EVALUATION OF MICROWAVE TRAFFIC DETECTOR

Final Report

Project 304-021

EVALUATION OF MICROWAVE TRAFFIC DETECTOR AT THE CHEMAWA ROAD/INTERSTATE 5 INTERCHANGE

Final Report

PROJECT 304-021

by

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16. Abstract

In 2001, the Oregon Department of Transportation installed a microwave traffic detection sensor, and compared it's performance to conventional inductive traffic loops. The objective of the study was to evaluate the capabilities of the microwave traffic detection sensor to function as a viable detection device in a signalized intersection. The sensor was to detect vehicles in advance of the intersection, providing "extension" and "call" functions for the signal controller.

The microwave detector provides a non-intrusive method of detection and the need to cut grooves is eliminated. The microwave can be installed and maintained from the shoulder area with lower impact on the motorist. Safety for highway workers is also improved.

The Remote Traffic Microwave Sensor was installed and traffic counts made over four weeks. The microwave sensor generally counted lower than the traffic loops. Potential errors for various traffic conditions for both the inductive loops and the microwave sensor were identified and analyzed. Although the counts differ, the microwave provide reasonable detection for the extension and call functions.

This study did not look at long term performance or cost benefits of the detector.

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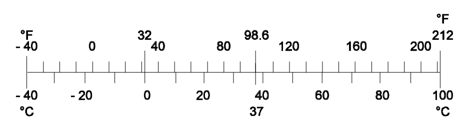
SI* (MODERN METRIC) CONVERSION FACTORS

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	millimeters	mm^2
ft^2	Square feet	0.093	meters squared	M^2
yd^2	Square yards	0.836	meters squared	M^2
Ac	Acres	0.405	Hectares	Ha
mi^2	Square miles	2.59	kilometers squared	Km^2
		VOLUME		
fl oz	Fluid ounces	29.57	Milliliters	ML
Gal	Gallons	3.785	Liters	L
ft^3	Cubic feet	0.028	meters cubed	m^3
yd^3	Cubic yards	0.765	meters cubed	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	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celsius temperature	°C

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	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
ha	Hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
mL	Milliliters	0.034	fluid ounces	fl oz
L	Liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	Grams	0.035	ounces	oz
kg	Kilograms	2.205	pounds	lb
Mg	Megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8C + 32	Fahrenheit	°F



* SI is the symbol for the International System of Measurement

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EVALUATION OF MICROWAVE TRAFFIC DETECTOR
AT CHEMAWA RD/I-5 INTERCHANGE

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1.0 INTRODUCTION

1.1 BACKGROUND

In January 2001, the Oregon Department of Transportation (ODOT) installed a microwave traffic detection sensor on Chemawa Road near Salem, where it crosses over Interstate 5 (I-5) at milepoint 260.2. The sensor monitors four travel lanes over a steel reinforced concrete bridge structure. The microwave system is non-intrusive to the road surface and bridge deck.

1.2 OBJECTIVES

The objective of this study was to evaluate the capabilities of a microwave traffic detection sensor to function as a viable detection device in a signalized intersection. To assess the accuracy of the device, traffic counts for the microwave were compared with counts made by inductive traffic loops. Traffic counts would provide an indicator of the microwave's ability to detect vehicles for traffic control purposes.

1.3 SENSOR INSTALLATION AND LAYOUT

The microwave sensor was mounted mid-span of the Chemawa Road structure and situated between two signalized intersections for the I-5 ramps. It detects vehicles about 105 m in advance of the northbound and southbound intersection STOP lines, and provides "Extension" and "Call" functions for the signal controller. The sensor monitors two westbound and two eastbound lanes of traffic.

The device was a Remote Traffic Microwave Sensor (RTMS) manufactured by Electronic Integrated Systems, Inc. It was mounted on a pole 6 m above the road, offset 6.1 m from the nearest travel lane and faced perpendicular to the travel lanes. Because of its position outside the travel lanes, it can be installed with less disruption on traffic movements. The RTMS operates as a side-fired passage detector.

Also located at the Chemawa intersection were conventional inductive loops cut into the pavement at 60 m (westbound) and 77 m (eastbound) from the microwave. The loops also provided Extension and Call functions for the signal controller. The loop counts were used in this study to compare with the microwave counts.

The microwave and loop layout is shown in Figure 1.1. Microwave and loop lane counters are indicated by numbers on the figure.

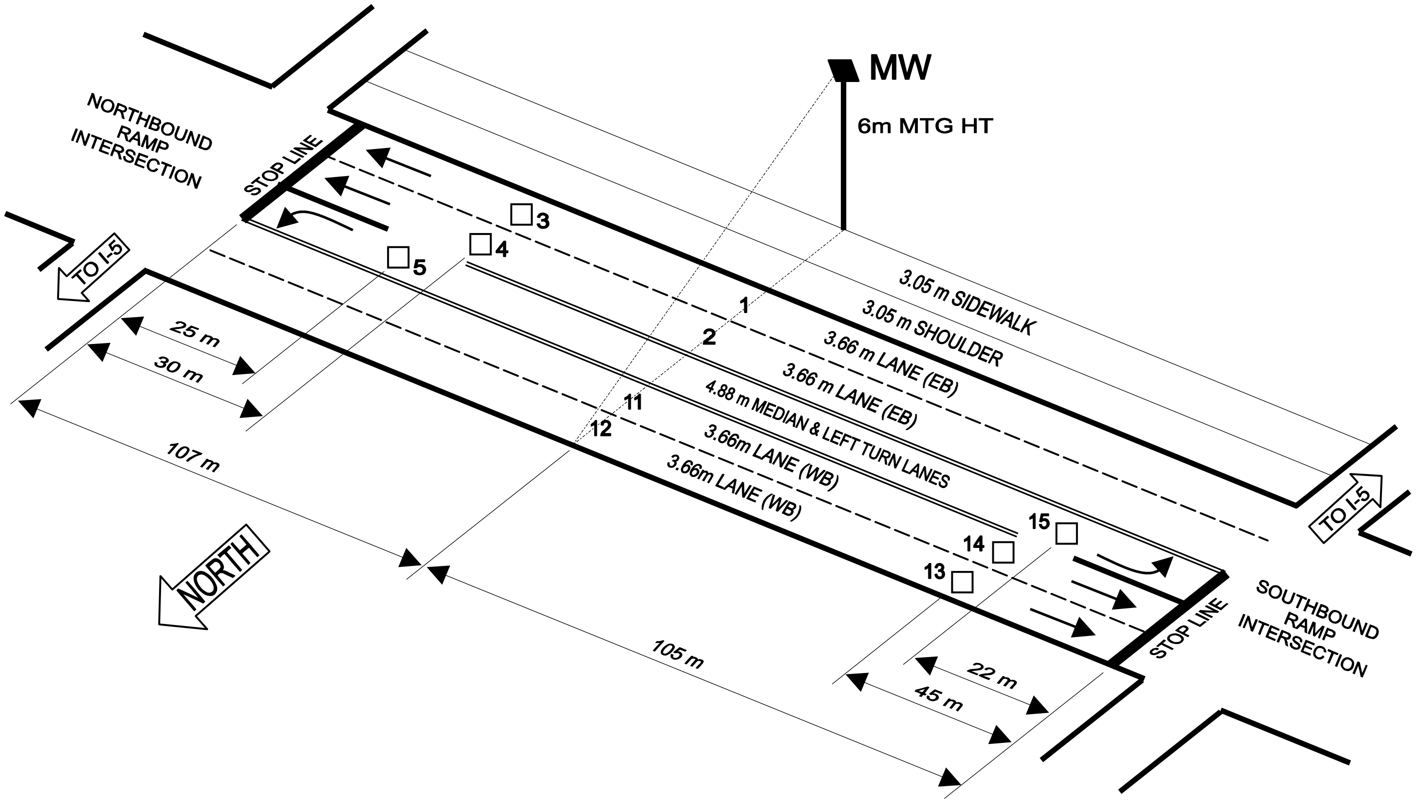

Figure 1.1 Layout of Microwave and Loop Sensors on Chemawa Road

1.4 GENERAL OPERATING PARAMETERS

According to the manufacturers literature, the RTMS can provide eight discrete user-defined detection zones up to 60 m away. The resolution (ability to distinguish between different objects) is about 2 m. Rain, snow, fog and other obstructions smaller than 10 mm should not hinder its detection capabilities. The preferred mounting height ranges from 5 to 10 m, which is controlled in part by the setback from travel lane. Lower mounting heights are recommended for shorter setbacks.

Microwaves can diffract around corners, allowing the RTMS to detect vehicles that are completely hidden by other vehicles with about a 60% success rate. Over-counts can occur in very low speed traffic conditions.

The RTMS can be mounted in a side-firing or forward-facing configuration and set for passage or presence detection modes.

2.0 DATA AND ANALYSIS

2.1 TRAFFIC COUNTS

Traffic counts from the loop and microwave sensors were downloaded from the traffic controller for analysis. The count was accumulated in 15-minute intervals from 6:00am to 8:00pm for four weeks (see appendix for dates).

Figure 2.1 shows the traffic count of all eastbound lanes (traffic headed towards the northbound ramp intersection). The left "bars" show the total count from traffic loops 3, 4 and 5 and compares it to the difference between loop counts and counts of microwave (MW) zones 1 and 2, shown in the right "bars". Ideally, the difference would be zero, but the graph indicates the microwave counts differ by a range of -28 to +10 vehicles from the loop counts. For the most part, the microwave counts were less than the loop counts.

Similarly, Figure 2.2 shows the traffic count of the westbound lanes (traffic headed towards the southbound ramp intersection). The left bars show the total count from loops 13, 14 & 15 and compares it with the differences between loop counts and the microwave counts for zones 11 and 12, shown in the right bars.

The results are quite different from the eastbound results, as the microwave counts are consistently higher than the loop counts. The difference can be explained by the wiring methods. Westbound loops numbered 13 and 14 are connected in series. This method undercounts the total vehicles since only one vehicle can be detected when two vehicles simultaneously occupy the loop zones. Visual observations by the principal investigator found frequent occurrences of vehicles passing over the adjacent loops simultaneously. The westbound loop counts were not used in the remainder of this study due to the unavoidable undercount.

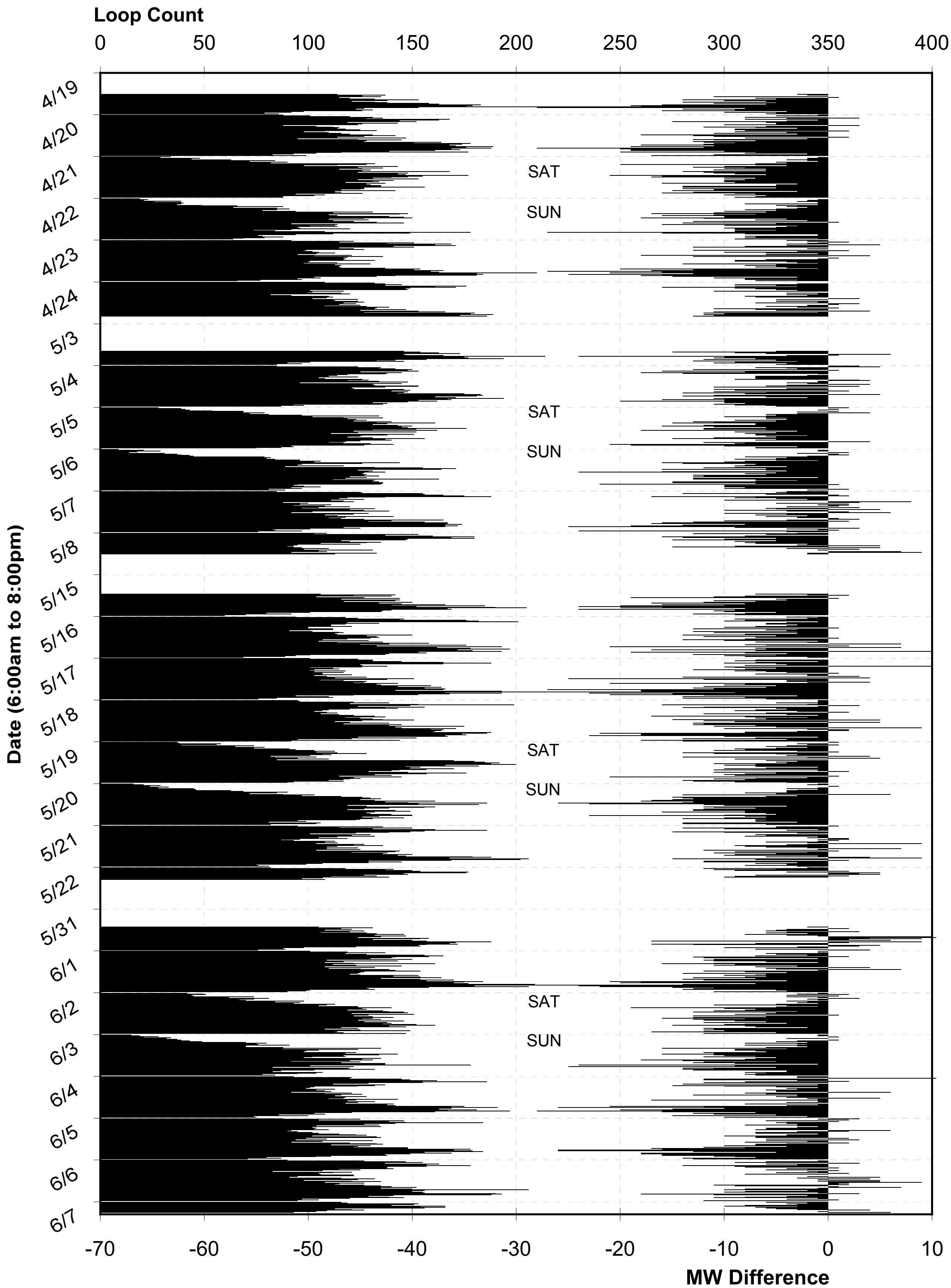

Figure 2.1: Eastbound Traffic Counts (NB Intersection) – Loops vs. Microwave

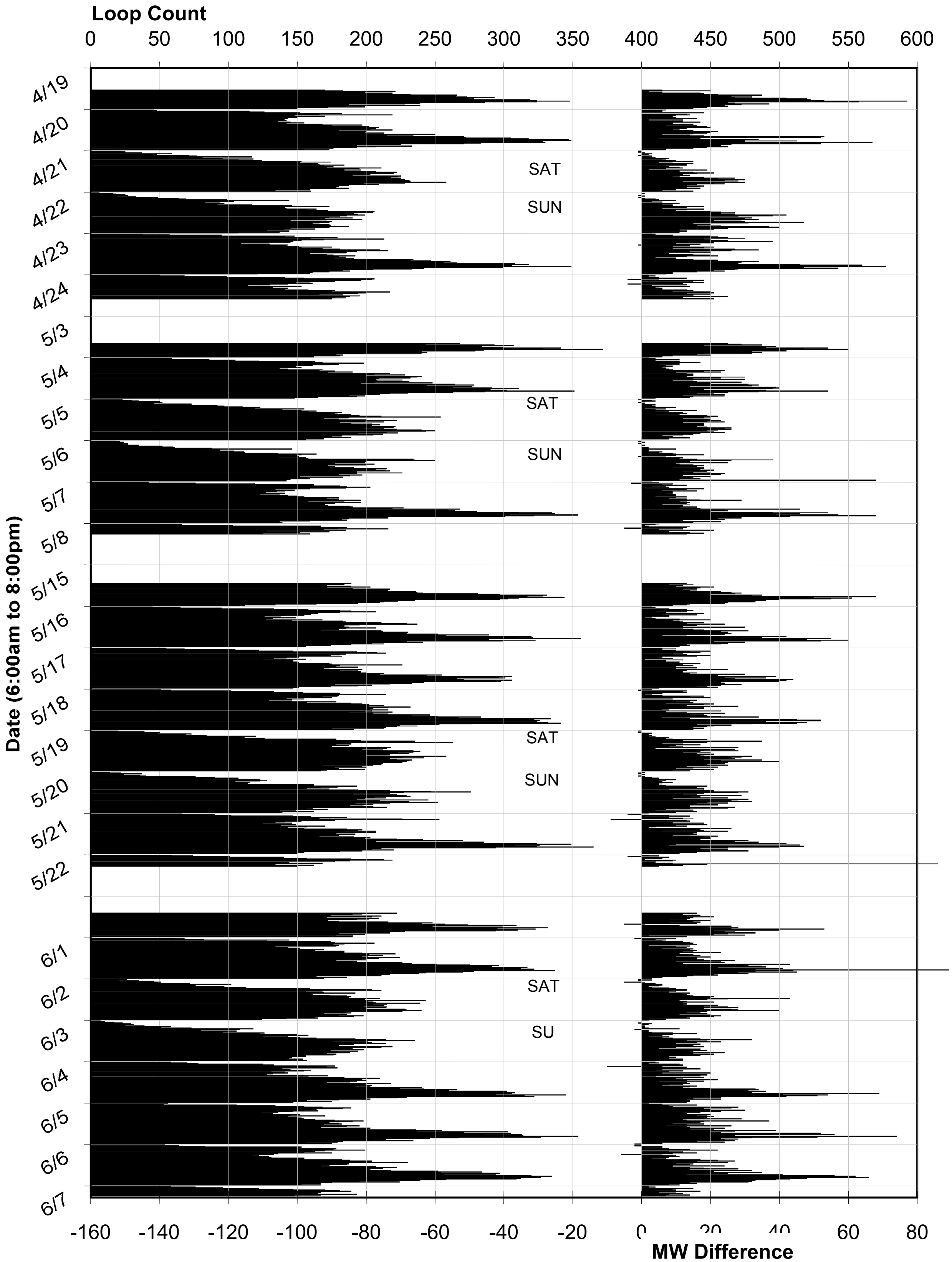

Figure 2.2: Westbound Traffic Counts (SB Intersection) – Loops (series connected) vs. Microwave

2.2 DESCRIPTIVE STATISTICS

The descriptive statistics and quarter intervals for the eastbound (EB) lanes are shown in Table 2.1. For a detailed explanation of the derivation of statistical values, see Appendix B.

Table 2.1: Descriptive Statistics for EB Traffic (NB Intersection)

	n	Mean	Median	Standard Deviation	s.e.	Min	Max	Q1	Q3	Tr. Mean
Loops	1336	124.05	125.00	33.95	0.93	9.00	215.00	105.00	145.00	125.12
MW	1336	117.31	199.00	31.83	0.87	9.00	203.00	99.00	137.00	118.35

The data shows that, on average, the loop count was higher by 7 vehicles (per 15-minute interval) than the microwave count (124 vs. 117). Confidence intervals and a two-sample t-test were run on the loops and microwave counts. The comparison shows the difference between the mean count for loops (124 counts per 15 minute interval) and microwave (117 counts) is statistically significant, where p=0.00. The percent difference between the means is 5.7%.

Table 2.2 provides the confidence intervals for the loops and microwave counts.

Table 2.2: Two Sample T-Test and Confidence Intervals for Loops and Microwave Counts

Variable	n	Mean ($\bar{X}$)	St. Dev (s)	Standard Error (se)	95% CI
Loops	1336	124.055	33.951	0.929	122.232, 125.877
MW	1336	117.314	31.832	0.871	115.605, 119.022

95% CI for $\mu_{LOOPS} - \mu_{MW}$: (4.24, 9.24)

t-Test: $\mu_{LOOPS} = \mu_{MW}$ (vs not =): $t = 5.29$ $p = 0.0000$ $df = 2658$

Of the 1336 records, the microwave count was lower than the loop count about 85% of the time (1131 of 1336). It was higher than the loop count 12% of the time (154 of 1336), and equal 4% of the time (51 of 1336).

Possible reasons for this inconsistency may be found in the way the loops and microwave detect vehicles. Loops detect ferrous metal objects passing over the loop area. When metal is no longer detected (e.g. there is at least a 1.7 m gap between ferrous metal objects), the loop amplifier resets and waits for the next vehicle (see Figure 2.3). On the other hand, the microwave detects objects within a horizontal beam pattern and is dependent on the detector's response time, hold time setting and distance from traffic lanes. These factors are probable causes for count discrepancies. Section 2.3 discusses some other potential discrepancies between loops and microwave.

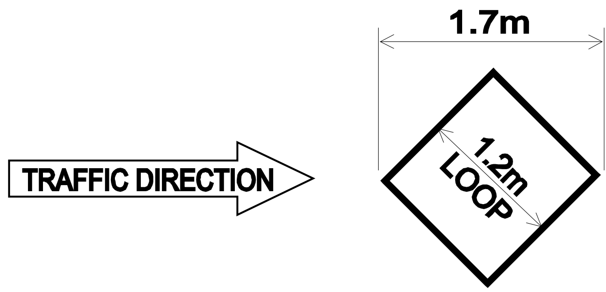

Figure 2.3: Inductive Loop Dimensions

From the data shown in Figure 2.1, it is apparent that the microwave typically counts lower than the loops. As noted earlier, however, the microwave counted higher 12% of the time. The graph indicates these higher counts occur more often on weekdays. The reason for the higher counts is unknown but may be explained by the increased traffic density and potential for more lane changes. During a lane change, a vehicle occupies a portion of two lanes and could potentially be counted as two different vehicles by the microwave. Another possibility may be that the loops undercount as vehicle spacing converges near the STOP line.

Figure 2.4 shows the same data but sorted by traffic count. Occurrences of the microwave counting higher than the loops appear random, meaning traffic density alone does not appear to cause the high counts. However, the figure does indicate the difference between the loops and microwave increases as the traffic density increases. This is expected if the loops and microwave are consistent in how each detects vehicles, that is, they are consistent in how they over or undercount. The higher the traffic density, the greater the difference between loop and microwave counts.

Figure 2.5 takes this comparison one step further by comparing the percent difference between the two types of counts. The figure suggests the difference between loop and microwave counts increase 2% for every 100 vehicles. This change in rate indicates the loop and/or microwave error rates increase as traffic density increases, although this is a weak argument, with an R-squared of only 0.0275.

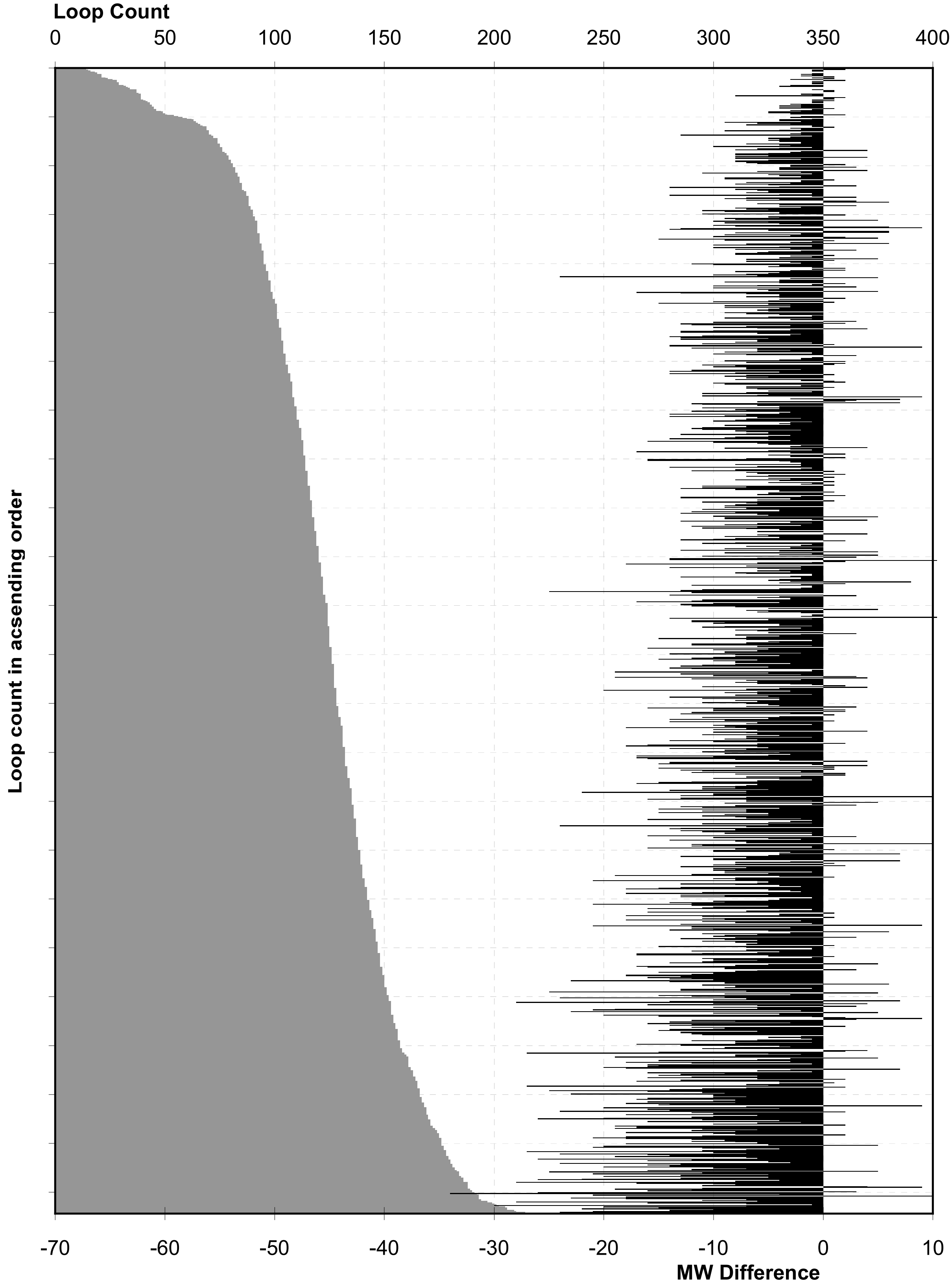

Figure 2.4: Eastbound Traffic Counts (NB Intersection) - Sorted by Loop Count

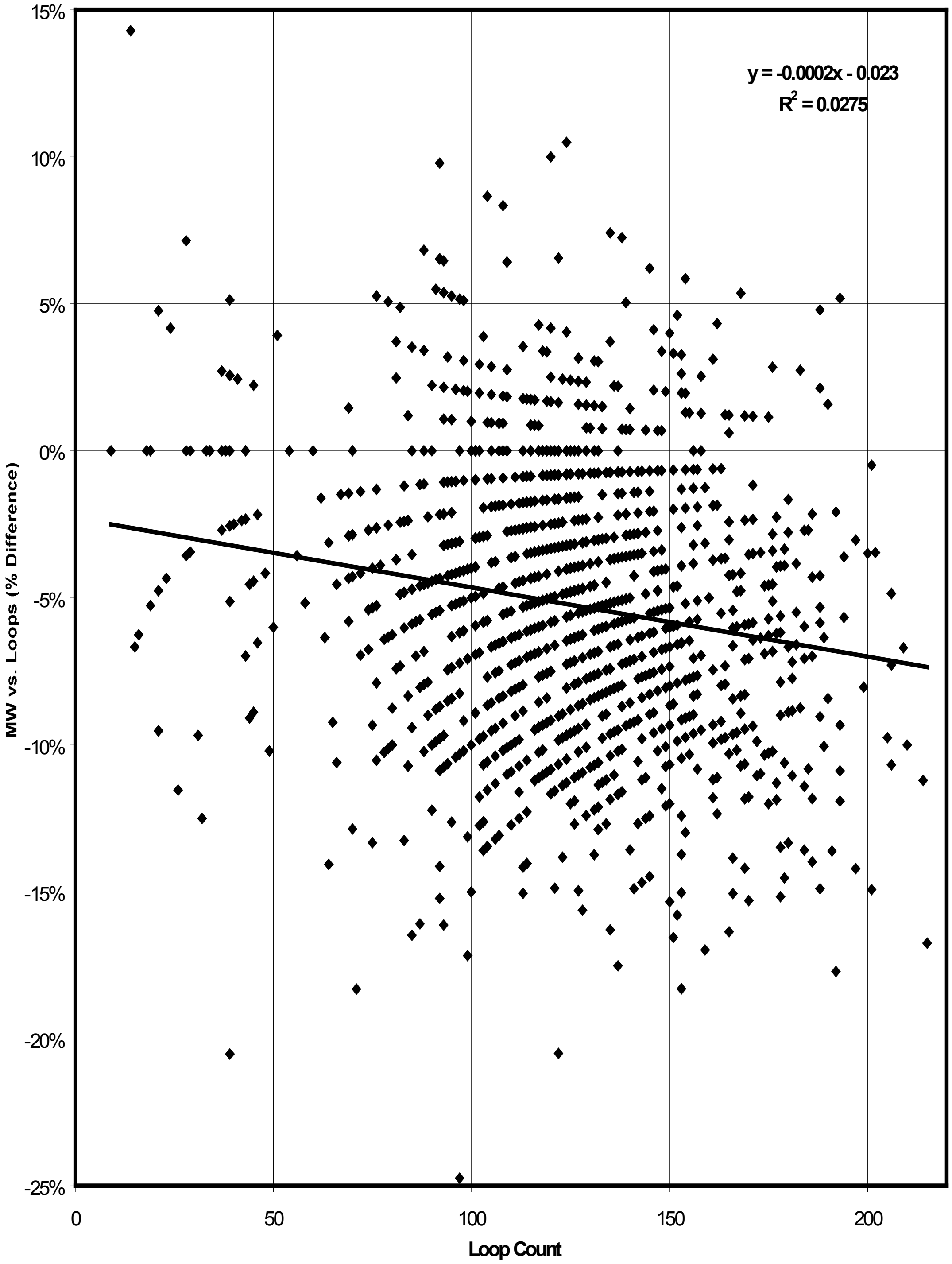

Figure 2.5: Eastbound Traffic Counts (NB Intersection) – Percent Difference

2.3 POTENTIAL ERROR COUNTS

Although not tested, some assumptions for potential over- and undercounting are shown in Table 2.3. Errors are not limited to those shown. Further, it is assumed that the devices are properly aimed and tuned.

Table 2.3: Potential Errors for Various Traffic Conditions

Traffic Condition or Vehicle Type	Probability of occurrence †	Inductive Loops	Microwave Sensor*
Trailer with short tongue, < 1.7m	<1%	Okay	Okay
Trailer with long tongue	1%	Over-count potential	Okay
Multi-axle trucks	10%	Over-count potential on high clearance truck bed	Okay
Small vehicle well hidden by larger vehicle in adjacent lane	1%	Okay	Undercount potential
Motorcycle	<1%	Okay	Undercount potential (at normal or low sensitivity setting)
Tailgating or bumper-to-bumper traffic	<1%	Undercount if spacing is <1.7m	Undercount if spacing is <2.1m
Slow moving traffic	<1%	Okay	Over-count potential (due to null effect)
Vehicle occupying a portion of two lanes (e.g. changing lanes)	5%	Undercount if vehicle passes between loops.	Over-count potential
Vehicle not in lane (e.g. vehicle using shoulder or median to make a right or left turn)	1%	Undercount	Undercount potential (depends on zone setup)

† Approximate probability traffic condition occurrs at the Chemawa Road intersection only.

* Microwave detection is dependent on the detector's response time and hold time setting. *Response time* is the time for an input, generated by a vehicle in the field of regard, to be processed by the detector and registered as an output in the form of a presence, count, or other appropriate indication. A response time is also defined for the time required by the detector to drop an output when the vehicle leaves the field of regard. Response time of current models is <0.3 seconds. *Hold times* are designed to eliminate dropout of vehicle detection as may occur when towing vehicles with long tongue couplings. *(Klein and Kelly 1996)*

In general, the above table indicates that loops are more likely to produce higher counts than the microwave.

Another explanation of the differences in counts is the distance between the microwave and loop sensors. There is potential for vehicles to be located between the microwave and loop sensors as a new 15-minute time interval begins. The distance between the microwave and loop is 77 m. A close group of vehicles traveling 19 m apart could result in a difference of 8 vehicles, although this would be an infrequent occurrence.

2.4 FIELD COUNTS

Visual observations were made on June 7, 2001 to compare actual vehicle counts with the sensor detection counts. The visual count was lower than the loop and microwave counts by 3 to 5%. In a non-typical case, the microwave produced counts similar to the loops, rather than being 5.7% lower as found earlier in this report. This period of time was also during commute traffic in which traffic density was higher and lane changing was common.

Table 2.4: Comparison of Visual, Loop and Microwave Traffic Counts

Source	Eastbound lanes	Westbound lanes
Visual	328	692
Loops	340 (+4%)	*na*
Microwave	343 (+5%)	714 (+3%)

The number in parenthesis is the percent difference from the visual count.
See the appendix for more detailed data.

2.5 IMPACT ON SIGNAL TIMING PHASE

Although the number of vehicles detected by the loops and microwave differ, it appears the microwave provides reasonable detection for the extension and call functions to properly operate. In most cases, miscounting the number of vehicles in an extension function should have little impact on the signal phase timing. This includes counting a vehicle with trailer as two vehicles or counting two vehicles as one.

A worst case situation would be failure to detect an approaching vehicle in “green” phase and not allowing it to proceed through the intersection, especially when no other vehicles are waiting in the opposing lanes. This situation could result in the vehicle running a red light, either intentionally or unintentionally. Although an alert and prudent driver should have sufficient time to stop safely.

A possible case of a failed detection as discussed above is a situation where a large vehicle traveling in the east bound lane (closer to microwave) blocks from view a small vehicle traveling west. If the small vehicle is the only west bound vehicle, the traffic controller may not extend the “green” phase for the vehicle.

3.0 CONCLUSIONS AND RECOMMENDATIONS

3.1 CONCLUSIONS

There is a statistically significant difference in how the loops and microwave detectors count vehicles. The data showed that the microwave undercounted the loops by an average of 5.7%. The reason for the difference is unknown, but the conditions shown in Table 2. could be probable causes.

Although there is a difference in counts, it is not believed to be significant enough to affect the proper operation of the signal controller. As such, the microwave appears to be suitable for this type of installation – serving an extension function for the signal controller.

A benefit of the microwave is the non-intrusive method of detection. This is desirable for use on reinforced-concrete structures, eliminating the need to cut grooves near the reinforcing steel. With the microwave located away from the travel lanes, it can be installed and maintained with little impact on the motorist. The location is also safer for the highway workers.

It should be noted that this study did not look at the long-term performance or cost benefits of the microwave detector. The cost-benefit would vary by site if one considers the value on traffic disruption to install or repair, or the value of reduced stress on a pavement or structure.

4.0 REFERENCES

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APPENDIX A

TRAFFIC COUNT DATA

TRAFFIC COUNT DATA

Table A.1 lists the dates and times of the vehicle count data used in this study. Table A.2 compares traffic counts for visual, loop and microwave systems for June 7, 2001.

Table A.1: Traffic Data Download List

Travel Lanes	Date	Time	Time interval	Number of records
Eastbound (NB Int.)	4/19/01 (Thurs)	1:30pm to 8:00pm	15 minutes	27
	4/20/01 to 4/23/01	6:00am to 8:00pm	15 minutes	56/day
	4/24/01 (Tues)	6:00am to 5:45pm	15 minutes	47
	5/3/01 (Thurs)	3:15pm to 8:00pm	15 minutes	19
	5/4/01 to 5/7/01	6:00am to 8:00pm	15 minutes	56/day
	5/8/01 (Tues)	6:00am to 1:15pm	15 minutes	29
	5/15/01 (Tues)	12:30pm to 8:00pm	15 minutes	30
	5/16/01 to 5/21/01	6:00am to 8:00pm	15 minutes	56/day
	5/22/01 (Tues)	6:00am to 10:15pm	15 minutes	17
	5/31/01 (Thurs)	Noon to 8:00pm	15 minutes	32
	6/1/01 to 6/6/01	6:00am to 8:00pm	15 minutes	56/day
	6/7/01 (Thurs)	6:00am to 9:45pm	15 minutes	15
Westbound (SB Int.)	4/19/01 (Thurs)	1:30pm to 8:00pm	15 minutes	26
	4/20/01 to 4/23/01	6:00am to 8:00pm	15 minutes	56/day
	4/24/01 (Tues)	6:00am to 2:15pm	15 minutes	33
	5/3/01 (Thurs)	3:15pm to 8:00pm	15 minutes	19
	5/4/01 to 5/7/01	6:00am to 8:00pm	15 minutes	56/day
	5/8/01 (Tues)	6:00am to 9:45am	15 minutes	15

Table A.2: Comparison of Visual, Loop and Microwave Traffic Counts for June 7, 2001

Eastbound travel lanes (NB intersection) – at Loops

Travel Lane	Count Method	Vehicle counts per 15 min. Time interval				**Total**
		8:30-8:45	8:45- 9:00	9:00-9:15	9:15- 9:30	
Right	Visual	*na*	32	21	22	**75**
Left		*na*	56	51	48	**155**
Left turn		*na*	36	35	27	**98**
Total		***na***	**124**	**107**	**97**	**328**
Right	Loop 3	*34*	33	24	27	**84**
Left	Loop 4	*56*	57	51	48	**156**
Left turn	Loop 5	*31*	37	34	29	**100**
Total *	Loops 3, 4, 5	***121***	**127** (+2%)	**109** (+2%)	**104** (+7%)	**340** (+4%)
Right	MW 1	*37*	45	31	29	**105**
Left	MW 2	*81*	86	78	74	**238**
Total *	MW 1 & 2	***118***	**131** (+6%)	**109** (+2%)	**103** (+6%)	**343** (+5%)

Westbound travel lanes (SB intersection) – at MW

Right	Visual	56	69	74	62	**261**
Left		118	120	103	90	**431**
Total		**174**	**189**	**177**	**152**	**692**
Right	MW 12	62	75	78	63	**278**
Left	MW 11	115	126	103	92	**436**
Total *	MW 11 & 12	**177** (+2%)	**201** (+6%)	**181** (+2%)	**155** (+2%)	**714** (+3%)

* number in parenthesis is percent difference from visual count

Note: the interval for the visual count might have been slightly different than the controllers' system clock due to human error synchronizing watches.

APPENDIX B

DESCRIPTIVE STATISTICS

DESCRIPTIVE STATISTICS

The descriptive statistics and quarter intervals for the eastbound (EB) lanes are shown below.

Table B.1: Descriptive Statistics for EB Traffic (NB Intersection)

	n	Mean	Median	Standard Deviation	s.e.	Min	Max	Q1	Q3	Tr. Mean
Loops	1336	124.05	125.00	33.95	0.93	9.00	215.00	105.00	145.00	125.12
MW	1336	117.31	199.00	31.83	0.87	9.00	203.00	99.00	137.00	118.35

n = Sample size.
Mean ($\bar{X}$) which is the sample mean.
Median = The middle value in the distribution
Standard Deviation (s) = A measure of the standard distance from the sample mean. It is a measure of dispersion around the sample mean. Large standard deviations indicate the distribution is widely dispersed.
s.e. = Standard error of the mean. The standard error is the standard deviation of the distribution of possible sample means. The standard error measures the standard amount of difference one should expect between the sample mean ($\bar{X}$), and the population mean (μ). It is calculated using the formula:

$$\text{s.e.} = s/\sqrt{n} \qquad \textbf{\textit{Eq. B.1}}$$

Standard error provides a measure of how well a sample mean approximates the population mean (*Gravetter and Wallnau 1999*). If the standard error is small, this is an indication the sample mean more closely approximates the population mean.
Min = The minimum value in the distribution.
Max = The maximum value in the distribution.
Q1 = The value below which one quarter of the distribution of values lie.
Q3 = The value below which three quarters of the distribution of values lie.
TR. Mean = The mean when only considering the range of values between Q1 and Q3.

The data shows that, on average, the loop count was higher by 7 vehicles (per 15-minute interval) than the microwave count (124 vs. 117). Confidence intervals and a two-sample t-test were run on the loops and microwave counts.

A two sample t-test uses the data from two separate samples (loop count and microwave count) to test a hypothesis about the difference between two population means. In statistical analysis, the null hypothesis is always tested. In a two sample t-test, the null hypothesis (H_0) is that:

$$\mu_{MW} - \mu_{LOOPS} = 0. \qquad \textbf{\textit{Eq. B.2}}$$

Another way of stating the null hypothesis is that the two population means are equal.

Since the population means are unknown, the *t-test* uses the sample means and standard errors to test the null hypothesis. The formula is:

$$t = \frac{(\bar{X}_{MW} - \bar{X}_{LOOPS}) - (\mu_{MW} - \mu_{LOOPS})}{\sqrt{se_{MW} + se_{LOOPS}}} \qquad \textbf{\textit{Eq. B.3}}$$

In using equation 2.3, it is assumed that the null hypothesis is true and thus, the difference in the two population means is 0. The other terms in the equation are:

$\bar{X}_{MW}$ = Sample mean for the microwave counts.
$\bar{X}_{LOOPS}$ = Sample mean for the loop counts.
se_{MW} = Sample standard error for microwave counts
se_{LOOPS}= Sample standard error for loop counts

The *t* statistic calculated using Equation 2.3 is 5.29.

To test for statistical significance, the critical *t* value is determined from statistical tables using an assumed significance level (α) and degrees of freedom. Degrees of freedom are calculated by adding the sample size for the microwave counts (minus one), and the sample size for loops (minus one). The degrees of freedom are:

$$(1336 – 1) + (1336 – 1) = 2{,}670$$

The assumed significance level (α) represents the probability of error that is accepted in making an inference about rejecting a true null hypothesis. A value of 0.05 is typically used in scientific research.

The critical *t* value is 1.96 at a 0.05 level of significance. Since the calculated value of *t* is greater than the critical t value, it can be inferred (with a 0.05 probability of error) that the two sample means are not from the same population. Therefore, the null hypothesis is rejected, and there are statistical differences between the mean count for loops (124 counts) and microwave (117 counts). The percent difference between the means is 5.7%.

In Table 2.2, the 95% confidence intervals (CI) are placed around the sample means. The 95% confidence interval is the interval in which there is a 95% probability that the true population mean μ, lies inside it. In other words:

$$\mu = \bar{X} \text{ +/- some error.}$$

The confidence interval is calculated by placing error limits around the sample mean, $\bar{X}$. Generally, it is assumed that the sample mean is located somewhere in the center of the distribution of all possible sample means, which is a normal distribution. The limits for a 95% confidence interval are within 95% of the normal distribution curve of all possible sample means. The 95% confidence interval is calculated by placing limits around the sample mean. The confidence limits are determined using the following formula:

$$\bar{X} \text{ +/- } k\frac{(s)}{\sqrt{n}} \qquad \textbf{\textit{Eq. B.4}}$$

where:

$\bar{X}$ = sample mean.
k = k is a value determined from normal distribution tables.
For 95% confidence limits, $k = 1.96$.
s = standard deviation for sample
n = sample size

Using the sample mean for the loops as an example, the confidence limits around the mean are:

$$124.055 \text{ +/- } 1.96\frac{(33.951)}{\sqrt{1{,}336}} = 122.232,\ 125.877$$

Table 2.2 below provides the confidence intervals for the loops and microwave counts.

Table B.2: 95% Confidence Intervals for Loops and Microwave Counts

Variable	n	Mean ($\bar{X}$)	St. Dev (s)	Standard Error (se)	95% CI
LOOPS	1336	124.055	33.951	0.929	122.232, 125.877
MW	1336	117.314	31.832	0.871	115.605, 119.022

The confidence limits for the loops do not overlap with the microwave confidence limits. Therefore, with a 95% degree of confidence, one can say that the population means for the microwave and the loops are different.

The difference in means = $\bar{X}_{LOOPS}$ - $\bar{X}_{MW}$: 124.055 – 117.314 = 6.741

95% Confidence Interval for Difference in Means:
= 6.741 +/- (4.24, 9.24)

t-Test $\mu_{LOOPS} = \mu_{MW}$ (vs not =): $t = 5.29$ $p = 0.0000$ $df = 2658$

Of the 1336 records, the microwave count was lower than the loop count about 85% of the time (1131 of 1336), higher 12% (154 of 1336) and equal 4% (51 of 1336).