were 100 and 71 percent for both WIM 4 and 5.

Table 15. Springfield ATRWS first and second evaluation calibration summary comparisons for weight and speed accuracy (box truck).

WIM #	GVW % Accuracy		Speed % Accuracy	
	First Evaluation Period	Second Evaluation Period	First Evaluation Period	Second Evaluation Period
WIM 1	0	100	44	89
WIM 2	100	50	44	88
WIM 4	89	100	78	89*
WIM 5	100	100	78	100**

* This percentage is the average of two different calibration days. The percent accuracies were 100 and 78 percent.
** This percentage is the average of two different calibration days. The percent accuracies were both 100 percent.

Table 16. McLean ATRWS first and second evaluation calibration summary comparisons for weight and speed accuracy (tanker and box truck).

Trailer Type	WIM #	GVW % Accuracy		Speed % Accuracy	
		First Evaluation Period	Second Evaluation Period	First Evaluation Period	Second Evaluation Period
Tanker	WIM 1	100	44	100	96
	WIM 2	100	19*	100	91
Box	WIM 1	100	20	100	40
	WIM 2	100	0	100	100

* This percentage is the average of two different calibration days. The percent accuracies were 39 and zero percent.

Table 17. Beltsville ATRWS first and second evaluation calibration summary comparisons for weight and speed accuracy (tanker truck).

WIM #	GVW % Accuracy		Speed % Accuracy	
	First Evaluation Period	Second Evaluation Period	First Evaluation Period	Second Evaluation Period
WIM 1	75	83	100	100
WIM 2	100	7	100	100
WIM 4	100	83	100	100
WIM 5	100	100	100	100

Table 3 shows the latest calibration day (October 6,1996) having a much higher weight measurement percent accuracy (with the exception of WIM Station 2) than the first calibration conducted on May 11, 1995.

Table 18. Beltsville ATRWS first and second evaluation calibration summary comparisons for weight and speed accuracy (box truck).

WIM #	GVW % Accuracy		Speed % Accuracy	
	First Evaluation Period	Second Evaluation Period*	First Evaluation Period	Second Evaluation Period*
WIM 1	89	ND	89	ND
WIM 2	100	ND	78	ND
WIM 4	100	ND	100	ND
WIM 5	0	ND	100	ND

* The system was down; thus, scheduled box calibration was canceled in the field. Also, trucks were not available when system was brought back online.

Table 19. Springfield ATRWS first and second evaluation calibration summary comparisons for classification accuracy (tanker truck).

WIM #	Classification % Accuracy	
	First Evaluation Period	Second Evaluation Period
WIM 1	100	33
WIM 2	100	33
WIM 4	100	72*
WIM 5	100	79**

* This percentage is the average of two different calibration days. The percent accuracies were 100 and 43 percent.

** This percentage is the average of two different calibration days. The percent accuracies were 100 and 57 percent.

Table 20. Springfield ATRWS first and second evaluation calibration summary comparisons for classification accuracy (box truck).

WIM #	Classification % Accuracy	
	First Evaluation Period	Second Evaluation Period
WIM 1	100	100
WIM 2	100	100
WIM 4	100	68*
WIM 5	100	84**

* This percentage is the average of two different calibration days. The percent accuracies were 57 and 78 percent.
** This percentage is the average of two different calibration days. The percent accuracies were 100 and 67 percent.

Table 21. McLean ATRWS first and second evaluation calibration summary comparisons for classification accuracy (tanker and box truck).

Trailer Type	WIM #	Classification % Accuracy First Evaluation Period	Classification % Accuracy Second Evaluation Period
Tanker	WIM 1	100	85*
	WIM 2	100	85*
Box	WIM 1	100	100
	WIM 2	100	100

* This percentage is the average of two different calibration days. The percent accuracies were 100 and 69 percent.

Table 22. Beltsville ATRWS first and second evaluation calibration summary comparisons for classification accuracy (tanker truck).

WIM #	Classification % Accuracy	
	First Evaluation Period	Second Evaluation Period
WIM 1	100	100
WIM 2	100	100
WIM 4	100	100
WIM 5	100	100

Table 23. Beltsville ATRWS first and second evaluation calibration summary comparisons for classification accuracy (box truck).

WIM #	Classification % Accuracy*	
	First Evaluation Period	Second Evaluation Period*
WIM 1	100	ND
WIM 2	100	ND
WIM 4	100	ND
WIM 5	100	ND

* The system was down; thus, scheduled box calibration was canceled in the field. Also, trucks were not available when system was brought back online.

Table 24. Comparison of first and second evaluation of classification and speed measurement accuracies for all ATRWS sites.

	Classification % Accuracy		Speed % Accuracy	
ATRWS Site	First Evaluation Period	Second Evaluation Period	First Evaluation Period	Second Evaluation Period
Springfield	100	100	87	88
McLean	100*	100	80*	70
Beltsville	88	97	78	96

* Analysis primarily used Class 5 through 6 trucks because Class 9 trucks did not use this ATRWS site frequently.

Tables 25, 26, and 27 compare the first and second evaluation of speed measurements accuracies of each WIM station for each ATRWS site for additional Class 5 through Class 11 trucks.

Table 25. Springfield comparison of first and second evaluation speed measurement accuracies for additional trucks.

WIM #	Speed % Accuracy	
	First Evaluation Period	Second Evaluation Period
WIM 1	100	98
WIM 2	78	94
WIM 3	82	95
WIM 4	96	90
WIM 5	96	73
WIM 6	71	79
* Analysis used Class 5 through 11 trucks.		

Table 26. McLean comparison of first and second evaluation speed measurement accuracies for additional trucks.

WIM #	Speed % Accuracy	
	First Evaluation Period	Second Evaluation Period
WIM 1	100	81
WIM 2	87	74
WIM 3	52	56
* Analysis used Class 5 through 9 trucks.		

Table 27. Beltsville comparison of first and second evaluation speed measurement accuracies for additional trucks.

WIM #	Speed % Accuracy	
	First Evaluation Period	Second Evaluation Period
WIM 1	86	ND
WIM 2	86	ND
WIM 3	78	98
WIM 4	73	98
WIM 5	63	94
WIM 6	ND	92
* Analysis used Class 5 through 9 trucks.		

Tables 28 and 29 present a summary of the findings for the first and second evaluation periods for the sign activation and sign non-activation acccuracy, respectively. A sample spreadsheet of the detailed results for the Springfield ATRWS site is shown in appendix C.

Table 28. First and second evaluations comparisons for fiber-optic sign activation accuracy.

ATRWS Site	Lane No.	Sign Activation Percent Accuracy	
		First Evaluation	Second Evaluation
Springfield	1	100	95
	2	90	ND
McLean	1	ND	98
Beltsville	1	82	ND
	2	48	100

Table 29. First and second evaluations comparisons for fiber-optic sign non-activation accuracy.

ATRWS Site	Lane No.	Sign Non-Activation Percent Accuracy	
		First Evaluation	Second Evaluation
Springfield	1	100	100
	2	86	ND
McLean	1	ND	90
Beltsville	1	ND	ND
	2	ND	100

TASK C SYSTEM MAINTENANCE

This section presents the findings of maintenance activities that were conducted during the evaluation of this project. The findings are presented in two parts:

1. Design vs. As-Built Plans.

2. Operational Maintenance.

Design Plans vs. As-Built Plans

All three ATRWS systems were designed and built to the exact specifications, with only a few differences. The typical operation, layout, and hardware components for these systems were mentioned earlier in this report. The differences found between the design and as-built construction of the ATRWS systems are discussed below.

Springfield ATRWS

1. The placement of WIM stations 1, 2, 4, and 5 was shifted 30.5 m (100 ft) upstream. This modification in the design allowed WIM stations 2 and 5 to not be installed in the cooler shaded area below the bridge overpass and allowed the temperature sensors to be much more effective in autocalibrating the system.

2. The type, location, and placement of power to service the system was excluded in the design plans. Design of power requirements, location, and placement for this system was determined during construction.

McLean ATRWS

1. The current amplifier included in the design was not used in the as-built plans. The current amplifier was initially designed to boost the signals produced by piezo sensors. However, after installation it was determined that the piezo sensors were carrying noise along with the increased piezo signal, which adversely caused the ATRWS to incorrectly recognize the piezo signal.

2. The type, location, and placement of power to service the system was not designed or specified from the design plans, but included later in the as-built plans.

3. The as-built plans show the height detector and disconnect switch/pole placed in a different spot from the design plans. However, this placement does not affect the operation of the system.

Beltsville ATRWS

1. Same as McLean #1.

Operational Maintenance

This portion of the evaluation presents the maintenance issues observed throughout the 3-year operation of the systems. The following areas of maintenance are discussed as they pertain to all ATRWS sites:

1. Hardware Issues.

2. Site Software Issues.

3. Office Software Issues.

4. Operational Tests/Maintenance.

5. Maintenance Contracts.

While there was a procedure established for the States or maintenance contractor to report maintenance activities, it is likely that some activities went unreported.

Hardware Issues

Throughout the 3-year evaluation of the ATRWS sites it was seen that generally all the hardware components of these systems performed in accordance with their design specification. However, some equipment, such as the height detector and cellular communication, performed sporadically at times. The performance of some of the more critical components is discussed below:

1. Height Detector — The purpose of this component of the system was to supply a signal instantaneously to the ATRWS notifying the system that the vehicle traveling through the lane was a either a tank or box trailer truck. Based on Task B (Calibration) results, this component performed as designed. However, sometimes the height detector would pick up the antennas of tanker trucks and incorrectly classify them as a box truck. Determining to what extent this occurred with the height detector would require additional field observations to determine what is happening and the effects it has on the overall operation of the system. Also, in some remote cases the height detector would erroneously send a signal to the ATRWS controller identifying a tanker and box truck traveling in opposite lanes, but nearly at that exact same location as they passed the detector, both would be recorded as a box truck. The height detector was replaced on at least four different occasions by the maintenance contractor for the following reasons: (1) it was knocked down by truck from its placement at the top of the concrete retaining wall at the Springfield site, and (2) internal electrical cards were malfunctioning at all three sites. From field observations, it was observed that it is difficult to calibrate the 3.5 m (11.5 ft) detection zone.

2. Cellular Phone/Modem — The purpose of this component was to allow bidirectional communication between the ATRWS site computer and the host computer at the State agency's office. The cellular modem communications between the host computer and the site computer malfunctioned continuously throughout this evaluation for the Virginia ATRWS sites. Frequently, cellular communication was disconnected and/or no connection occurred. This communication problem caused the user (VDOT) and the

evaluators to make numerous visits to the Virginia sites to confirm operation of the system and download files. Conversely, the Maryland ATRWS site had considerably less of a problem with their land line communications.

3. Back-up power supply — The purpose of this component was to supply power to the ATRWS for 24 hours when there was absence of main line power to the system. The 24-h uninterrupted power supply operated as designed throughout the evaluation period. However, in the case where the main line power is shut off and the system operates on back-up batteries for 24 hours, the system will not recharge the back-up batteries when the main line power re-energizes, if the charge-down setting on the ac inverter does not allow the batteries to maintain minimal amount of charge-down current. For example, on two separate occasions at the McLean site, when the power was lost to the system because of lightning near the site, the surge protector disconnected from the ATRWS to the main line, thereby causing the back-up power to be engaged. After the back-up battery charged down totally for 24 hours and the system was placed back on the main line, the back-up batteries would not recharge.

4. Fiber-optic sign — The purpose of this component was to provide the warning message "TRUCKS REDUCE SPEED" to truckers whose speed exceeded their predicted maximum safe speed or rollover threshold speed calculated by the system. Based on the results of Task B (Calibration) data, it was determined that the fiber-optic sign operated effectively throughout this evaluation. However, on three occasions the fiber-optic cables making up the warning message had to be refitted into the sign face. Other than that, cleaning the sign face was usually the only maintenance required for the fiber-optic sign.

5. Piezoelectric sensors — The primary purpose of these components of the system were to supply vehicle weight, speed, and classification (axle spacing) length information to the controller. Based on the analysis of field data and real-time viewing of trucks, it was determined that for the first 1½ years (January 1994 to June 1995) of evaluation, piezo sensors operated as they were designed for the Virginia ATRWS. The Maryland ATRWS operated as it was designed for nearly 3 years. These conclusions were reached based on the ability of the sensors to be recalibrated. All weight-measuring discrepancies resulting from piezo sensor output were attributed to pavement deterioration surrounding the sensors. The results also showed that when the pavement deterioration caused the piezo sensors to operate ineffectively, it also misclassified trucks. However, pavement deterioration was seen to reduce their effective operation. Pavement deterioration at all three sites caused piezo sensors to either be damaged from vehicle tires and/or vibration of the roadway. The pavement deterioration at the Springfield site caused all the piezo sensors to be replaced, as well as the loops for WIM stations 1, 2, 4, and 5. The results showed that, although the weight and classification measuring accuracy of the systems was reduced as sensor operational effectiveness went down, the speed-measuring accuracy still remained within specification.

6. Loop sensors — The primary purpose of these components was to provide an interrupt signal to the ATRWS that notifies the system that there is a vehicle present and determines the vehicle length. Based on the results of Task B (Calibration), it was determined that all loops operated as they were designed. The only significant problem occurred when pavement deteriorated around the corners of loops, causing the loop wires to be exposed to rain and snow. Deteriorating pavement surrounding the corners of the loops was observed on at least three different occasions. For these occasions, the pavement was either patched or the loop was reinstalled. However, the loop maintenance occurred much longer than required by the maintenance contract, which rendered the system inoperable for several days.

<u>Site Software Issues</u>

In general the ATRWS site software operated as designed. However, there were specific instances where the system's operation required some software modifications throughout the evaluation. For the first evaluation period, it was observed from the DOT_TXT file that when a truck was missed by WIM stations 1 and/or 2 the system did not record an "On" or "Off" sign activation into the file. For example, throughout the 3-year evaluation, the system periodically would not accurately match a truck traveling from WIM stations 2 to 3, or 5 to 6. This software problem caused several trucks to not be recorded in the DOT_TXT file, the principal file used for evaluating the effectiveness of the systems.

<u>Office Software Issues</u>

The office software allowed the ATRWS users to view and analyze daily site records, and produce a number of reports such as speed by hour, speed by class, weight by class, and error by lane, etc. It was seen from numerous observations that the office software (installed on the host computer) operated as designed. However, the "Reports" section of the software was the only area that required additional programming throughout the evaluation.

<u>Operational Tests</u>

Operational tests were performed throughout the 3-year evaluation of the three ATRWS sites. These tests were usually conducted for scheduled periods. But in some instances, piezo/loop malfunction required additional operational tests to be conducted. These tests were twofold: (1) recalibration of components for accurate operation, and (2) scheduled preventive maintenance. Recalibration tests consisted of running a Class 9 tanker and box truck through each site to adjust and/or confirm accurate weight, speed, and height measurements by the systems. The scheduled maintenance, which sometimes occurred in conjunction with the recalibration activities, consisted of performing a list of activities described in the System Evaluation Plan report.[3] The maintenance contractors had a somewhat difficult time getting trucks scheduled to conduct recalibration tests. Trucking associations used by the maintenance contractor to provide trucks usually could not guarantee trucks far in advance or with short notice. In some cases, the system was not recalibrated for long periods of time. When the systems were not recalibrated because of State request or sensor malfunction, the delay affected the number of evaluation periods that could be conducted for all ATRWS sites.

Maintenance Contracts

The importance of a maintenance contract for the ATRWS systems was noted throughout this evaluation. It was assumed that the prototype ATRWS sites would require some amount of periodic/unscheduled maintenance, but the extent of this maintenance was not known at the start of the evaluation. Initially, it was assumed that both States would expeditiously award a maintenance contract to conduct operational (recalibration) tests and schedule periodic maintenance activities at their ATRWS sites. However, after several meetings with the manufacturer, the Maryland State Highway Administration (MDSHA) decided not to award a maintenance contract to the manufacturer, citing that their maintenance personnel could conduct the maintenance at a lower cost.

The maintenance activities required for the Virginia ATRWS sites were conducted without additional costs or extended down time due to malfunctions in the system. However, it was observed that several maintenance activities were performed by maintenance contractors well beyond the 7-day receipt of written notice, cited in the maintenance contract.

It was seen that initially the MDSHA was able to handle on a small scale some of the maintenance requirements for the Maryland ATRWS. However, 1 year into operation of the system, the maintenance department responsible for the ATRWS was closed due to MDSHA restructuring. Thus, there were no State personnel to conduct scheduled or periodic maintenance on the Maryland ATRWS site for nearly 1 year. The absence of an executed maintenance contract by the MDSHA caused the State to pay the manufacturer of the system hardware to conduct maintenance activities. For example, on several occasions lightning caused the surge protectors to be tripped, powering down the system. Since there was no maintenance contract in effect, the MDSHA had to request by purchase order that the manufacturer investigate and repair the problem at the Maryland ATRWS site. The MDSHA awarded a sole-source maintenance contract to the manufacturer that has been in effect for the past 7 months. The award of the maintenance contract allowed several outstanding maintenance problems to be resolved, which improved the last 6 months of this evaluation. However, as with the Virginia ATRWS sites, it was observed on many occasions that the maintenance contractor performed the requested maintenance well beyond the 7-day receipt of written notice.

4. SYSTEM EVALUATION

The objective of ATRWS was to prevent truck rollover occurrences. This was to be accomplished by identifying trucks traveling at or near their rollover speed or maximum safe speed, and advising the driver to reduce the truck's speed. Hence, the ability of the ATRWS to affect a reduction in the speed of trucks was a key measure of its effectiveness. This chapter presents the results of: (1) Task D Speed Reduction Evaluation, (2) Accident Evaluation Analysis, (3) System Costs, and (4) Cost Effectiveness of the Systems.

TASK D SPEED REDUCTION

In conducting this task, the ATRWS system dot_txt file was used in the analyses. Figure 10 shows sample dot_txt file printout. Truck data such as gross vehicle weight, axle weights, speeds, classification, etc., were recorded by the ATRWS software in ASCII text format. Although the dot_txt file stores a number of truck-specific parameters, only the following parameters were used: site name, lane number, vehicle number (per station), vehicle class, vehicle speed (per station), speed reduction between WIM stations 2 and 3, and WIM stations 4 and 5, predicted and rollover speeds at the point of curvature (PC), deceleration rate between WIM stations 1 and 2, and 4 and 5, system errors for WIM stations 1 through 6, vehicle height (tanker or box), fiber-optic sign turned "On" or "Off", and GVW of WIM stations 1 and 2, and WIM stations 4 and 5. Also, in some cases the veh_rcrd file was used to confirm dot_txt file data.

	A	B	C	D	E	F	G	H	I	J	K	L
1	Site: Springfield, VA I-495WA-955											
2			Vehicle Number			Veh.	Measured Speed (mph)			Difference	Predicted	Rollover
3	Date / Time	Lane	WIM 1	WIM 2	WIM 3	Class	WIM 1	WIM 2	WIM 3	WIM2 - WIM3	Speed (mph)	
4	02/24/95 11:16:26.	1	31909	31913	31937	9	46.6	45.36	37.91	7.46	36.08	73.127
5	02/24/95 11:16:35.	2	31934	31938	31954	9	45.36	44.74	34.18	10.56	41.28	67.096
6	02/24/95 11:17:25.	1	32010	32014	32028	9	45.36	44.74	37.28	7.46	41.28	73.127
7	02/24/95 11:17:26.	1	32013	32018	32030	6	45.36	45.98	38.53	7.46	49.15	69.477
8	02/24/95 11:22:40.	1	32468	32470	32483	9	50.95	49.71	44.74	4.97	42.8	62.059
9	02/24/95 11:26:30.	2	33000	33002	33015	9	49.71	50.33	44.12	6.21	53.52	73.127
10	02/24/95 11:29:41.	2	33100	33102	33120	9	43.5	43.5	38.53	4.97	43.5	67.096
11	02/24/95 11:30:17.	2	33165	33167	33181	9	40.39	39.15	32.93	6.21	31.74	73.127
12	02/24/95 11:35:32.	2	33637	33640	33650	9	57.17	55.95	46.0	9.94	53.12	73.127
13	02/24/95 11:36:39.	2	33728	33731	33751	9	55.93	55.93	50.95	4.97	55.93	67.096
14	02/24/95 11:42:08.	2	34271	34279	34284	6	84.06	79.64	36.04	43.6	166.20	69.477
15	02/24/95 11:45:26.	2	34584	34589	34607	10	54.69	54.06	45.36	8.7	60.63	61.632
16	02/24/95 11:45:29.	2	34593	34596	34612	9	52.2	52.82	53.44	-0.62	58.01	73.127
17	02/24/95 11:46:43.	2	34703	34704	34717	6	60.95	60.95	46.6	4.35	60.95	73.127
18	02/24/95 11:47:59.	2	34802	34806	34824	6	44.13	42.28	37.28	4.97	30.40	62.069

	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1											Axle Weights for:		
2			Error		Height	F.O. Sign	GVW				FIRST WIM		SEC
3	Decel.	WIM 1	WIM 2	WIM 3	> = 11'	Turned	WIM 1	WIM 2	1	2	3	4	
4	1.229	0	17	0	OVER	OFF	19302	23188	4017	3929	3748	3578	4
5	0.602	0	17	0	OVER	OFF	29860	37044	4639	6557	6138	6343	61
6	0.602	0	17	0	OVER	OFF	18961	23546	4467	4727	4032	2507	3
7	-0.81	0	0	0	UNDER	ON	6220	6208	2008	3212	0	0	
8	1.345	0	0	0	UNDER	OFF	12764	18869	3625	3120	2231	1922	1
9	-0.669	0	17	0	OVER	ON	24345	29567	4451	6319	6308	3116	4
10	0	0	17	0	OVER	OFF	35455	42823	4321	6751	7366	8706	6
11	1.063	0	17	0	OVER	OFF	16630	19860	4211	3554	3733	2663	2
12	0.79	0	17	0	OVER	ON	15917	19997	4279	3596	3600	1889	2
13	0	0	17	0	OVER	ON	35515	44151	4426	8107	8043	8762	8
14	-36.81	0	0	0	UNDER	ON	2230	2283	1116	1115	0	0	
15	0.727	0	0	0	UNDER	ON	37628	44371	3749	6673	6159	3442	2
16	-0.702	0	17	0	OVER	ON	20804	32513	4632	6264	6394	4178	5
17	0	0	17	0	OVER	ON	13066	15211	4297	8756	0	0	
18	1.732	0	0	0	UNDER	OFF	12343	13261	5080	3389	3874	0	

Figure 10. Sample dot_txt file printout.

The purpose of this section was to determine the effectiveness of the system on speed reduction of high speed trucks. Thus, the following two areas were evaluated:

1. Truck Speed-Reduction Evaluation (second evaluation period).

2. Comparison of First and Second Evaluation Periods for Speed Reduction.

Truck Speed-Reduction Evaluation (Second Evaluation Period)

This section summarizes data collected to determine the effectiveness of ATRWS systems in reducing truck speeds. Appendix D contains an excerpt of a spreadsheet data file used for the Springfield ATRWS site to determine the percent speed reduction of the system. Data gathered from all three ATRWS systems allowed the following speed-related issue to be answered— Does the activation of the ATRWS affect a speed reduction? If so, to what level?

Truck speed data were collected before the systems were installed at both the McLean and Beltsville sites in an attempt to gather reliable truck speed data to be used in a comparative study for this analysis. However, this data was not used in this analysis because the data collection procedures and equipment used were vastly different from the ones used during this analysis. Hence, this analysis could not establish if the presence of ATRWS caused a lasting speed reduction for all trucks or if speed reduction was attributed solely to ATRWS.

For this analysis, the average speed at WIM station 2 was compared to the average speed reduction from WIM station 2 to WIM station 3. As mentioned earlier in the fiber-optic sign activation analysis, it was essential that WIM station 2 was accurately matched to WIM station 3 (in lane 1), and likewise for WIM station 5 to WIM station 6 (in lane 2). Also, earlier it was mentioned that in some cases the WIM station 3 record number in dot_txt file appeared to be incorrectly matched to WIM station 2. Therefore, only dot_txt records that matched WIM stations 2 and 3 and WIM stations 5 and 6 within 25 record numbers were used as criteria for a valid dot_txt file record. Table 30 summarizes comparisons of truck speed reduction "with" and "without" sign activation per site. The results showed truck speed reductions were higher for each lane when the sign was activated compared to when sign was not activated.

For this second evaluation period, it is concluded that for all three ATRWS sites (five lanes total) the fiber-optic sign activation does in fact have an effect on truck speed reduction. This was seen by reviewing records of trucks that activated the fiber-optic sign after clearing WIM station 2 or 5. The results showed that 500 trucks activated the fiber-optic sign for an overall average speed reduction of 13.4 km/h (8.3 mi/h) from WIM stations 2 to 3 and WIM stations 5 to 6 for all three ATRWS sites. The results showed that 252 trucks did not activate the fiber-optic sign for an overall average speed reduction of 10.5 km/h (6.5 mi/h) from WIM stations 2 to 3 and WIM stations 5 to 6 for all three ATRWS sites. The findings showed also that the overall speed reduction of trucks "with" activation is 21.7 percent higher than those trucks that did not activate the sign. Therefore, it has been concluded that the ATRWS caused truck speed reductions at each of the sites for the second evaluation period.

Table 30. Comparative analysis for average WIM 2 speed vs. average speed reduction (WIM 2 - WIM 3)* (Second Evaluation).

Site No./Location	Lane No.	With Activation			Without Activation		
		Avg Speed @WIM 2 (mi/h)	Avg Speed Reduction WIM 2 to WIM 3 (mi/h)	% Speed Reduction	Avg Speed @ WIM 2 (mi/h)	Avg Speed Reduction WIM 2 to WIM 3 (mi/h)	% Speed Reduction
1. I-495W/I-95S, Springfield, VA	1	49.4	7.9	16.0	43.0	6.4	15.0
	2*	50.8	7.7	15.2	44.2	5.9	13.3
Lane 1 & 2 Averages		50.1	7.8	15.6	43.6	6.2	14.2
2. I-495W/RT 123N, McLean, VA	1	51.4	14.6	28.4	43.1	11.6	26.9
3. I-495E/I-95N, Beltsville, MD	1	46.8	5.0	10.7	39.5	3.5	8.8
	2*	50.4	6.1	12.1	44.5	4.9	11.0
Lane 1 & 2 Averages		48.6	5.6	11.4	42.0	4.2	9.9
Average (all 5 lanes)		49.7	8.3	16.7	42.9	6.5	15.2

* Average speed at WIM 5 and speed reduction from WIM 5 to 6.

1 mi/h = 1.61 km/h

Comparative Analysis of First and Second Evaluation Period Findings for Speed Reduction

This section compares the results of two different evaluation periods: May and November 1994, and May, July, and October 1996. A sample of the detailed results for the second evaluation period is shown in appendix D for the Springfield site. By analyzing the speed data of several trucks traveling through each site, the effectiveness of the systems for speed reduction was determined. The following two criteria were used: (1) data consistency, and (2) whether speed reduction was greater with sign activation than without activation. Tables 31, 32, and 33 showed that: (1) both evaluation periods results were consistent over approximately a 2-year span, and (2) for the first and second evaluation periods, 9 out of 10 lanes had greater speed reductions when the sign was activated than without activation. There were no results for one lane because of the corrupted dot_txt file. However, it is concluded from the comparison of the data results for both evaluation periods that the ATRWS systems for all three sites do, in fact, cause truck drivers to reduce their speed prior to entering ramps when their speed is exceeding the maximum safe speed (MSS).

Table 31. First and second evaluations comparisons for truck speed reduction with activation.

Site No./Location	Lane No.	First Evaluation: Avg Speed Reduction WIM 2 to WIM 3 (mi/h)	First Evaluation: % Speed Reduction	Second Evaluation: Avg Speed Reduction WIM 2 to WIM 3 (mi/h)	Second Evaluation: % Speed Reduction
1. I-495W/I-95S, Springfield, VA	1	6.4	12.6	7.9	16.0
	2*	6.1	13.2	7.7	15.2
Lane 1 & 2 Averages		6.3	12.9	7.8	15.6
2. I-495W/RT 123N, McLean, VA	1	11.4	21.2	14.6	28.4
3. I-495E/I-95N, Beltsville, MD	1	5.1	10.6	5.0	10.7
	2*	5.1	9.9	6.1	12.1
Lane 1 & 2 Averages		5.1	10.3	5.6	11.4

* WIM 5 to WIM 6
1 mi/h = 1.61 km/h

Table 32. First and second evaluations comparisons for truck speed reduction without activation.

Site No./Location	Lane No.	First Evaluation: Avg Speed Reduction WIM 2 to WIM 3 (mi/h)	First Evaluation: % Speed Reduction	Second Evaluation: Avg Speed Reduction WIM 2 to WIM 3 (mi/h)	Second Evaluation: % Speed Reduction
1. I-495W/I-95S, Springfield, VA	1	2.6	5.5	6.4	15.0
	2*	4.2	9.6	5.9	13.3
Lane 1 & 2 Averages		3.4	7.6	6.2	14.2
2. I-495W/RT 123N, McLean, VA	1	9.0	19.2	11.6	26.9
3. I-495E/I-95N, Beltsville, MD	1	3.7	8.2	3.5	8.8
	2*	ND	ND	4.9	11.0
Lane 1 & 2 Averages		3.7	8.2	4.2	9.9

* WIM 5 to WIM 6
1mi/h = 1.61 km/h

Table 33. Percentage of speed reduction from WIM stations 2 to 3, and 5 to 6 with sign activation.

ATRWS Site	Lane No.	First Evaluation		Second Evaluation	
		Percent Reduction	Overall*	Percent Reduction	Overall*
Springfield	1	59.4	45.0	19.0	21.0
	2	31.0		23.4	
McLean	1	21.0	21.0	21.0	21.0
Beltsville	1	27.5	27.5	30.0	25.0
	2	ND		19.7	
Overall Speed Reduction Per Evaluation Period**		29.0		21.0	

* - Comparisons of speeds not percentages
** - These speed reduction percentages represent the average speed reduction for all lanes with sign activation.
ND - No Data

It was mentioned earlier in this report that the States required the system design to include sign activation for truck speeds exceeding the maximum safe speed of the ramp as an additional operational function of the ATRWS. The results shown in appendix D of one such ATRWS site showed that all sign activations were caused by trucks whose speeds exceeded the maximum safe speed. There were no sign activations directly caused by trucks exceeding the rollover threshold speeds calculated by the systems. This function was deemed originally as the primary criteria for activation of the fiber-optic sign. Since all sign activations were due to exceeding the MSS, there was no data to determine if the reduction in truck speed resulted from the "rollover speed" criteria. Therefore, the final analysis was not able to present a definitive finding with regards to "rollover speed."

However, for sign activations, data were available to determine the speed threshold ranges for the calculated rollover speed (V_{roll}), calculated average V_{roll} speed, and the calculated average predicted speed (V_{pred}) at the PC based on deceleration rate. The speed threshold ranges for V_{roll} were identified for the Springfield, McLean, and Beltsville ATRWS sites, to have large ranges between the highest and lowest value. Table 34 presents the speed ranges of V_{roll} when signs were activated for the three ATRWS systems. Further analysis showed that the McLean ATRWS site had a calculated V_{pred} greater than V_{roll}. This result indicated that unlike the other two sites (Springfield and Beltsville), the rollover speed algorithm appears to be more critical for sign activations. The extent of the V_{roll} and V_{pred} differences suggest that for the Springfield and Beltsville ATRWS sites, the rollover speed algorithm can be eliminated from the sign activation operation. Further analysis of V_{roll} and V_{pred} data should be conducted before eliminating these operational parameters.

Table 34. Speed ranges for V_{roll} when the maximum safe speed is not used as a criteria for sign activation.

ATRWS Site	Lane No.	ATRWS Calculated Speed Range V_{roll} (mi/h)	Calculated Average V_{roll} (mi/h)	Calculated Average V_{pred} (mi/h)	Posted Maximum Safe Speed (mi/h)
Springfield, VA	1	24.5 - 73.1	60.5	50.0	35
	2	24.5 - 73.1	60.2	49.6	35
McLean, VA	1	20.4 - 69.4	44.2	46.9	40
Beltsville, MD	1	44.5 - 69.4	58.1	47.2	40
	2	20.1 - 69.4	55.0	44.4	40
1 mi/h = 1.61 km/h					

ACCIDENT EVALUATION

This part of the evaluation presents the results of the analysis to determine if the systems prevented rollover or other related accidents. This section presents findings for the number of accidents that have occurred before and after the ATRWS sites were installed. Also, it presents the findings regarding past and future percent probability of rollover accident occurrences at all three ATRWS sites.

As shown in table 35, there have been no reported truck rollover accidents at either of the three sites since the ATRWS were installed. In reviewing truck accident data provided by the VDOT and MDSHA, it was determined that most of the accidents that occurred at or near the ATRWS sites during the 3-year operation and evaluation involved cars or small trucks that sideswiped and/or rear-ended Class 9 box trucks.

Table 35. Truck rollover-type accidents before and after installation.

ATRWS Site	Accidents Before Installation	Accidents After Installation (3 Years of Operation)
Springfield	2	0
McLean	2	0
Beltsville	6	0

A predictive analysis for future percent chance of accident at each site was conducted. The Poisson Probability Distribution theory was used to predict the percent probability of zero, one, two, and three rollover accidents at each of the ATRWS sites, based on the previous number of rollover accidents that have occurred at each site for the following periods: (1) 1986-1989 for Springfield and McLean sites, and (2) 1985-1990 for the Beltsville site. Table 36 shows the percent probability for zero, one, two, and three rollover accidents that could occur at all three ATRWS site if the systems were not installed. Also, the results of this analysis showed that there is zero-percent probability of one future rollover accident in 1 year at all three sites, using the fact that no rollover accidents occurred during the 3-year operation of the systems.

Table 36. Probability of zero, one, two, and three rollover accidents occurring in 1 year using the number of past rollover accidents that have occurred.

ATRWS Site	Percent Probability of Rollover Accidents Occurring*			
	0	1	2	3
Springfield**	51.2	34.3	11.5	5.0
McLean**	51.2	34.3	11.5	5.0
Beltsville***	30.1	36.1	21.7	8.7

* Poisson Probability Equation used for this analysis is $P(r)=e^{-u}(u^r/r!)$ where **u** is average number of rollover accidents a year, and **r** is the number of rollover accidents being predicted.

** Percent probability is based on 0.5 rollover accidents per year from 1986 to 1989.

*** Percent probability is based on 1.2 rollover accidents per year from 1985 to 1990.

SYSTEM COSTS

The analysis of the installation and operational costs and accident-related data is presented here, and will be used later in this report to the determine the cost-effectiveness of systems installed. The purpose of this subtask was to present the estimated and actual operational and total costs for all three ATRWS systems.

System/Installation

The installation costs consist of: (1) software modification costs, (2) construction costs, and (3) system calibration, commissioning, and testing.

These costs were based on costs that were supplied by the contractors and States for the three ATRWS sites. A comparison of the estimated total installation and actual total installation costs has been summarized for each site in table 37. These higher installation costs were attributed to three items:

1. Fiber-optic sign cost.
2. Maintenance of traffic costs.
3. Additional construction costs primarily due to the installation of power at all three sites.

These system/installation costs were estimated in the feasibility study at about $104,000 for a one-lane installation based on the final design. This estimate was updated based on the final analysis of design and installation costs provided by the three States. The final controller modification cost of $23,100 is a quote from the manufacturer of a WIM system for modification of their particular controller to meet the requirements of this system. This development cost was a one-time cost for the three projects and presumably would not be a cost if the system were to be installed at a significant number of locations.

The construction costs vary for the three sites. Sites 1 and 3 are for dual-lane installations, and their final average cost is about $247,587. Based on the final three installation cost estimates, the construction cost for a typical one-lane installation would be $149,542 and for a two-lane installation about $247,587. In addition to the construction cost, the feasibility study final report approximated the system calibration, commissioning, and testing costs at $5,000 per site. However, this cost has been reduced to $920 per site due to the fact that some of the costs were included in the installation costs.

Table 37. Actual total installation costs.

Cost Item	Actual Cost* ($)
Controller Modifications	$ 23,100
Construction Cost	
Site 1: I-495W/I-95S, Springfield, VA	$ 254,329
Site 2: I-495W/RT 123N, McLean, VA	$ 149,542
Site 3: I-495E/I-95S, Beltsville, MD	$ 240,845
System Calibration, Commissioning, and Testing Cost ($920 per ramp)**	$ 2,760
Total Installation Costs	$ 670,516

* Costs for Work Zone Traffic Control were approximated for actual costs ($25,000 for Site 1 and $15,000 for Site 2).

** This cost also included calibration test trucks.

This would bring the installation cost up to $150,462 and $248,507 for a single-lane and dual-lane system, respectively. It was assumed that the operational costs per site would be $1,000. The final cost for installation, not shown in table 37, includes the engineering design cost. The feasibility report cited the engineering design cost to be $10,000 and $15,000 for single- and dual-lane installations, respectively. This estimate proved to be low with the actual costs closer to $15,000 and $20,000 for single- and dual-lane installations. In summary, the total design and installation costs are as follows:

- Single-lane ramp - $166,462.
- Dual-lane ramp - $268,507.

Based on cost data gathered from the two States, the annual operation costs are estimated at about $44,328 and $39,304 per year, with the maintenance contract accounting for 96 percent of the total costs for both the Virginia and Maryland sites, respectively. The maintenance contract allows for inspection, reduction of data from the controller, etc. With proper installation, the system should have a service life of at least 10 years.

The annual operation and maintenance costs have been used in this study to also determine the total present worth of systems. The results of the total present worth analysis for each ATRWS site are shown in table 38. The total present worth analysis was used to: (1) predict the total required operational costs to sustain each ATRWS site for 10 years of operation, and (2) provide an estimate of operational costs for long range planning of future system installations. These costs are derived from the sum of initial system costs and present worth of annual costs. Since the individual operational costs provided by the States were incomplete, the estimated operational costs were used to calculate the total present worth of the systems.

It is concluded from the data shown in table 38 that it is more cost effective for the States to conduct their own maintenance; this assumes that Department staff is adequately trained to conduct the maintenance. It is assumed that the total present worth costs and required operational costs shown in table 38 will be lower for future systems, because nearly all the required modifications in design and programming for the prototype systems will have been corrected.

Operational Costs

The operational costs consist of:

1. Technician Costs (one per State to monitor system).
2. Maintenance Costs (per site).
3. Electrical Costs (per site).
4. Phone Costs (per site).

Table 38. Total present worth of each ATRWS system based on total initial costs plus present worth of annual costs for two interest rates.

Interest Rate	ATRWS Site					
	Springfield		McLean		Beltsville	
	Maintenance Contract		Maintenance Contract		Maintenance Contract	
	Yes	No	Yes	No	Yes	No
5%	$515,000	$303,000	$266,300	$185,000	$515,000	$303,000
Required Operational Costs Account	$246,500	$34,500	$99,800	$18,500	$246,500	$34,500
7%	$493,000	$300,000	$257,200	$183,000	$493,000	$300,000
Required Operational Costs Account	$224,500	$31,500	$90,800	$16,500	$224,500	$31,500

Notes:
- The total present worth of systems is based on systems operating for 10 years.
- The Springfield and Beltsville ATRWS sites total initial costs used for this analysis was $268,507.
- The McLean ATRWS site total initial costs used for this analysis was $166,462.
- When the maintenance contract was in effect, the total present worth equation used $32,000 and $12,900 per year for operational costs, for the two-lane and one-lane sites, respectively.
- When the maintenance contract was not in effect, $4,400 and $2,400 were used as the actual operational costs for both two-lane sites and one-lane sites, respectively, in determining the total present worth of the systems for 10 years of operation.
- All total present worth costs are rounded to the nearest $100.

Technician Costs

It is concluded that the previous ATRWS host computer technician man-hour estimate of 15 minutes per day to maintain the system was too low. The two States estimate that at least 30 minutes a day are required for the ATRWS technician to monitor system operations. ATRWS software problems, such as transferring files from site to host computer, were the primary cause of increased technician hours. It is anticipated that these costs will be reduced over a period of time due to additional training, familiarization with the ATRWS system, and increased computer literacy.

Maintenance Costs

These costs consist of: (1) Routine Maintenance and (2) Special Problem/Malfunction Maintenance. VDOT, MDSHA and the maintenance contractor, International Road Dynamics (IRD) were provided with maintenance data reporting forms to assist them in conducting the appropriate maintenance and documenting all activities and maintenance costs. These forms were provided to facilitate a timely and accurate maintenance analysis.

Routine Maintenance. The purpose of this analysis was to conduct a comparative analysis of the actual maintenance costs versus the cost of the maintenance contract to the States. This routine maintenance was scheduled to be conducted semi-annually for 3 years (for a total of six maintenance periods). However, since the ATRWS was approved by the States later than anticipated, the desired schedule was not achieved. To effectively evaluate this type of maintenance activity conducted at each of the ATRWS sites, it was imperative that both States and the contractors use the scheduled preventive maintenance record checklist cited in the System Evaluation Plan. This maintenance checklist contained specific maintenance items that must be maintained in order for the systems to operate as designed. It was confirmed during this evaluation that the routine maintenance was conducted six times; however, only two service reports that summarized the maintenance activities conducted were provided. The lack of scheduled maintenance service reports prevented any conclusive evaluation of the findings here.

Special Problem/Malfunction Maintenance. The purpose of this analysis was to analyze: (1) ATRWS problems cited by States and/or found by the technician during routine viewing of records for truck type and (2) the frequency of problems and time and cost to resolve them. To effectively evaluate this type of maintenance activity conducted at each of the ATRWS sites, it was imperative that both States and the maintenance contractors use the maintenance request forms cited in the System Evaluation Plan. For the first evaluation period, an approved maintenance agreement had not been in effect for the three ATRWS sites; however, there were numerous system components that were repaired during this period that should have been covered under the maintenance agreement. Maintenance repairs on back-up power supply, height detector, and piezo-sensor relocation installation were conducted during the first evaluation period. Although some maintenance request forms were submitted via facsimile transmittal and/or verbally by telephone from States to the maintenance contractor, not enough information was recorded to form a conclusive evaluation of the maintenance activities for the first evaluation period. For the second evaluation period, a maintenance contract was in effect for both the Virginia and Maryland ATRWS sites for 1½ years and 7 months, respectively. Although both States now have approved maintenance contracts, it was seen that few special problems and malfunctions found at all three ATRWS sites were submitted on maintenance request form via facsimile transmittal and/or verbally from the States to the maintenance contractor. In some instances where component or system malfunction continued, both States would submit the appropriate maintenance requests; however, maintenance contractor response times were longer than the specified contract time on several occasions. In some cases, the slow maintenance response time was not the fault of the maintenance contractor, but in part due to weather and/or traffic control information not provided by the States. In conclusion, a thorough evaluation of the maintenance activities could not be conducted due to the small amount of maintenance-related data recorded by the States and maintenance contractor.

Electrical Costs (Power Usage)

The electrical cost estimates for each site were based on the power consumption of the ATRWS sites, provided by the manufacturer, and the fuel charge, provided by the power company. The estimated power costs were found by multiplying the average power consumption of each site by the average electrical rate charged to public agencies. Since the estimated electrical costs were found to be minimal compared to other operational costs, they were used as the actual electrical costs of the systems. The electrical fuel charge equals $0.08 cent per kilowatt-hour (kW-h) per day per 30 days for each site. Table 39 presents the findings for power consumption and electrical costs for each ATRWS site.

Table 39. Power consumption and electrical costs for ATRWS sites.

ATRWS Site	Power Consumption	Cost per Month
Springfield	8.016 kW-h	$19.24
McLean	7.152 kW-h	$17.17
Beltsville	8.016 kW-h	$19.24
Sample electrical cost calculation: 8.016 kW-h/day x 30 days x $0.08/kW-h = $19.24		

These particular operational costs are minimal ($231, $206, and $231 per year for the Springfield, McLean, and Beltsville sites) compared to other cost items to the system. These costs should remain low over the life of the system; however, any major modifications to these systems that would increase the electrical load could cause these costs to increase.

Phone Costs

Based on the data provided by VDOT and the telephone company, the 3-year average actual costs were $198 and $73 per month for the Virginia ATRWS sites. Cellular phone cost appeared in some cases to be very high; however, they actually included previous month invoices that were not paid before the next billing date. High cellular phone billing rates were attributed to: (1) the immense amount of evaluation data downloaded from site computer to the evaluators' host computer, (2) States' daily monitoring of the system, and (3) costs for numerous hangups after connections and during downloading transmissions.

The Maryland phone costs averaged $38 a month. The much lower Maryland ATRWS phone costs were principally due to it being a land line, instead of the cellular connection used by the Virginia sites.

Summary of Operational Costs

Tables 40 and 41 compare the estimated operational and actual operational costs of the two Virginia sites and the Maryland site, respectively. In summary, it is concluded that the operational costs data are insufficient to make a conclusive analysis. Also, based on data that was provided by the States, maintenance contractor, and other utility agencies, it is concluded that all the operational costs involved in these systems are minimal, with the exception of the maintenance costs provided by the maintenance contractor and cellular phone costs (Virginia only).

BENEFIT/COST ANALYSIS

This subtask evaluated the benefit/cost of the ATRWS systems. The benefits from the automatic truck warning system are a reduction in rollover accidents and their associated costs. An accurate analysis of benefit/costs can be realized by either of the following two methods: (1) analyzing system costs with respect to truck accident costs per accident, or (2) analyzing system costs with respect to the assumed prevention of the theorized number of future rollover occurrences by the systems, truck accident costs, and previous number of accidents at each site. Method one is being followed for this analysis.

The benefit costs are the dollar values assigned to the reduction of: fatalities, injuries and vehicle property damage, and cargo loss; the possible damage to the highway facility and appurtenances; the cost imposed on motorist(s) delayed by the accident; and the traffic control and cleanup. Although the number of truck accidents is small, they can be very costly, especially if hazardous cargo is involved. For instance, a truck rollover accident that occurred at a Capital Beltway interchange and involved a fuel tanker truck resulted in a fatality, substantial structural damage to the bridge overpass due to fire, and enormous delay and vehicle operating costs to motorists caused by the 3-hour blockage of the Beltway. A study of truck accidents on urban freeways presented accident cost data that indicates that the average total cost of a truck accident is $13,274.[7] This value is based on the reported $634,000 per freeway mile ($394,000 per freeway kilometer) cost (considering all the cost elements discussed above for 2,221 reported accidents over 74.9 km (46.5 mi) of freeway).

Another estimate of the cost of a truck accident was found in a study of the Washington Bypass.[8] In that study, an analysis of truck accidents on the Capital Beltway was performed and a cost per accident was established. Applying the observed distribution of accidents by severity for truck accidents on the Beltway for 1986 to 1987, the costs per accident type of $1,200,000 per fatality, $13,650 per injury, and $2,425 per property damage only (PDO) accident, a $15,470 per accident value was developed. This value did not include any delay costs or cleanup costs.

Table 40. Estimated operational costs vs. actual operational costs for two Virginia ATRWS sites.

Type Cost	Estimated Operational Costs ($) (month) Spring./McLean	Springfield ATRWS		McLean ATRWS	
		First Evaluation	Second Evaluation	First Evaluation	Second Evaluation
		Actual (month)	Actual (month)	Actual (month)	Actual (month)
1. Technician	$34/$14	$100	$150	$100	$150
2. Maintenance*	$2,575/$1,031	NP[1]	NP[1]	NP[1]	NP[1]
3. Electrical	$19/$17	NP[2]	NP[2]	NP[2]	NP[2]
4. Phone*	$35/$15	$246	$175	$112	$43
Total Operational Cost	$2,663/$1,077	$346	$325	$212	$193

* - Although this cost is shown as estimated, it is considered the actual cost, based on the actual maintenance contract. These costs were not estimated; however, there was a maintenance contract in effect through an independent contractor. It was seen in this evaluation that 40 percent of this cost was attributed to Lightning Damage Option.

NP[1] - Not provided by maintenance contractor.

NP[2] - Not provided by the States.

Table 41. Estimated operational costs vs. actual operational costs for one Maryland ATRWS site.

Type Cost	Beltsville ATRWS		
	Estimated (month)	First Evaluation	Second Evaluation
		Actual (month)	Actual (month)
1. Technician	$48	$70	$70
2. Maintenance*	$2,575	$300	NP[1]
3. Electrical	$19	NP[2]	NP[2]
4. Phone*	$50	$35	$41
Total Operational Cost	$2,692	$405	$111

* - Although this cost is shown as estimated, it is considered the actual cost, based on the actual maintenance contract. These costs were not estimated; however, their was a maintenance contract in effect through an independent contractor. It was seen in this evaluation that 40 percent of this cost was attributed to Lightning Damage Option.

NP[1] - Not provided by maintenance contractor.

NP[2] - Not provided by the States.

Both of the values cited above — $13,274 and $15,470 — are likely to be lower than the average costs of a truck rollover accident. A more likely average is estimated at $20,000 with a significant probability that a given accident of this type could result in a fatality.

The cost-effectiveness of the automatic truck rollover warning system is assessed by establishing how many accidents would have to be eliminated by the system to make it "pay for itself." Table 42 provides the results of this type of analysis. Increments of total accident costs ranging from the estimated average costs of $20,000 to $1,000,000 are listed with the number of accidents that would have to be eliminated by a one-lane or two-lane system. The system costs are those installation costs identified earlier, plus a $1,000 per year cost for maintenance over the 10-year life. The analysis revealed that a single lane system would have to eliminate just over eight accidents, resulting in an average of $20,000 total costs, in 10 years. However, if the average rollover accident was to result in $100,000 of economic loss, then the elimination of nearly two accidents in 10 years would more than pay for the system. For a two-lane system, just over 13 accidents averaging $20,000 in costs would have to be eliminated in 10 years. For a two-lane accident with $100,000 of economic cost, the elimination of nearly three accidents would more than pay for the system.

Obviously the cost-effectiveness of this system is very much dependent upon whether or not it prevents the high cost rollover accident — an event which is relatively rare. From the feasibility study, it was cited that there were 12 rollover accidents at 7 ramps in Virginia over a 4-year period. A linear extrapolation of this frequency rate would reveal that there could be an average of 4.25 accidents per ramp for those 7 ramps. Hence, it appears from this simplistic, but reasonable, analysis that an effective automatic truck rollover warning system could be cost-effective if applied at ramps with a history of truck rollover accidents of at least one every 5 years.

Earlier in this report, a more theoretical prediction of rollover accidents made use of the Poisson Probability Analysis. That analysis predicted the percent probability of rollover accidents for each ATRWS site. The results of that analysis were previously shown in table 36. Using those percent probabilities, it is concluded that there is a higher probability of future rollover accidents without the systems being installed than with an installation for each of the ATRWS sites. That conclusion surmised that there was a 34.3-percent probability of one rollover accident occurring in 1 year at each site without the systems and zero rollover accidents predicted using the fact there were no accidents for 3 years. Additional accident percent probability statistics were determined using the earlier conclusion that stated that an effective system would be one where system installed at a site had the occurrence of one rollover accident every 5 years. Given that one accident every 5 years averages out to 0.20 accidents per year, the Poisson Probability Analysis theorizes that the probability of one rollover accident in a year would be 16.4 percent

Table 42. Required rollover accident reduction for system cost-effectiveness.

All Accident Costs ($)	No. of Rollover Accidents	
	One-Lane System @$166,462[1]	Two-Lane System @$268,507[1]
20,000	8.32	13.42
50,000	3.33	5.37
100,000	1.66	2.69
500,000	0.33	0.54
1,000,000	0.17	0.27

Note:
[1] Installation costs plus $1,000 per year for 10 years of maintenance. The previous maintenance costs assumes that States would conduct their own maintenance, reducing the operational maintenance costs from $36,800 and $15,400 for the two-lane and one-lane site, respectively, to $1,000 per year for 10 years of maintenance.

compared to the zero percent probability when using the current data of no accidents occurring for the 3-year operation of the systems.

5. RECOMMENDATIONS

The following are recommendations for future installations and evaluations of ATRWS systems. These recommendations will be presented in four areas: (1) Modifications/Enhancements to Current Design, and (2) Site-Specific Modifications, (3) Suggested Changes for Future Evaluations, and (4) Alternative ATRWS Designs (Simplified Systems).

MODIFICATIONS/ENHANCEMENTS TO CURRENT DESIGN

1. Location of power drops and phone connections should be determined prior to final design plan approval for future systems of this type. This element proved to be expensive where these connections were not close by.

2. Pavement analysis should be done using the latest testing procedures for suitable use in weigh-in-motion systems as outlined in ASTM E1318-90. Any deterioration in the pavement will cause a faulty piezoelectric sensor measurements and/or damaged sensor. (The manufacturer of the current piezo sensors claims that new designs are less sensitive than previous designs to pavement deterioration.)

3. Pavement sealant should be applied over all WIM stations biannually to prevent pavement deterioration.

4. The ATRWS algorithm should allow either the average or largest GVW measured for WIM stations 1 and 2, and WIM stations 4 and 5, instead of using the larger of the two GVW measurements for determining the rollover threshold (RT). This recommendation would increase ATRWS accuracy for selecting the appropriate rollover threshold value for each truck that travels through the system.

5. The ROLLUTIL.EXE modification should be incorporated into the office software. It should allow scrolling up and down, and it should label Lane 2 vehicles by WIM 4, WIM 5, and WIM 6 for both the screen preview and the Excel output file. It should also include GVW and total axle spacing for vehicles, not just individual axle spacings in the screen preview, as well as the following screen modifications:

   - Field for selecting trucks that only activate the sign.
   - Field for selecting lane 1 and/or 2 to be included, assuming system is a two-lane site.
   - Print site-specific parameters as a header to screen display and spreadsheet file, i.e., radius (R), elevation (e), WIM 2 to WIM 3 distance.

6. Height detectors should maintain an operational system check at its installation location, e.g., component seen from outside of device showing its operation, and software

programming that causes the system to send a warning message to site computer when a preset percentage of box and tanker truck measurements by height detector are exceeded.

7. Incorporate hardware/software modification that verifies fiber-optic sign activation (e.g., sign design includes an optical-relay switch that sends message to DOT_TXT and VEH_RCRD file that sign was actually activated, independent of current software message sent to DOT_TXT file).

8. Incorporate ATRWS Debug Screen (calibration mode) into separate Rollover Menu in site software. This menu would serve as the primary view vehicles screen.

9. Future controller cabinets should have a sliding shelf for the keyboard.

10. All cabinets should be installed so that glare does not affect the technician's viewing of records at site computer.

11. The cabinet should be installed in a location where the fiber-optic sign activation can be viewed.

12. Allow date/time group adjustments through the site's Main Menu.

13. Modify the site's Main Menu to display real-time size of DOT_TXT file.

14. Allow the DOT_TXT file to record data daily (24-h intervals), like the VEH_RCRD file.

15. Office Software — under the View Vehicles menu, the Start and End times should allow seconds to be included as a search criteria, e.g., 9:08:15 or 16:00:30, instead of hours and minutes only. This future modification would speed the search of records, thus allowing the data to be evaluated faster and more efficiently.

16. ATRWS Site Main Menu should include a real-time window, similar in operation to the current ROLLUTIL program display, that summarizes rollover specific parameters included in the DOT_TXT file, but is more specific with regards to WIM station *number*.

17 Future ATRWS site and host computer should be programmed for Windows environment. This modification would make system much more user friendly, and would also allow the ATRWS program to be networked with other computers in office, thus allowing the system to be accessed by several users.

18. Either through the Office Software Reports Menu or modified DOT_TXT/ Rollutil Program, the system should produce a statistical report that includes ATRWS-specific summaries. It was mentioned earlier in this report, that the system produces an enormous amount of data to be analyzed. The ability of the system to produce statistical summaries

on rollover-specific parameters would significantly reduce the amount of time required to analyze the data of the system. This report should summarize by the following:

- Site No./Location/Date and Time
- Classification (All Trucks or Truck Specific Class)
- Lane
- Average Predicted Speed at PC for Lanes 1 and 2
- Average Speed Reduction for WIM 2 to WIM 3 or WIM 5 to WIM 6
- Percent (%) Speed Reduction (Average Speed Reduction Compared to Average Predicted Speed at PC)
- With Activation
- Without Activation

Table 43 represents the recommended format of the ATRWS statistical report for the above criteria.

Table 43. Sample report format for ATRWS statistical summaries.

Site No./Location/ Date/Time	Lane No.	With Activation			Without Activation		
		Avg Predicted Speed @ PC (mi/h)	Avg Speed Reduction WIM 2 to WIM 3* (mi/h)	% Speed Reduction	Avg Predicted Speed @ PC (mi/h)	Avg Speed Reduction WIM 2 to WIM 3* (mi/h)	% Speed Reduction
1. I-495W/I-95S, Springfield, VA/ 08:00:30 to 13:30:45	1						
	2						
2. I-495W/RT 123N, McLean, VA/ 08:00:30 to 13:30:45	1						
3. I-495E/I-95N, Beltsville, MD/ 08:00:30 to 13:30:45	1						
	2						
Average Speed Reduction							

* - Average speed reduction from WIM 5 to WIM 6 for Lane No. 2 of two-lane system.
1 mi/h = 1.61 km/h

19. Install trailing loops in future systems, i.e., loop-piezo-piezo-loop configuration instead of the current loop-piezo-piezo configurations. This change will allow each WIM station to be less dependent on headway (msec) set by upstream loop. For example, in the current ATRWS systems, slower vehicles cause system to time out before the truck clears the loop, causing the system to not count the fifth axle of Class 9 trucks. This modification would also introduce a level of redundancy in the system, in case of loop failure.

20. If paved shoulder width is available, extend piezo sensor installations 0.91 to 1.22 m (3 to 4 ft) into it. This will prevent a number of trucks from being missed by the system due to the fact that they are traveling out of their lane.

21. Use a land phone line instead of a cellular phone. This recommendation will reduce the costs associated with communicating to sites. Also, it would increase the ability of the system to maintain connection between the site and host computers via the communication software. This recommendation reduces the effects of weather and/or heavy cellular traffic disconnecting the system from ongoing ATRWS communication and/or downloading of files.

22. Future ATRWS system technical manuals should include detailed maintenance troubleshooting procedures so that States would not necessarily have to award a maintenance contract to keep systems operational. This recommendation would allow States to conduct their own maintenance activities at the ATRWS sites, since future maintenance needs may be required to correct unanticipated software problems.

23. Since all the data required for this report have been collected, and the transfer of DOT_TXT and VEH_RCRD files from site computer to the host computer requires 1 to 5 hours, it is recommended that all future data files produced by the systems be overwritten biweekly, and saved only in the event of an accident or when requested by States. This user-related change for storing files would make it more cost and time efficient for the States to monitor systems. Refer to software user's manual for instructions on how to automatically overwrite system data files.

SITE-SPECIFIC RECOMMENDATIONS

The following are recommendations specific to each ATRWS site.

Site 1: I-495W/I-95S - Springfield, Virginia

1. Height detectors installed on top of concrete retaining wall at road shoulder edgeline should be mounted on pole with offset from shoulder to prevent knockdowns by highway department vehicles and/or private tractor trailer carriers.

2. Piezoelectric sensor length specification for all WIM stations should be shortened to prohibit placement on centerline. This recommendation would reduce the error effects of Class 9 five-axle trucks that partially stray into two lanes.

Site 2: I-495W/RT 123N - McLean, Virginia - No additional recommendations.

Site 3: I495E/I-95N - Beltsville, Maryland

1. Piezoelectric sensor length specification for all WIM stations should be shortened to prohibit placement on centerline. This recommendation would reduce the error effects of Class 9 five-axle trucks that partially stray into two lanes.

SUGGESTED CHANGES FOR FUTURE EVALUATIONS

1. The proper operation of the DOT_TXT should be confirmed before any future evaluations are conducted.

2. Fiber-Optic Sign Activation and Speed Reduction Analyses should use a constant study group size.

3. A newer model laser speed gun or one that has been recently calibrated and/or tested for WIM speed verifications should be used.

4. Future system evaluations should include the effects of trucks (other than Class 9 tanker or box trucks) whose heights are less than 3.5 m (11.5 ft) on the system. Presently all three ATRWS systems consider trucks with heights less than 3.5 m (11.5 ft) as tanker trucks in the algorithm that determines the rollover threshold speed.

5. Determine whether Class 9, five-axle dump trucks and car carriers should be classified in ATRWS system as tanker or box trucks.

6. Future calibration tests should include individual axle weights in the analysis.

7. Calibrate box and tanker trucks using the same speed.

8. Accurate weight measurements by system should be confirmed by determining if WIM stations 1 and 2, and 4 and 5 are within 15 percent of each other. If weight differences are greater than 15 percent, it should be assumed that one of the WIM stations is failing or needs to be recalibrated manually. To accomplish this, States must download a current VEH_RCRD or DOT_TXT files once a month.

9. For all future calibrations, use only one truck trailer type, (specifically the tanker), because of the difficulty in calibrating the system.

ALTERNATIVE ATRWS DESIGNS (SIMPLIFIED SYSTEMS)

This section presents two possible ATRWS alternatives: (1) a simplified system using limited in-ground sensors or (2) a system that requires no in-ground sensors.

Alternative Design # 1 — Limited In-Ground Sensors

Since the data show a much higher sign activation for trucks exceeding the maximum safe speed (MSS) than the rollover threshold speed, it is recommended that the weight and height program measurement parameters used in determining the sign activation be eliminated from future system installations. Thus, for future systems a cost savings can be realized by changing Class 1 piezos to the new AMP Class 2 piezo sensor, eliminating the height detector and cable, and reducing the following construction materials: loop wire/cable, junction boxes, and guardrail. These modifications would yield an estimated $20,000 to $30,000 and $40,000 to $60,000 reduction in system cost for one- and two-lane ATRWS systems, respectively. Also, although workzone traffic control was not considered in these estimates, it is assumed that this cost item will be less costly due to the reduced amount of time for lane closures. Table 44 presents this cost-savings estimate by number of lanes.

Table 44. Estimated cost for Alternative Design #1 compared to current ATRWS system.

Type of Cost	Alternative Design # 1 (with in-ground sensors)	
	One-Lane	Two-Lane
Construction/Equipment Operation Design	$122,000 to $132,000 $1,000/yr $15,000	$189,000 to $209,000 $1,000/yr $20,000
Total Cost of Simplified System*	$137,000 to $147,000	$209,000 to $229,000
Current ATRWS Cost**	$166,462	$268,507
Maintenance Cost (State or Contractor)***	$1,000/yr or $12,500/yr	$1,000/yr or $20,000/yr

* This item includes construction, system calibration, and design costs only.
** Includes construction, operation, system calibration, and design costs.
*** The greater estimate is primarily due to an option for lightning damage.

Alternative Design # 2 — No In-Ground Sensors Required

This alternative system uses upgraded acoustic sensing and signal processing technology. The system consist of two main components: (1) a Variable Message Sign (VMS), and (2) a SmartSonic™ Traffic Surveillance Sensor (TSS-1). This system is more practical than the current ATRWS in-ground piezo and magnetic loop sensor, because it does not require expensive piezo sensors, cutting pavement, and long lane closures for installation, which are costly. The SmartSonic has the ability to trigger a VMS sign for commercial trucks with more than two axles that are exceeding a user-definable speed. The following are some additional characteristics of this system:

1. Operates from current overhead and roadside structures.

2. Able to distinguish between cars, small trucks, and large trucks.

3. Provides demonstrable detection ability (at all speeds), which compares very well with loop detector sensitivity.

4. Small [38 cm by 38 cm by 7.6 cm (15 in by 15 in by 3 in)] and lightweight [less than 3.6 kg (8 lb)].

5. Controller Card is Type 170 and NEMA TS2 cardfile compatible.

6. Easy and rapid installations (45 minutes on average per sensor), minimum training for installation, and no maintenance or cleaning.

The estimated cost for a one-lane system installation would be $33,000, much less than the current system and less than alternative design #1. This cost includes the following:

1. SmartSonic™ sensor with controller card, transition module/surge suppressor, 152.4-m (500-ft) home run cable kit, serial cable, modular cable, cable assembly, pole mounting bracket, and bracket support tubes.

2. Variable Message Sign with mounting bracket.

3. Installation supervision.

The estimated costs does not include the following items:

1. Installation labor and equipment (bucket truck, electrician, and technician).

2. Traffic control.

3. Conduit.

4. Support structure for TSS-1 if one is not in place.

5. Power supply.

6. Telephone.

6. CONCLUSIONS

Based on the evaluation results, it is concluded that were no rollover accidents at either of the ATRWS sites located in Springfield and McLean, VA, and Beltsville, MD, over the 3-year operation of the systems. Since there were no rollover accidents at these sites, the Poisson Probability theory was used to predict that there is a zero-percent probability of future accidents at the sites. However, this conclusion should be studied further due to the fact that these systems are prototypes and there are not enough current substantive accident data to more accurately predict long range rollover accident probabilities.

Based on the data collected and analyzed, it is concluded that overall the three ATRWS systems located in Springfield and McLean, Virginia and Beltsville, Maryland performed as they were designed. It is concluded that for all three ATRWS sites, the main criteria for an effective system "Does the activation of the ATRWS affect a speed reduction" was answered. The results showed that all three systems caused truck drivers to reduce their speeds prior to entering the point of curvature for the ramp, based on their predicted speeds exceeding the maximum safe speed for the ramp. The results of the speed reduction analysis showed that there was an overall 29.0 and 21.7 percent speed reduction from WIM 2 to WIM 3 for the first and second evaluation periods when the fiber-optic sign was activated at all three ATRWS sites.

Although the hardware and software of the systems usually operated as designed, there were some instances where they operated in less than optimal fashion. These instances are characterized by deficiencies in height and weight measurements by the systems. These system deficiencies could be reduced or even prevented by: (1) placing a percent volume category in the algorithm that compares preset volumes for box and tanker trucks, and notifies the host computer when differences are greater than the preset volume, and (2) installing the new improved generation of piezoelectric sensors that reduce the effects of cracks in pavement surface, and substructure, that causes the system to measure what is termed as "ghost axles." The site and office software required modifications throughout the 3-year operation of these systems. Program modifications included corrections for: (1) adjusting sign activation duration times, (2) allowing sign activations when WIM station 1 or 2 for lane 1, or station 4 or 5 for lane 2 are missed, (3) recording vehicles in the DOT_TXT file even if they are missed by WIM stations 3 or 6, and (4) providing accurate viewing and printing of reports from VEH_RCRD data files.

Truck speed and classifications measurements by the ATRWS systems were typically within specifications. However, it is concluded that for instances where speed measurement discrepancies were observed, they were attributed to speed gun operator tracking error.

It is concluded that the cellular phone costs for the Virginia sites could be reduced with use of land line connections between site and host computers. However, lower cellular phone costs can still be achieved because of: (1) the reduced demand for downloading daily files (i.e., veh_rcrd and dot_txt) for evaluation purposes, and (2) general communication to sites by States should be minimal, i.e., twice a month.

In addition, it is concluded that although the fiber-optic signs performed as they were designed, future systems should include a fail-safe message confirming all sign activations. This could be achieved by installing some type of optical relay switch that sends a signal back to ATRWS computer attached to the veh_rcrd and dot_txt files.

Since there are no industry standards for the functions of these systems and they are all prototype, it is understandable that some maintenance issues have not been fully addressed. Nevertheless, based on the components of the systems and numerous field observations, it is concluded that States should keep a maintenance contract in effect until States can provide the necessary maintenance required to keep systems operational. Maintenance turnaround times for correcting maintenance activities were not conducted as timely as maintenance contracts stated to contractor. It is concluded that throughout the 3-year operation of the ATRWS systems, instances where maintenance turnaround times were delayed caused systems to perform less than optimally.

The statically evaluated rollover threshold (RT) and maximum safe speed values are the primary parameters used to determine sign activation for these ATRWS systems. Based on truck type and weight, the RT parameter is applied to all trucks traveling on curved ramps to predict rollover threshold (or lateral acceleration) speeds of Class 9 five-axle tanker and box trucks. The maximum safe speed parameter was required by States to cause speeding trucks that do not fit rollover threshold speed criteria to reduce their speeds. The data in this evaluation showed that for nearly every case where a sign was activated, it was because the truck exceeded the maximum safe speed. Therefore, it is concluded that systems such as these should be designed for ramps where the maximum safe speed is nearer to the average rollover speeds. A case could be made that these prototype systems and future ones should remove the rollover threshold speed parameter from the ATRWS algorithm, since most trucks activate the signs based on the maximum safe speed. However, it is concluded that these systems (specifically the Springfield and Beltsville sites) and future ones like them should continue to include the RT speed if there is a substantial tanker truck population.

Based on the final meetings with VDOT and the MDSHA, it is concluded that both States were satisfied with the design operation of the systems. Both States have decided to continue maintaining these systems in their current locations. In addition to the specific design operation of the systems, both States are using truck average daily traffic (ADT) and weight data for Department purposes on a minimal level. However, both States expressed a major concern with the amount of time required to oversee and download large data files from systems, the conduct of periodic maintenance, and recalibrations (weight and height measurements) of the systems. Thus, both VDOT and the MDSHA recommend the development of a more simplified system, which would require less time spent on oversight and less maintenance.

Based on numerous conversations with drivers of tanker and box trucks, such as Exxon, Mobil, Shell, Giant, and Safeway, it is concluded that they considered these systems beneficial for preventing truck rollover accidents on exit ramps. Furthermore, truck drivers stated that this system would especially benefit truck drivers who were not familiar with this geographical area. Therefore, a survey of local and non-local truck drivers should be conducted to determine the subjective reactions of existing and future system installations.

APPENDIX A
SAMPLE CALIBRATION DATA RESULTS FOR WEIGHT AND SPEED MEASUREMENTS

Appendix A.1 Springfield Weight Measurement Results

Table 45. Box truck weight calibration evaluation results for right lane of the Springfield site.

Site Location: I495W/I95S	Date: Wed. 7-17-96							
Truck Type : Box	Actual GVW = 58,580							
Right Lane (WIM 1)				Right Lane (WIM 2)				
Run # / vehrcrd #	Measured GVW (lbs)	% Difference From Actual GVW*	Truck Type Class 9 (Y/N)	Run # / vehrcrd #	Measured GVW (lbs)	% Difference From Actual GVW	Truck Type Class 9 (Y/N)	Height Detector Activation at WIM 2
1/ missed				1/ 34552	71,600	22.2%	Y	Y
2/ 35684	57,700	-1.5%	Y	2/ 35687	53,600	-8.5%	N(8)	Y
3/ 37640	53,700	-8.3%	Y	3/ 37642	66,300	13.2%	Y	Y
4/ 40734	53,500	-8.7%	Y	4/ 40738	65,500	11.8%	Y	Y
5/ 42342	56,800	-3.0%	Y	5/ 42348	65,400	11.6%	Y	Y
6/ 43481	57,700	-1.5%	Y	6/ 43485	67,700	15.6%	Y	Y
7/ 44629	56,400	-3.7%	Y	7/ missed				
8/ 47293	59,600	1.7%	Y	8/ 47295	73,700	25.8%	Y	Y
9/ 48638	56,900	-2.9%	Y	9/ 48641	75,400	28.7%	Y	Y
Average	56,538	-3.5%		Average	67,400	15.1%		
Standard Deviation	1,923	3.3%		Standard Deviation	6,331	10.8%		
Summary:				Summary:				
% of Trucks w/in +/- 15% of the actual GVW		100%		% of Trucks w/in +/- 15% of the actual GVW		50%		
% of Trucks w/in ATWS truck classification spec.			100%	% of Trucks w/in ATWS truck classification spec.			88%	100%

Table 46. Box truck weight calibration evaluation results for left lane of the Springfield site.

Site Location: I495W/I95S	Date: Wed. 7-17-96							
Truck Type : Box	Actual GVW = 58,580							
Left Lane (WIM 4)				Left Lane (WIM 5)				
Run # / vehrcrd #	Measured GVW (lbs)	% Difference From Actual GVW*	Truck Type Class 9 (Y/N)	Run # / vehrcrd #	Measured GVW (lbs)	% Difference From Actual GVW	Truck Type Class 9 (Y/N)	Height Detector Activation at WIM 2
1/ 49841	59,600	1.7%	Y	1/ 49844	55,200	-5.8%	Y	Y
2/ 51231	51,200	-12.6%	N(7)	2/ 51236	61,400	4.8%	Y	Y
3/ 52493	50,500	-13.8%	N(11)	3/ 52498	57,300	-2.2%	Y	Y
4/ 53885	59,200	1.1%	Y	4/ 53890	54,600	-6.8%	Y	Y
5/ 55331	58,300	-0.5%	Y	5/ 55336	53,000	-9.5%	Y	Y
6/ 56946	59,300	1.2%	Y	6/ 56952	51,200	-12.6%	Y	N
7/ 58460	59,200	1.1%	Y	7/ 58463	60,600	3.4%	Y	Y
8/ 60176	60,100	2.6%	Y	8/ 60180	59,900	2.3%	Y	N
9/ 62647	60,500	3.3%	Y	9/ 62652	54,600	-6.8%	Y	N
Average	57,544	-1.8%		Average	56,422	-3.7%		
Standard Deviation	3,629	6.2%		Standard Deviation	3,370	5.8%		
Summary:				Summary:				
% of Trucks w/in +/- 15% of the actual GVW		100%		% of Trucks w/in +/- 15% of the actual GVW		100%		
% of Trucks w/in ATWS truck classification spec.			78%	% of Trucks w/in ATWS truck classification spec.			100%	67%

Appendix A.2 Springfield Speed Measurement Results

Table 47. Box truck speed calibration evaluation results for right lane of the Springfield site.

Site Location: I495/I95S	Date: Wed. 7-17-96				
Truck Type : Box					
Right Lane (WIM 1)			Right Lane (WIM 2)		
Run #	Measured Speed (mi/h)	Actual Speed (mi/h)*	Run #	Measured Speed (mi/h)	Actual Speed (mi/h)*
1	22**	30	1	29	30
2	31	30	2	30	30
3	30	30	3	31	30
4	36	35	4	36	35
5	34	35	5	34	35
6	34	35	6	34	35
7	39	40	7	missed	40
8	38	40	8	39	40
9	36	40	9	37	40
% of Trucks w/in the +/- 2 mi/h Requirement		78%	% of Trucks w/in the +/- 2 mi/h Requirement		88%

* - Box truck driver was instructed to travel at these speeds.
** - Significant Speed Change Warning.

Table 48. Box truck speed calibration evaluation results for left lane of the Springfield site.

Site Location: I495/I95S	Date: Wed. 7-17-96				
Truck Type : Box					
Left Lane (WIM 4)			Left Lane (WIM 5)		
Run #	Measured Speed (mi/h)	Actual Speed (mi/h)*	Run #	Measured Speed (mi/h)	Actual Speed (mi/h)*
1	30	30	1	31	30
2	31	30	2	31	30
3	24**	30	3	29	30
4	35	35	4	35	35
5	34	35	5	35	35
6	38	40	6	39	40
7	39	40	7	40	40
8	39	40	8	39	40
9	37	40	9	38	40
% of Trucks w/in the +/- 2 mi/h Requirement		78%	% of Trucks w/in the +/- 2 mi/h Requirement		100%

* - Box truck driver was instructed to travel at these speeds.
** - Significant Speed Change Warning.

APPENDIX B
SAMPLE CLASSIFICATION AND SPEED DATA RESULTS FOR ADDITIONAL TRUCKS

Table 49. Additional truck classification and speed comparison data results for WIM station 1 of the Springfield site.

Date: Friday - 8/23/96

Run No.	Vehicle Record No.	Visual Observation of Truck Type*	Is ATRWS Observation of Truck Type Correct?	(1) Radar Speed (mi/h)	(2) ATRWS WIM Speed (mi/h)**	Speed Difference (1) - (2)	Sign Activation (Yes/No)***
1	3006	B,2X6T	Y	46	45	1	N
2	1110	B	Y	45	44	1	N
3	2062	B,2X6T	Y	59	57	2	Y
4	2102	B	Y	45	47	1	N
5	2196	F	Y	50	50	0	—
6	2251	B	Y	51	50	1	Y
7	missed	B,2X6T	missed	54	missed		Y
8	2492	B,4X	Y	50	49	1	Y
9	2516	B,2X	Y	49	47	2	Y
10	2584	B,2X	Y	57	57	0	—
11	missed	B,2X	missed	56	missed		Y
12	2755	B	Y	50	49	1	Y
13	2796	BUS, 3X	Y	47	45	2	N
14	2842	B	Y	42	40	2	N
15	2907	B,3X	Y	53	53	0	—
16	3071	B	Y	58	56	2	Y
17	3227	B	Y	43	43	0	Y
18	3419	B	Y	52	51	1	Y
19	3466	B,3X or 4X	Y	53	53	0	Y
20	3736	B,2X	Y	49	48	1	Y
21	3906	B	Y	51	51	0	Y
22	4045	B	Y	42	41	1	N
23	4082	B	Y	52	50	2	—
24	missed	B,2X	missed	50	missed		N
25	4356	DT	Y	64	59	5	Y
26	4469	D	Y	45	45	0	Y

* - For truck type column B represents Box Class 9, five-axle truck; T = Tanker Class 9, five-axle truck; F = Flatbed Class 9, five-axle truck; D = Double Trailer; and DT = Dump Truck.

** - Speeds displayed by ATRWS of 79 mi/h indicates that the system was measuring vehicles heavy. Please note: pickup trucks with heavy loads will classify as Class 4 or 5.

*** - Sign activation recorded after truck clears WIM 2.

1 mi/h = 1.61 km/h

Table 49. Additional truck classification and speed comparison data results for WIM station 1 of the Springfield site (continued).

Date: Friday - 8/23/96

Run No.	Vehicle Record No.	Visual Observation of Truck Type*	Is ATRWS Observation of Truck Type Correct?	(1) Radar Speed (mi/h)	(2) ATRWS WIM Speed (mi/h)**	Speed Difference (1) - (2)	Sign Activation (Yes/No)***
27	4680	D	Y	40	40	0	—
28	4743	F,6X	Y	43	44	1	Y
29	4963	B	Y	46	45	1	—
30	5005	B	Y	45	45	0	Y
31	5081	F	Y	41	39	2	Y
32	5233	B,6X	Y	51	50	1	Y
33	5372	B	Y	47	46	1	Y
34	5637	B	Y	36	35	1	N
35	5781	B	Y	45	44	1	—
36	5814	B	Y	32	32	0	—
37	5871	B	Y	53	53	0	—
38	5941	B	Y	57	56	1	Y
39	5995	B	Y	46	45	1	Y
40	6285	B	Y	64	63	1	Y
41	6333	F	Y	57	55	2	Y
42	6636	DT, 3X	Y	44	43	1	N
43	6672	B	Y	48	47	1	N
44	6927	B	Y	47	46	1	—
45	8010	B	Y	44	42	2	—
46	8307	B,2X	Y	44	43	1	—
47	8391	B	Y	49	49	0	Y
48	8471	B	Y	48	47	1	Y
49	8570	B	Y	50	47	3	Y
50	8615	B	Y	50	48	2	Y
51	8651	B	Y	51	50	1	Y
52	8967	B	Y	46	47	1	—
53	8967	B	Y	36	35	1	N

* - For truck type column, B represents Box Class 9, five-axle truck; T = Tanker Class 9, five-axle truck; F = Flatbed Class 9, five-axle truck; D = Double Trailer; and DT = Dump Truck.

** - Speeds displayed by ATRWS of 79 mi/h indicates that the system was measuring vehicles heavy. Please note: five pickup trucks with heavy loads will classify as Class 4 or 5.

1 mi/h = 1.61 km/h

APPENDIX C
SAMPLE FIBER-OPTIC SIGN ACTIVATION COMPARISON RESULTS

Table 50. Fiber-optic sign activation comparison analysis for lane 1 of the Springfield site.

Date: Tuesday - 10/1/96

Run No.	Time	ATRWS Vehicle Record Number	Truck Type (B/T)	ATRWS Predicted Speed at PC (mi/h)	Visual Sign Activation* (Yes/No)	Visual Activation Confirmed by ATRWS DOT_TXT File (Yes/No)	Vehicle Displayed In VEH_RCRD File
1	13:17:57	1436	B	31	N	Y	Y
2	13:22:19	1870	B	52	Y	Y	Y
3	13:23:57	1994	B	43	N	Y	Y
4	13:24:08	2018	B	38	N	Y	Y
5	13:24:22	2053	B	44	N	Y	Y
6	13:25:20	2121	F	47	Y	Y	Y
7	13:26:15	2233	B	53	Y	Y	Y
8	13:26:37	2280	B	58	Y	Y	Y
9	13:28:57	2454	D	54	Y	Y	Y
10	13:29:40	2533	B	42	Y	N	Y
11	13:39:22	3399	B	53	Y	Y	Y
12	13:48:18	4181	B	37	N	Y	Y
13	13:49:04	4224	B	50	Y	Y	Y
14	13:49:22	4258	B	57	Y	Y	Y
15	13:54:47	4631	B	57	Y	Y	Y
16	13:56:56	4822	B	45	Y	Y	Y
17	13:57:57	4926	B	54	Y	Y	Y
18	13:59:14	5045	B	46	Y	Y	Y
19	14:25:41	5057	B	54	Y	Y	Y
20	14:40:35	7583	B	59	Y	Y	Y
21	14:41:14	9183	B	51	Y	Y	Y
22	14:41:51	9255	B	58	N	Y	Y
23	14:47:50	9323	B	31	Y	Y	Y
24	14:49:28	9822	B	48	Y	Y	Y
25	14:49:28	10008	B	49	Y	Y	Y
26	14:53:05	10458	B	52	Y	Y	Y

1 mi/h = 1.61 km/h

Table 51. Fiber-optic sign activation comparison analysis for lane 2 of the Springfield site.

Date: Tuesday - 10/1//96

Run No.	ATRWS Vehicle Record Number	Truck Type (B/T)	ATRWS WIM 5 Speed (mi/h)	Visual Sign Activation* (Yes/No)	Visual Activation Confirmed by ATRWS DOT_TXT File (Yes/No)	Vehicle Displayed In VEH_RCRD File
1	1714	B	34	N		Y
2	1892	B	48	N		Y
3	2203	B	47	Y		Y
4	2228	B	52	Y		Y
5	2266	FB	62	Y		Y
6	2329	FB	62	Y		Y
7	2340	B	46	Y		Y
8	2391	B	49	Y		Y
9	2405	B	47	N		Y
10	2640	Loadboy	48	Y		Y
11	2810	B	59	Y		Y
12	3205	B	50	Y		Y
13	3224	B	50	Y		Y
14	3348	B	52	Y		Y
15	3370	B	50	N		Y
16	3642	B	47	Y		Y
17	3786	B	52	Y		Y
18	3865	D	47	Y		Y
19	missed	B	missed	N		N
20	3987	B	54	Y		Y
21	4073	B	42	N		Y
22	4097	B	56	Y		Y
23	4112	T	55	Y		Y
24	4178	B	46	Y		Y
25	4205	B	57	Y		Y

1 mi/h = 1.61 km/h

Table 51. Fiber-optic sign activation comparison analysis for lane 2 of the Springfield site (continued).

Date: Tuesday - 10/1/96

Run No.	ATRWS Vehicle Record Number	Truck Type (B/T)	ATRWS WIM 5 Speed (mi/h)	Visual Sign Activation* (Yes/No)	Visual Activation Confirmed by ATRWS DOT_TXT File (Yes/No)	Vehicle Displayed In VEH_RCRD File
26	missed	D	missed	N		Y
27	missed	B	missed	N		Y
28	4571	B	48	Y		Y
29	4621	B	55	Y		Y
30	4871	B	47	N		Y
31	4959	B	58	Y		Y
32	5003	T	52	N		Y
33	5105	B	51	Y		Y
34	5163	B	46	Y		Y
35	5373	B	44	N		Y
36	5399	B	55	Y		Y
37	5417	D	53	Y		Y
38	5445	T	45	Y		Y
39	5525	B	55	Y		Y
40	5600	B	49	Y		Y
41	5662	B	49	Y		Y
42	5742	B	50	N		Y
43	5800	4X,B	56	Y		Y
44	5975	B	52	Y		Y
45	6049	B	55	Y		Y
46	6084	FB	55	Y		Y
47	6231	B	49	Y		Y
48	6559	B	51	Y		Y
49	6640	B	59	Y		Y
50	6833	B	54	Y		Y

1 mi/h = 1.61 km/h

Table 51. Fiber-optic sign activation comparison analysis for lane 2 of the Springfield site (continued).

Date: Tuesday - 10/1//96

Run No.	ATRWS Vehicle Record Number	Truck Type (B/T)	ATRWS WIM 5 Speed (mi/h)	Visual Sign Activation* (Yes/No)	Visual Activation Confirmed by ATRWS DOT_TXT File (Yes/No)	Vehicle Displayed In VEH_RCRD File
51	7084	B	60	Y		Y
52	7244	FB	57	Y		Y
53	7264	T	49	Y		Y
54	7332	B	55	Y		Y
55	7431	B	49	Y		Y
56	7571	DT	55	Y		Y
57	missed	B	missed	Y		N
58	7778	B	39	Y		Y
59	7889	B	54	Y		Y
60	7973	B	50	Y		Y
61	missed	B	missed	Y		N
62	8328	B	51	Y		Y
63	missed	B	missed	Y		N
64	missed	B	missed	Y		N
65	9161	B	47	Y		Y
66	9320	4X, B	49	Y		Y
67	9379	FB	56	Y		Y
68	missed	B	missed	Y		N
69	9775	B	54	Y		Y
70	9797	B	42	Y		Y
71	10076	FB	44	Y		Y

1 mi/h = 1.61 km/h

APPENDIX D

SAMPLE SPREADSHEET FILE USED FOR SPEED REDUCTION ANALYSIS

Table 52. Speed reduction analysis data results for lane 1 of the Springfield site, Sign "On" and "Off."

	A	B	C	D	E	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
2				Vehicle						Speed										
3	Site:	95S		Number		Vehicle	Speed (mi/h)			Difference	Speed				Error			Sign	GVW	
4	Date / Time	Lane	WIM 1	WIM 2	WIM 3	Class	WIM 1	WIM 2	WIM 3	WIM2-WIM3	Predicted	Rollover	Decel.	WIM1	WIM2	WIM3	Overheight	Turned	WIM1	WIM2
235	07/17/96 2:09:19.54.5	1	3852	3853	3857	9	43.5	43.5	40.39	3.11	43.5	67.096	0	0	17	0	OVER	OFF	37467	32290
236	07/17/96 2:13:46.59.5	1	3966	3967	3972	9	39.15	39.15	34.8	4.35	39.15	55.413	0	0	17	0	OVER	OFF	71825	62785
237	07/17/96 2:27:38.60.6	1	4308	4309	4316	9	44.12	42.88	32.93	9.94	33.12	55.413	1.163	0	17	0	OVER	OFF	60078	65412
238	07/17/96 2:27:42.06.0	1	4310	4313	4317	9	41.63	39.77	35.42	4.35	23.26	62.059	1.632	0	17	0	OVER	OFF	56539	59163
239	07/17/96 2:30:11.08.0	1	4353	4359	4362	9	45.36	36.04	41.01	-4.97	0	55.413	8.16	0	17	0	OVER	OFF	71183	61336
240	07/17/96 2:46:10.30.3	1	4608	4615	4618	9	53.44	47.23	42.26	4.97	0	24.464	6.727	0	0	0	UNDER	OFF	75783	100326
241	07/17/96 2:47:37.35.3	1	0	4645	4647	9	0	41.63	37.91	3.73	41.63	73.127	0	0	17	0	OVER	OFF	0	27276
242	07/17/96 2:48:00.15.1	1	4655	4656	4662	9	41.63	41.63	36.66	4.97	41.63	55.413	0	0	17	0	OVER	OFF	56207	65958
243	07/17/96 2:51:13.98.9	1	4736	4740	4745	9	44.74	43.5	37.91	5.59	33.77	62.059	1.179	0	17	0	OVER	OFF	64900	53193
244	07/17/96 3:06:19.37.3	1	4983	4984	4986	9	50.33	49.09	41.01	8.08	39.53	62.059	1.329	0	17	0	OVER	OFF	43986	56865
245	07/17/96 3:09:16.18.1	1	5042	5044	5048	9	43.5	43.5	42.26	1.24	43.5	67.096	0	0	17	0	OVER	OFF	40555	46920
246	07/17/96 3:25:25.23.2	1	5339	5342	5354	9	42.26	42.26	32.31	9.94	42.26	62.059	0	0	17	0	OVER	OFF	52285	61793
247	07/17/96 3:26:04.77.7	1	5366	5368	5371	9	47.23	46.6	37.91	8.7	42.1	55.413	0.627	0	17	0	OVER	OFF	53160	69203
248	07/17/96 3:35:50.66.6	1	5555	5556	5558	9	44.12	43.5	39.15	4.35	38.97	62.059	0.586	0	17	0	OVER	OFF	45277	50157
249	07/17/96 3:38:38.90.9	1	5651	5653	5662	9	43.5	43.5	36.66	6.84	43.5	54.226	0	0	17	0	OVER	OFF	77489	92429
250	07/17/96 4:21:33.81.8	1	6605	6607	6611	9	47.23	46.6	41.63	4.97	42.1	67.096	0.627	0	17	0	OVER	OFF	36833	45146
251	07/17/96 4:27:54.66.6	1	6773	6775	6781	9	47.85	45.98	39.77	6.21	30.25	54.226	1.881	0	17	0	OVER	OFF	85077	88337
252	07/17/96 4:32:35.82.8	1	6888	6889	6895	9	45.98	45.36	39.15	6.21	40.85	62.059	0.61	0	17	0	OVER	OFF	46394	50660
253	07/17/96 4:57:09.75.7	1	7170	7171	7187	9	41.63	41.01	33.56	7.46	36.47	54.226	0.552	0	17	0	OVER	OFF	73484	84262
254	07/17/96 4:57:18.76.7	1	7181	7188	7197	9	45.98	44.74	36.04	8.7	35.05	54.226	1.213	0	17	0	OVER	OFF	69652	82566
255	07/17/96 4:57:23.26.2	1	7190	7193	7206	9	44.74	44.12	33.56	10.56	39.6	47.853	0.594	0	0	0	UNDER	OFF	63087	75334
256	07/17/96 4:57:48.91.9	1	0	7222	7240	9	0	43.5	39.15	4.35	43.5	62.059	0	0	17	0	OVER	OFF	0	51801
257	07/16/96 10:16:24.96.9	1	29475	29476	29488	8	47.23	45.98	42.88	3.11	36.33	73.127	1.246	0	17	0	OVER	OFF	27511	31510
258	07/16/96 12:09:05.74.7	1	39807	39811	39824	8	41.63	41.63	39.15	2.49	41.63	61.532	0	0	0	0	UNDER	OFF	18237	23465
259	07/16/96 21:30:41.27.2	1	30784	30787	30793	8	44.12	43.5	41.01	2.49	38.97	67.096	0.586	0	17	0	OVER	OFF	36833	42007
260	07/17/96 2:36:19.63.6	1	4452	4453	4456	8	49.09	47.85	41.01	6.84	38.25	62.059	1.296	0	0	0	UNDER	OFF	12262	14126
261	07/17/96 3:59:02.75.7	1	6113	6114	6119	8	47.23	46.6	38.53	8.08	42.1	67.096	0.627	0	17	0	OVER	OFF	32402	39344
262	07/16/96 21:56:16.60.6	1	32343	32346	32359	7	41.63	41.63	36.04	5.59	41.63	73.127	0	0	17	0	OVER	OFF	33802	34720
263	07/17/96 0:32:48.69.6	1	0	1227	1234	7	0	30.45	26.72	3.73	30.45	62.059	0	0	0	0	UNDER	OFF	0	18519
264	07/17/96 2:13:07.10.1	1	3947	3950	3957	7	32.31	32.31	29.21	3.11	32.31	62.059	0	0	17	0	OVER	OFF	53981	53200
265	07/17/96 4:29:36.05.0	1	6802	6804	6814	7	36.66	36.66	29.83	6.84	36.66	55.413	0	0	17	0	OVER	OFF	60642	67491
266	07/17/96 4:59:43.32.3	1	7378	7379	7398	7	38.53	39.15	34.8	4.35	43.17	62.059	-0.519	0	17	0	OVER	OFF	49578	51070
267																				
268																				
269		Average for 176 trucks		Sign "On" (Class 9 - 11)				49.40		7.91	50.02	60.51								
270																				
271																				
272		Average for 84 trucks		Sign "Off" (Class 7 - 9)				42.83		6.44	36.73	60.23								

1 mi/h = 1.61 km/h

Table 53. Speed reduction analysis data results for lane 2 of the Springfield site, Sign "On" and "Off."

	A	B	C	D	E	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
2				Vehicle						Speed										
3	Site:	95S		Number		Vehicle	Speed (mi/h)			Difference	Speed				Error			Sign	GVW	
4	Date / Time	Lane	WIM 4	WIM 5	WIM 6	Class	WIM 4	WIM 5	WIM 6	WIM5-WIM6	Predicted	Rollover	Decel.	WIM4	WIM5	WIM6	Overheight	Turned	WIM4	WIM5
311	07/17/96 2:25:24.31.3	2	4214	4215	4216	9	46.6	45.36	41.63	3.73	35.69	61.532	1.229	0	0	0	UNDER	OFF	20820	23957
312	07/17/96 2:25:48.26.2	2	4217	4218	4223	9	49.09	47.85	30.45	17.4	38.25	61.532	1.296	0	0	0	UNDER	OFF	39851	41701
313	07/17/96 2:26:39.61.6	2	4253	4256	4266	9	45.98	45.36	37.91	7.46	40.85	54.226	0.61	0	17	0	OVER	OFF	84001	83088
314	07/17/96 2:26:52.96.9	2	4272	4276	4285	9	46.6	45.98	39.77	6.21	41.47	67.096	0.619	0	17	0	OVER	OFF	38595	43275
315	07/17/96 2:26:55.10.1	2	4278	4280	4287	9	45.98	44.74	39.77	4.97	35.05	67.096	1.213	0	17	0	OVER	OFF	36786	38276
316	07/17/96 2:26:56.75.7	2	4279	4282	4291	9	44.74	43.5	41.63	1.86	33.77	47.853	1.179	0	0	0	UNDER	OFF	65578	75576
317	07/17/96 2:31:05.34.3	2	4373	4375	4381	9	42.88	42.88	41.01	1.86	42.88	55.413	0	0	17	0	OVER	OFF	70928	79777
318	07/17/96 2:32:29.43.4	2	4402	4403	4406	9	49.09	47.85	37.28	10.56	38.25	67.096	1.296	0	17	0	OVER	OFF	33255	38038
319	07/17/96 2:42:35.98.9	2	4549	4551	4554	9	43.5	42.88	36.04	6.84	38.35	62.059	0.577	0	17	0	OVER	OFF	57103	64155
320	07/17/96 2:46:25.34.3	2	4619	4621	4626	9	46.47	47.23	35.42	11.81	37.61	47.853	1.279	0	0	0	UNDER	OFF	59431	70697
321	07/17/96 2:54:13.37.3	2	4772	4773	4774	9	41.01	40.39	38.53	1.86	35.84	62.059	0.544	0	17	0	OVER	OFF	48527	57281
322	07/17/96 2:57:16.16.1	2	4815	4817	4821	9	45.36	44.12	36.66	7.46	34.41	61.532	1.196	0	0	0	UNDER	OFF	48144	49900
323	07/17/96 3:12:51.98.9	2	5093	5096	5100	9	40.39	39.77	38.53	1.24	35.21	62.059	0.536	0	17	0	OVER	OFF	56994	64425
324	07/17/96 3:14:17.17.1	2	5127	5128	5137	9	46.6	45.36	37.28	8.08	35.69	67.096	1.229	0	17	0	OVER	OFF	43736	47309
325	07/17/96 3:25:15.17.1	2	5326	5327	5344	9	42.26	42.26	34.8	7.46	42.26	54.226	0	0	17	0	OVER	OFF	80634	89349
326	07/17/96 3:36:58.11.1	2	5589	5592	5598	9	39.15	39.15	37.91	1.24	39.15	54.226	0	0	17	0	OVER	OFF	79869	81702
327	07/17/96 3:43:53.73.7	2	5754	5757	5763	9	52.2	50.95	47.85	3.11	41.44	61.532	1.379	0	0	0	UNDER	OFF	35686	39443
328	07/17/96 3:53:06.06.0	2	5970	5971	5978	9	42.88	42.88	38.53	4.35	42.88	61.532	0	0	0	0	UNDER	OFF	40371	39287
329	07/17/96 3:58:56.60.6	2	6109	6111	6115	9	47.23	46.6	41.01	5.59	42.1	62.059	0.627	0	17	0	OVER	OFF	52359	51260
330	07/17/96 4:05:37.50.5	2	6243	6244	6248	9	47.85	45.98	38.53	7.46	30.25	73.127	1.881	0	17	0	OVER	OFF	31531	26605
331	07/17/96 4:08:51.77.7	2	6312	6313	6322	9	56.93	52.82	47.23	5.59	21.75	62.059	3.634	0	0	0	UNDER	OFF	15818	19280
332	07/17/96 4:19:17.32.3	2	6557	6558	6565	9	44.12	43.5	36.04	7.46	36.97	67.096	0.586	0	17	0	OVER	OFF	43985	47257
333	07/17/96 4:19:19.90.9	2	6559	6561	6567	9	44.74	43.5	37.28	6.21	33.77	55.413	1.179	0	17	0	OVER	OFF	62300	68855
334	07/17/96 4:22:59.11.1	2	6637	6640	6645	9	49.09	47.85	40.39	7.46	38.25	54.226	1.296	0	17	0	OVER	OFF	72868	92073
335	07/17/96 4:24:37.04.0	2	6676	6679	6692	9	43.5	42.26	34.8	7.46	32.48	24.464	1.146	0	0	0	UNDER	OFF	73737	84317
336	07/17/96 4:28:46.45.4	2	6792	6793	6797	9	49.71	48.47	37.91	10.56	38.89	54.226	1.312	0	17	0	OVER	OFF	74971	85922
337	07/17/96 4:56:05.05.0	2	7086	7087	7093	9	52.82	50.95	45.98	4.97	35.64	61.532	2.081	0	0	0	UNDER	OFF	29929	34487
338	07/17/96 4:56:50.58.5	2	7138	7141	7143	9	42.88	42.88	45.36	-2.49	42.88	55.413	0	0	17	0	OVER	OFF	59957	74249
339	07/17/96 4:57:00.91.9	2	7157	7159	7172	9	41.01	39.77	39.15	0.62	29.89	67.096	1.08	0	17	0	OVER	OFF	31486	36155
340	07/17/96 4:57:04.26.2	2	7162	7164	7177	9	44.12	41.01	33.56	7.46	0	55.413	2.845	0	17	0	OVER	OFF	71845	77404
341	07/17/96 4:57:58.58.5	2	0	7243	7260	9	0	42.88	36.04	6.84	42.88	61.532	0	0	0	0	UNDER	OFF	0	47461
342	07/17/96 4:58:33.46.4	2	7295	7299	7313	9	37.91	37.28	30.46	6.84	32.71	47.853	0.502	0	0	0	UNDER	OFF	74764	78936
343	07/17/96 4:59:49.42.4	2	7388	7392	7407	9	47.23	46.6	40.39	6.21	42.1	62.059	0.627	0	17	0	OVER	OFF	53442	59274
344																				
345		Average for 191 trucks			Sign "On" (Class 9 -11)			50.80		7.69	49.63									
346																				
347																				
348		Average for 146 trucks			Sign "Off" (Class 9 -11)			44.20		5.94	35.63									

1 mi/h = 1.61 km/h

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