Improving the Quality of Motorcycle Travel Data Collection

DETAILS

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 760

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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FOREWORD

By Christopher Hedges
Staff Officer
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This report presents an analysis of traffic counting technologies and data collection protocols to improve the reliability of motorcycle travel data. The technologies included infrared classifiers, inductive loops/piezoelectric sensors, magnetometers, multi-sensor technologies, and tracking video. The report describes the performance of each technology in terms of accuracy, initial cost, portability, and ease of setup and operation. The report also evaluates and validates a hypothesis that motorcycle crash locations are reasonable predictors of traffic volume. A correlation between crash sites and volume enables a Department of Transportation to select traffic counting locations that will yield more accurate data on motorcycle traffic volumes.

The report will provide valuable guidance to traffic engineers, transportation planners, and safety professionals who need more accurate data to determine motorcycle exposure risk based on vehicle-miles traveled (VMT).

Motorcycle fatalities and the related fatality rates have been significantly increasing over the last 10 years based on total registrations as a proxy for volumes and usage/exposure. Motorcycle fatalities have become a serious safety issue for the National Highway Transportation Safety Administration (NHTSA) and the Federal Highway Administration (FHWA). According to FHWA data between 1996 and 2005, motorcyclist fatalities increased more than 110 percent and currently account for more than 10 percent of all motor vehicle traffic crash fatalities. The best measure of exposure risk for motor vehicle crashes is based on actual vehicle volumes and VMT. Therefore it is critical that timely, complete, and accurate volume and VMT data be collected and reported. Furthermore, beginning in 2008, the reporting of motorcycle travel to the federal Highway Performance Monitoring System (HPMS) is now required for all states.

To date, research has indicated that there are significant problems with methodologies currently used to detect motorcycles. Most current detection systems primarily focus on the collection and classification of trucks and automobiles. These systems frequently misclassify motorcycles or miss them altogether, making the data unacceptable for required reporting purposes. There is a need for improved methods that could be used by transportation agencies at all levels to assist them in determining the policies and decisions necessary to improve safety and mobility.

Under NCHRP Project 08-81, a research team led by the Texas A&M Transportation Institute (TTI) field tested five traffic counting technologies to determine their accuracy in motorcycle detection. Researchers conducted field tests of various traffic counting technologies on a controlled test track and at two motorcycle rallies in Texas and Florida. The report outlines the pros and cons of each technology and recommends a protocol to optimize the accuracy of the counts by selecting sites on routes most likely to be used by motorcycles.

CONTENTS

Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains the color versions.

SUMMARY

Improving the Quality of Motorcycle Travel Data Collection

Introduction

Between 2000 and 2008, motorcyclist fatalities increased by 83 percent, but FHWA data indicates that motorcycle vehicle-miles traveled (VMT) did not grow nearly as much during that period, increasing only by 38 percent (*4*). Accurate and reliable motorcycle travel data are necessary to examine highway safety trends over the course of several years and for the nation as a whole.

Most commercially available traffic monitoring systems have difficulty detecting and classifying motorcycles accurately because motorcycles have unique features such as their small size, narrow width, low metal mass, and single wheel track.

Better detection of motorcycles is only part of the solution. The other part has to do with the spatial distribution of vehicle classification sites to accurately represent the distribution of vehicles by class, especially motorcycles. To obtain a representative count of motorcycles, state traffic monitoring programs need to know the locations and times most appropriate for counting motorcycles. Consideration of weekend rural counts also is needed to improve estimates of motorcycle average annual daily traffic (AADT) and VMT.

Data Collection Protocols

For NCHRP Project 08-81, the research team's examination of existing data collection protocols found that none of the protocols in current use could serve as a model for all states. The team's alternate methodology was to investigate crash data to determine whether motorcycle crash locations are distributed geographically in a pattern that reflects the geographic distribution of traffic volume. Researchers approached this analysis based on an initial mapping of crash and traffic volume data for four states that recorded precise locations of crashes (Michigan, Montana, Texas, and Wisconsin). The goal of this analysis was to determine to what extent a state might be able to rely on the spatial distribution of motorcycle crashes when attempting to determine where best to count motorcycle traffic.

Field Data Collection and Analysis

The field data analysis initially used two methods of calculating the accuracy of each detection system. The first method, called "simple detection accuracy," compares total correct detections of motorcycles by each test system to total correct detections. The second method, called "overall detection accuracy," combines correct detections and correct rejections in the numerator, divided by the total of all responses in the denominator. Although appropriate for many applications of signal detection, the overall detection accuracy method resulted in accuracy values so close to unity in almost all cases that it did not facilitate comparisons and was not deemed appropriate for further use in this study.

Simple detection accuracy is defined as follows:

$$\text{Simple detection accuracy:} \frac{\text{Classification Count by Test System}}{\text{Classification Count by Ground Truth}}$$

Testing occurred for each of five selected detector technologies using representative products. Within each technology group, products other than those tested could yield different results. Much of the testing occurred at the TTI test facility on State Highway 6 (SH 6) in College Station, Texas. Additional data was collected at two motorcycle rallies—one at New Ulm, Texas, in May 2012, and the other at Daytona Beach, Florida, in October 2012 (*see* Table S-1).

Table S-2 presents the findings of the field studies in terms of simple detection accuracy, initial cost, portability, and ease of setup. These findings cover both motorcycles and other vehicles for technologies designed to detect all vehicles. These accuracy values represent optimum conditions, so the technologies would not always perform this well. The multiple technology system is designed specifically to detect only motorcycles. The full lane-width inductive loops/piezoelectric sensors system appeared to exhibit problems with regard to detecting motorcycle and other light vehicles during testing, which suggests that results could improve as problems are resolved. Magnetometer accuracy values assume that motorcycles pass very close to the sensors.

For non-motorcycle detection, results from four detectors are in the acceptable range. The only technologies in the group likely to be affected significantly by inclement weather such as rain and fog are the tracking video system and the multi-technology system, although the research team did not encounter these conditions. In northern climates with the potential for snow or ice accumulation, the IR Classifier's performance would likely be affected as long as the accumulation remains.

The cost and portability of each system should be considered together because a highly portable system can serve several sites instead of only one. A good example is the IR Classifier, which has an initial cost for four lanes that is almost twice the cost of magnetometers, the multi-technology detector, or the tracking video. The discrepancy is even greater for two-lane sites, but the IR Classifier's portability is high. The multi-technology system is the least expensive and is portable, but its accuracy is not sufficient for it to be a viable con-

Table S-1. Test locations and products used for this research.

Technology	Product Selected	SH 6	Texas Rally	Florida Rally
Infrared (IR) Classifier	Transportable Infrared Traffic Logger (TIRTL)	No	Yes	Yes
Inductive loops/piezoelectric sensors (full lane-width)	IRD TRS Rack II classifier,[a] MSI BL piezoelectric sensor [b]	Yes	No	No
Magnetometer	Sensys Networks	Yes	No	No
Multi-technology system	Migma System	Yes	Yes	No
Tracking video system	TrafficVision™	Yes	Yes	No

[a] IRD: International Road Dynamics; [b] MSI: Measurement Specialties, Inc., BL: Brass Linguini®

Table S-2. Overall technology comparison.

Technology	MC Accuracy	Non-MC Accuracy	Initial Cost		Portability	Skill Level for Setup [a]
			Two-lane	Four-lane		
Infrared (IR) Classifier	95%	98%	$26,850	$26,850	Fixed/Portable [b]	Expert
Inductive loops/piezoelectric sensors (full lane-width)	45%	95%	$33,000[c]	$61,000	Fixed	Field tech.
Magnetometers	80%	95%	$10,204	$15,964	Fixed [d]	Field tech.
Multi-technology system	50%	N/A	$6,000	$12,000	Fixed [d]	Field tech.
Tracking video system	75%	90%	$15,000	$15,000	Fixed [d]	Field tech.

[a] Setup skill level required: expert versus field technician with proper training.
[b] TIRTL is available as either portable or fixed, but only portable TIRTL was tested in this research.
[c] Estimated by Texas Department of Transportation: $61,000 total for four-lane site and $33,000 total for two-lane site.
[d] Some components could be portable, or detector could be portable with modification.

tender at this time. The video system could become portable by using a trailer-mounted camera and power supply. The video system also could use fixed cameras that are used for other purposes provided their pan/tilt/zoom capability is available during the data collection period. Certain components of the magnetometers are portable, but the sensor nodes in the pavement are fixed.

Recommendations

Data Collection Protocols

Evidence indicates that the spatial distribution of motorcycle crashes is associated with the spatial distribution of traffic (and vice versa) to the point that a state could be confident in using crash locations as an indicator of where it should invest first in improved motorcycle count setups. As a logical extension, the methodology can work equally well for weekends and weekdays; that is, the locations of weekend motorcycle crashes can be used to determine where to conduct weekend counts, just as the location of weekday crashes can be used to determine where to conduct weekday counts. The authors believe this is a viable method of checking existing classification count locations and determining the need for additional sites for detecting motorcycles, but this belief should be verified with data from additional states.

Technology Selection

Recommendations pertaining to the five detectors address each technology individually rather than ranking them against each other. Direct comparison would not be appropriate for the following reasons:

- This research did not test all the technologies simultaneously under the same conditions.
- Different technologies have their own inherent strengths and weaknesses.
- Environmental conditions affect some technologies more than others.

IR Classifier. The setup of the portable system appears to require an expert and site selection is critical to a proper setup, but this technology's accuracy for all vehicle types and ability to classify all of the FHWA Scheme F classes are strong positive attributes. The portable IR Classifier can provide lower cost per lane compared to other alternatives.

Inductive Loops/Piezoelectric Sensors. Many states are already using inductive loops and piezoelectric sensors, but the low detection rate for motorcycles plus other negative factors associated with these legacy systems should encourage states to replace them with non-intrusive detectors that are more accurate. At the very least, states will need to replace existing 6 ft piezos with full lane-width piezos for detection of motorcycles.

Magnetometers. The data collected in this research indicates that covering the full lane-width in a way to avoid gaps in coverage will require at least two (and perhaps three) magnetometers at each station in a 2-2 or 3-3 configuration, separated longitudinally by at least 12 ft. Magnetometers appear to overestimate the length of motorcycles, so future research needs to verify length estimates. This research did not investigate detector sensitivity settings and their impact on Class 1 detections or length estimates.

Multi-Technology Sensor. This sensor is already undergoing improvement through Small Business Innovation Research (SBIR) funding and will be evaluated again with rigorous field testing following modifications. Changes known to be underway include an improved user interface and the ability to detect non-motorcycles. The user community should wait until these new features are incorporated and full testing shows it to be a reliable sensor.

Tracking Video. Planned improvements by the manufacturer that are already underway suggest that the tracking video system has the potential to perform better than indicated by this research. It is suggested that future testing of this technology include a variety of environmental conditions using both IR and traditional cameras.

CHAPTER 1

Background

Motorcyclist fatalities declined in 2009 for the first time in 11 years. Data from the NHTSA's Fatality Analysis Reporting System (FARS) show that motorcyclist deaths decreased by 16 percent, from a record high of 5,312 in 2008 to 4,452 in 2009 (*1*). Some states attributed the decline to fewer beginning motorcyclists, expanded motorcycle safety efforts, and fewer miles traveled due to bad weather and the economic downturn (*2*).The decline did not continue, however, and the 2010 and 2011 data both indicate increases in fatalities, to 4,518 in 2010 and to 4,612 in 2011 (*3*).

Meanwhile, according to FHWA, the primary indicator of motorcycle travel—VMT—did not grow nearly as much during that period, increasing by 38 percent from 10.5 million miles in 2000 to 14.5 million miles in 2008 (*4*). Even though these trends illustrate how disproportionate fatality data are in comparison to reported increases in VMT, studies based on the numbers of fatalities alone (in lieu of crash *rates*) have little meaning within the context of highway safety trends. Based on the concept of exposure, fatality crash rates are better measures of long-term motorcycle safety trends. The fatality rate measures the risk of a person dying in a crash based on the number of miles traveled, usually expressed per 100 million VMT.

Accurate and reliable motorcycle travel data are necessary to examine highway safety trends over the course of several years and for the nation as a whole (*4*). These data are important because, in addition to being used to calculate fatality, crash, and injury rates, they are used to evaluate funding at the federal, state, and local levels, forecast tax revenue, estimate roadway capacity and condition, assess safety countermeasures, and develop policies and legislation (*5*).

FHWA publishes state-level motorcycle VMT data, which states submit as part of the Highway Performance Monitoring System (HPMS). Before 2007, it was optional for states to report motorcycle VMT data. If states elected to report motorcycle VMT data, they often calculated the measure as a standard proportion of total VMT rather than collecting those data directly through surveys or roadside counters. In turn, FHWA would estimate motorcycle VMT data for states that did not report based on data from states that did report the motorcycle VMT data. Thus, motorcycle travel trends based on these data were highly speculative.

Beginning in 2008 with data for the preceding year, the reporting of state-level motorcycle travel data became mandatory. Since that time, FHWA has worked proactively with states to enhance their vehicle classification and motorcycle travel capturing capabilities in the following ways:

- Hosted the Motorcycle Travel Symposium (2007) (*6*)
- Updated the *Traffic Monitoring Guide* (TMG) providing guidance on how to collect travel data for motorcycles (2008) (*7*)
- Hosted a motorcycle highway travel monitoring and operations demonstration (2008) to showcase technologies for motorcycle detection (*8*)

FHWA continues to support ongoing research on technologies demonstrating the potential to improve motorcycle count data and for estimating accurate motorcycle VMT (*8*).

Most commercially available traffic monitoring systems have difficulty detecting and classifying motorcycles accurately because motorcycles have unique features, such as their small size and narrow width, low metal mass, and single wheel track (*9*). Some traffic detection and monitoring systems may detect motorcycles but incorrectly classify them as another type of vehicle. Moreover, detectors have difficulties accurately counting motorcycles that travel side-by-side, in large groups, or in staggered formations, and distinguishing larger motorcycles from subcompact passenger vehicles. Because existing systems often undercount motorcycles, estimates of motorcycle VMT based on data from these systems result in overestimates of motorcycle crash, injury, and fatality rates (*10*).

Better detection of motorcycles is only part of the solution. State traffic monitoring programs typically focus on weekday peak travel periods, which fail to fully account for weekend travel of motorcycles. The locations and times most appropriate for counting motorcycles are probably not the same as those for other vehicle types. Many states that have used the same methodologies for motorcycles as for other vehicles might need to implement weekend rural counts and develop adjustment factors to improve their estimated motorcycle AADT and VMT. Moreover, 2008 survey results from Nationwide Insurance suggest that ridership demographics have changed in recent years as rising gas prices have encouraged increased use of motorcycles for commuting (*11*). In addition, routes used by commuting motorcyclists may not correspond to those used by other commuter traffic (*12*).

CHAPTER 2

Research Approach

Literature Review

This research included a comprehensive literature search covering a 5 year period (2007–2011) and an Internet search to retrieve empirical articles, publications, data, ongoing research, and other information sources. Review of these sources was helpful in determining existing and promising vehicle detector systems for accurately detecting motorcycles and generating VMT-related data. The review identified methodologies for estimating motorcycle VMT when motorcycle count data are unavailable. A keyword search used various combinations of words, such as *motorcycle detection, motorcycles, counting traffic volume, detectors, data collection, FHWA classification, Highway Performance Monitoring System (HPMS), inductive loop detectors, infrared, moped, non-intrusive detectors, piezoelectric, radar, sensors, spatial, temporal traffic patterns, traffic count, vehicle detection, vehicle-miles traveled, video*, and *video image processor.*

The keyword search yielded more than 90 records, which were examined in conjunction with resources held by TTI researchers from previous studies conducted on traffic detection and monitoring systems, motorcycle detection, and motorcycle safety. Of the records retrieved, some were duplicates and others were judged to be less applicable after initial review. Beyond keywords, some of the criteria used for selecting existing and potential detector technologies for further evaluation were:

- Technologies known or found to be reliable and reasonably accurate
- Technologies with detection potential for motorcycles along with other vehicles
- Emphasis on modifications to existing systems for improved motorcycle detection while not reducing detection accuracy of other vehicles
- Emphasis on non-intrusive detectors, as long as they detect all vehicle types

Agency Engagement

The research team conducted a survey of 10 state departments of transportation (DOTs) and asked questions about the technologies and methodologies the states use to detect motorcycles. Upon approval of the research, the research team contacted the selected state DOTs with one or more phone calls, followed by the survey form, which was sent to one or more persons at each state DOT. In some cases, the person who was knowledgeable about technology used for detection was different from the person who decided where to collect data. Transportation agencies were contacted in the following states:

- Arizona
- California
- Florida
- Minnesota
- New York
- Ohio
- Oregon
- Utah (not completed)
- Virginia
- Washington

Data Collection Protocols

The research team anticipated that the survey would reveal that a few states were more experienced in temporal and spatial collection of motorcycle counts. However, the search was unable to identify any single model that was adequate for locating data collection sites. This finding led researchers to seek a method, using existing data sources where possible, to determine where motorcycle count/classification sites should be located. The literature search was helpful in verifying an early hypothesis that crash data might point to an initial method for locating count sites.

Levine, Kim, and Nitz (1995) analyzed the relationship between trip-generating activities and crashes (*13*). This work involved aggregating crash locations into small geographic zones for spatial analysis. The results indicated that crash frequency in a small geographic area (a census block) can be predicted with moderate accuracy ($R^2 = 0.55$) using predictors that include population, employment, and measures of overall roadway types passing through the zone. The model's importance is that neither the actual roadway types where the crashes occurred nor the traffic volume of the roadways were used. It could be argued that many of the model's predictors are surrogates for traffic volume in that they either bear on trip generation (employment factors) or on the mix of roadways—a factor that has a strong relationship to traffic volume. In essence, this model shows that crash locations can be predicted with moderate accuracy based on traffic-related factors on an area-wide basis. It is of interest to the present effort that the model did less well in predicting weekend crash location areas than it did for weekdays, and that for weekdays the best predictions were obtained during typical commuter times. This is to be expected based on the trip-generation variables selected (e.g., employment in various job sectors).

In the study by Levine, Kim, and Nitz (1995), the use of correlation coefficients to measure the model's predictive strength implies no causal linkage and no necessary directionality in the model's predictions. In other words, the model's predictions work equally well in the opposite direction—if one were to map crashes by area, the results could be used to predict trips (i.e., traffic volume) with the same level of accuracy at the area-wide level. Similarly, Quddus (2008) modeled the relationship between injury and fatal crashes in London using characteristics of the city's 633 census wards as predictors (*14*). The results for spatial models of crashes and two Bayesian models show that "traffic flow has a positive association with casualties," whereas other characteristics (e.g., employment, number of households with no cars) are predictive only in select circumstances (*14*). Thus, traffic volume/traffic flow variables are always positively correlated with area-wide crash experience.

Generally, there is agreement in the transportation safety field that traffic volume is directly related to crash frequency. In modeling crashes at specific locations or for specific roadway types, traffic volume is typically the single most significant predictive value. For example, Golob and Recker (2003) found that traffic flow characteristics accounted for 77 percent of the variance in crash location and type (*15*). This model was limited to urban freeways in California and thus had a constrained list of location types, perhaps accounting for the high level of correlation.

The research team was unable to identify any published studies that made the link between motorcycle traffic volume and crashes. However, the existing modeling results for crashes in general, along with logical reasoning based on past modeling results, led researchers to suspect that motorcycle crash locations, like all other motor vehicle crashes, are strongly linked to traffic volume. There are two ways to look at this as a hypothesis:

1. Considered in isolation from all other traffic count data, the volume of motorcycle traffic should be positively associated with crash locations (i.e., motorcycle crashes happen where the motorcycles travel).
2. Alternatively, the volume of overall traffic (counting all vehicles, including motorcycles) should be positively associated with motorcycle crash locations because of the already-established relationship between overall volume and crashes. This means that in the absence of reliable motorcycle volume data, one should still be able to predict with some accuracy the location of motorcycle crashes if the following two statements are true:
   - Motorcycles are a part of the vehicle mix, and
   - Motorcycle volume is related to overall traffic volume.

In most states, motorcycle crash data are easily obtainable. The statewide crash database contains variables identifying vehicle types, and motorcycles are typically coded as a single vehicle type. The most common difficulty in using crash data in a spatial analysis is that the crashes may not be located accurately. The reporting officer may have recorded the wrong information about streets and the nearest intersection. Global positioning system (GPS) coordinates may not be recorded or may be recorded incorrectly. States expend a great deal of effort to locate crashes on the roadway network, and these efforts often meet with good, although not perfect, success rates of "landing" crashes where they actually happened. Crash data recorded using the statewide linear referencing system or a geographic information system (GIS) typically include accurate location information more than 75 percent of the time, and many states achieve a 100-percent success rate through follow-up research. However, those states with 100-percent success rates may still experience errors in which a valid location code is mistakenly assigned so that the crash "lands," but in the wrong spot.

Traffic volume data, on the other hand, are almost always precisely located. The accuracy issues with respect to traffic volume have more to do with the ability of sensors and software to accurately detect and assign vehicles to the appropriate "bin" representing a particular vehicle type. NCHRP Project 08-81 has the primary goal of advising states how to obtain more accurate counts of motorcycles without compromising the accuracy of counts for other vehicle types. A secondary purpose is to advise states on where to collect motorcycle count data.

The research team's premise was that the correlation between traffic volume and crash location offers a solution to this second goal. If motorcycle crash locations can be predicted by traffic volume, then, logically, motorcycle volume data can be predicted to the same extent based on crash locations. This is the nature of a correlation—it is equally predictive in both directions.

The research team directed its effort, therefore, at establishing the correlation between motorcycle crash location and traffic volume. The researchers chose to use area-wide predictors because, for most states, the locations of traffic counters from which reliable, year-round total and classification counts are obtained are limited. At the area-wide level, these counts can be interpreted as indicating the portions of the state where traffic flow is the greatest and where it is the least. Classification of motorcycles as a portion of the vehicle mix is also likely to be more accurate at the area-wide level because the area count relies less on the specific roadways or roadway types and instead is a spatial aggregate of travel in a given area.

Unlike prior studies, which broke a state or city into discrete regions, analysts for NCHRP Project 08-81 realized that the spatial analysis could simply use distances to assess the spatial relationships between count locations and crashes. The areas thus analyzed are really spatial groupings in which a crash is considered related to the nearest traffic count. That relationship can be tested with and without a weighting factor based on the distance between the crash and the count site. In this case, the research team used the inverse of this distance measure, so crashes close to the count program could be viewed as “more associated” (have a higher weight) with the counts at that location than crashes at more distant count locations.

Methodology

The research team’s proposed approach to developing sampling strategies and data collection protocols used a multi-step process, as follows:

Step 1: Use multiple years of crash data (when multiple years are available for both crash and traffic data) to identify and map motorcycle crash locations.

Step 2: Gather the same years’ count data to include count locations, dates on which the counts were gathered (preferably full-year data, where available), and the total and motorcycle-specific AADT (or a measure that can be converted to AADT).

Step 3: Analyze the relationships between motorcycle crash location and (a) motorcycle traffic volume and (b) overall traffic volume. This analysis requires calculating the correlation coefficient between traffic counts and crashes near the count stations. In this analysis, each crash is assigned to its nearest count station. A companion analysis used a weighting factor for the distance between crash locations and the nearest count stations to estimate the strength of the association taking distance into account. See Appendix A for a list of data elements required for this procedure.

The research team conducted a search of states that record latitude/longitude information for vehicular crashes and initially found that Texas and Michigan data were available and would serve the purposes of this exercise. The goal was to find at least one state that represents a cold climate and another representing a hot climate because weather has an impact on motorcycle ridership. The Texas Department of Transportation (Texas DOT) sent 5 years of crash data (2006–2010) and the most recent (2011) traffic volume data. Likewise, the Michigan DOT provided crash data for June 2011 and July 2011 and the most recent (2011) traffic volume data. The analysis included only crashes involving motorcycles. The research team subsequently evaluated data from Wisconsin and Montana to investigate whether the associations between traffic crashes and traffic volume in those data were consistent with those from Texas and Michigan.

The research team mapped motorcycle crashes based on the latitude/longitude coordinates reported in the four states’ databases using a GIS (ESRI ArcGIS). This process began by mapping locations of vehicle classification stations, followed by crash latitude/longitude based on the location data provided in the states’ site description files. The next step was to use ESRI ArcGIS to calculate the linear distance from each crash to its nearest count station and record the distance along with identity of the count station.

The counts included sums of the total motorcycles (FHWA Class 1) along with sums of all classes for each classification station. The process then merged count station data with crash data to yield an analytic dataset composed of total motorcycle crashes near each count station, the count of motorcycles, and total vehicle counts for each count station. The weighted crash frequency is calculated using Equation (1), as follows:

$$\text{Weighted crashes} = N \times \frac{1}{\frac{1}{N}\sum_{i=1}^{N} D_i} \qquad (1)$$

where:

N = raw crash frequency in the vicinity of the count station.
D_i = distance of crash from the count station.

A second comparison similarly calculated the same measures related to crashes and highway count stations, but was different in that it used only crashes occurring on a roadway with a count station. The calculation used the distance measured from the crash to the nearest count station *on the same highway* instead of taking all crashes and calculating a straight-line distance. In some cases this metric was less useful, however, because the data tables were too sparse.

Analysis of the Michigan and Wisconsin crash data included a comparison of weekdays with weekend days to investigate possible differences in riding patterns for these two periods.

This comparison could not be reproduced for the Texas and Montana data because weekend versus weekday count data were not available.

Comparison of crash frequency (unweighted and weighted) and traffic volume used Pearson's *R* to determine whether a relationship exists between crash frequency and traffic volume for each count station in the two states. The comparison excluded a few records because the count locations were not completely documented or were not the nearest count station to any motorcycle crashes. Details of the authors' procedure suggested for state motorcycle programs are presented in the balance of this section.

Data Setup. An essential and critical component in this procedure that will facilitate processing data in a GIS environment is a list of the latitude and longitude of crash sites and count sites. For such a list to be feasible, states need to record latitude/longitude information in crash reports to be subsequently entered into their crash database. Likewise, states need to assign latitude/longitude information to count sites. Having the location data readily available makes this process amenable to the use of a GIS package to easily calculate distances between count sites and crash sites. Other data components for this process should already be available in most states, with the possible exception of traffic counts by weekend versus weekdays. It is suggested that states calculate motorcycle AADT and total AADT (all vehicle classes) by weekday and weekend to be able to investigate the viability of their motorcycle count program by weekend versus weekday.

Data Elements. Table 1 presents a list of essential data elements required to calculate the Pearson's *R* for state motorcycle programs. For the unweighted comparison, compare the weekday AADT of Class 1 vehicles against the number of Class 1 crashes near the count site. For the weighted comparison, compare weekday AADT Class 1 vehicles with distances along the same road. The goal of this process is to determine deficiencies in an existing motorcycle count program. The process relies on the locations of motorcycle crashes and determines the correlations between the *count* of motorcycle crashes in the vicinity of the vehicle classification site and (a) the *count* of all classes of vehicles at the station and (b) the *count* of motorcycles (Class 1 only) at the station.

States must decide which classification sites are accurately counting Class 1 vehicles. If existing equipment is known to be deficient (typically based on direct observations), the first step will be to replace this equipment. There is little value to applying the procedures in this section without having equipment that is generating reasonably accurate classification counts of Class 1 vehicles.

As indicated in Table 1, there are two categories for calculating the correlation coefficient: unweighted and weighted. The unweighted category requires only the locations of crashes and locations of count stations; it does not explicitly use distance of crashes from count sites, but only assigns groups of crashes in the vicinity of count stations to the station nearest the crash. In this research project, analysts began by using crashes within 1 mile of the classification site, but had to extend the range depending on the dispersion of classification sites.

Spatial Analysis. For both the weighted and unweighted categories, the process to set up the spatial analysis begins by assigning crashes to a route. The straight-line method bypasses this step and assigns crashes to classification sites based on straight-line distances. However, the straight-line method did not work in some cases in this research project, whereas distances measured along a route worked more often. Therefore,

Table 1. Data elements and pairings for calculation of correlation coefficient (Pearson's *R*).

From Traffic Count Database	From Crash Database	Categories	Data Element: Number of Crashes
Weekday AADT – Class 1 only	Number of weekday motorcycle crashes	Unweighted	Near count site
		Weighted	Along same road as count site
Weekend AADT – Class 1 only	Number of weekend motorcycle crashes	Unweighted	Near count site
		Weighted	Along same road as count site
Weekday AADT – All classes	Number of weekday motorcycle crashes	Unweighted	Near count site
		Weighted	Along same road as count site
Weekend AADT – All classes	Number of weekend motorcycle crashes	Unweighted	Near count site
		Weighted	Along same road as count site

it is best to use crashes along the same route as the process for determining the classification site.

The second step in the spatial analysis also applies to both the weighted and unweighted categories and involves assigning crashes to count stations. GIS software can assign each crash to its nearest count station at a distance not to exceed a selected value, beyond which the crash is either (a) closer to another count site or (b) considered an outlier and not included in subsequent calculations. The selected value is based on the user's judgment; however, a distance of 1 mile is suggested as an appropriate starting distance.

For the weighted category, computing the distance from the crash site to the nearest classification site allows crashes closer to the classification site to have a higher value than those at greater distance. The unweighted category allows all crashes assigned to a classification site to have the same value. Equation (1) provides the method for calculating weighted values using data entered into ArcGIS.

States will also want to determine whether the correlation of weekend crashes and counts is similar to that of weekday crashes and counts. The calculation procedure is exactly the same for weekdays as for weekends, but the state must be able to provide accurate AADT data for both weekends and weekdays. A GIS expert will be able use ArcInfo to classify crashes as weekend or weekday and classify count sites as continuous or temporary. Use the "NEAR" function in the analysis tools of ArcInfo to calculate the distance between the different crash sites and count sites. The states' original data for the analysis is acceptable either in Excel spreadsheet or ArcGIS shapefile format.

Statistical Analysis. Transportation professionals often need to consider the relationships between two or more variables of interest. In this case, state-level decision-makers need to know to what degree the locations of motorcycle crashes are related to the locations of motorcycle count sites in their state. The correlation coefficient (Pearson's R) is a measure of the strength and direction of the relationship between two numerical variables (*16*). The value of R can range between -1 and $+1$ and is unit-free. Positive values of R indicate an increasing relationship between variables (i.e., count sites and crash sites), and negative values of R indicate a decreasing relationship. A value close to 1 indicates a strong positive linear relationship (*16*). A value of 0.5 or higher indicates a moderate correlation between two variables.

For NCHRP Project 08-81, researcher intuition (corroborated by literature sources for other vehicle types) pointed to an analysis to determine whether a relationship exists between motorcycle crash locations and motorcycle traffic volume for a few selected states. The relationship described by Equation (1) is built around the distance between individual count sites and individual crashes. *Weighted comparisons* use this distance calculation and *unweighted comparisons* omit it.

To determine the correlation coefficient (Pearson's R) for the unweighted category, the data file should list each count station in a single row with the appropriate distances as described above for the statistical test. Both tests (weighted and unweighted) require two columns of numbers, which can be easily prepared in Microsoft Excel. One column contains the number of crashes assigned to a count station and the other contains the AADT derived from that same count station. One test uses the total AADT (all vehicle types) and a separate test uses only the number of Class 1 vehicles (motorcycles).

On determining the correlation coefficient (Pearson's R) using crashes on the same roadway, it may be helpful to check the straight-line method to determine whether using this method makes a difference. Crash counts on the same roadway will typically yield stronger correlated values and are thus recommended. In summary, for calculating the correlation coefficient, the two required columns are (a) traffic counts at each station and (b) motorcycle crash counts (weighted or unweighted) in the vicinity of the station. Most commonly used statistical software offers support for determining Pearson's R.

Field Data Collection and Analysis

At the direction of the NCHRP Project 08-81 panel, the research team investigated five technologies, selecting one detection system that fit within each of the five technology categories as indicated in Table 2.

Table 2. Selected detection systems.

Technology	Selected Detection System
Infrared (IR) Classifiers	Transportable Infrared Traffic Logger (TIRTL)
Inductive loops/piezoelectric sensors (full lane-width)	"BL" piezoelectric sensors by MSI, IRD classifier
Magnetometers	Sensys Networks
Multi-technology systems	Migma System
Tracking video systems	TrafficVision™

Methodology

The research team contacted all five of the selected equipment providers to determine their willingness to support field tests by providing loaned equipment, technical support, or both. In the case of the inductive loop/piezoelectric sensor system, the Texas DOT Transportation Planning and Programming Division (TPP), located in Austin, was the responsible agency. Much of the field data collection occurred at TTI's SH 6 test facility in College Station. The other in-pavement sensors were magnetometers. Figure 1 shows the site layout and some of the sensors involved in the tests. Also working at College Station, Texas DOT installed inductive loops and piezoelectric sensors in a loop-piezo-loop (LPL) configuration in each of the four lanes and connected the sensors to an International Road Dynamics (IRD) vehicle classifier. Figure 2 is a photograph of the loop/piezoelectric sensors installation process.

The research team used two systems for ground truth during detector tests at the College Station SH 6 test facility: (1) a Peek ADR-6000 vehicle classifier using Idris® technology and (2) recorded video. Comparing test detector data

Figure 2. Inductive loops and piezoelectric sensors installed in SH 6.

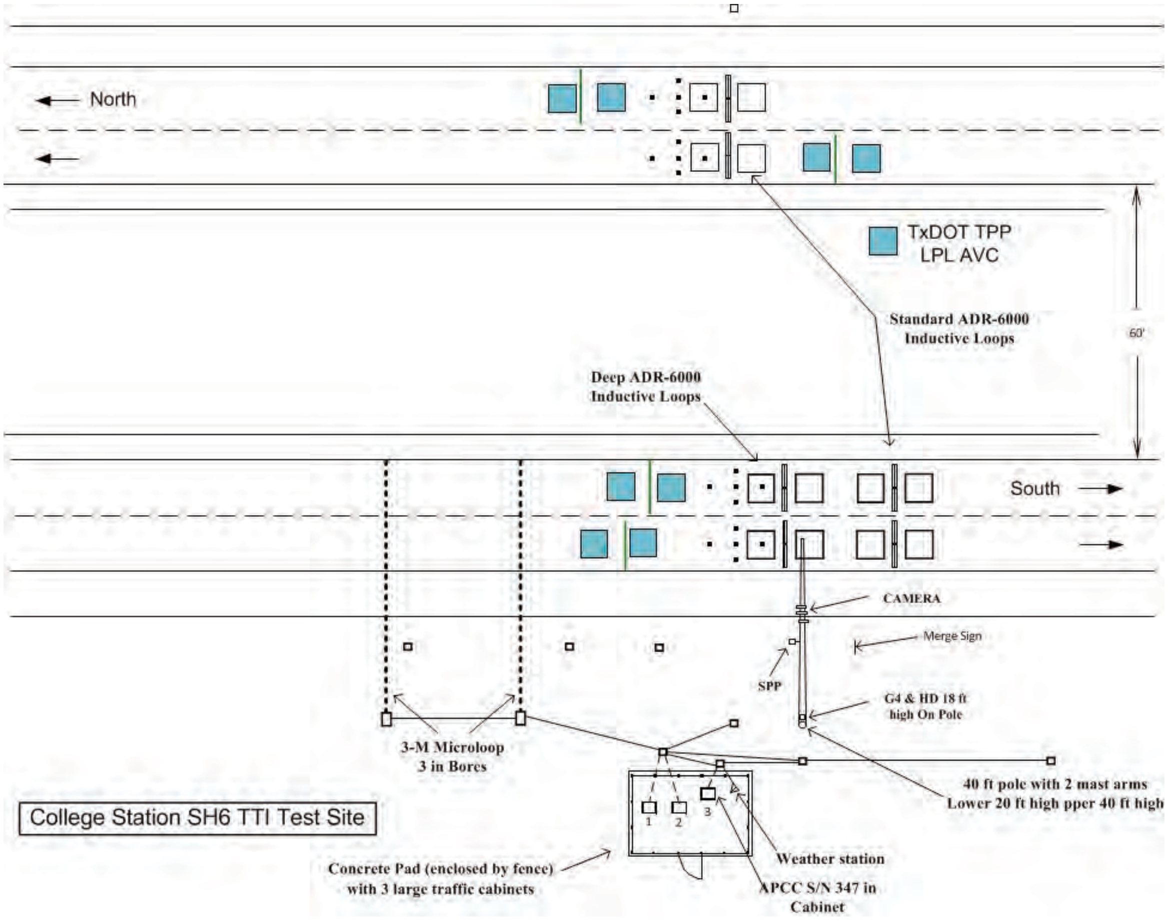


Figure 1. Detector test site on SH 6.

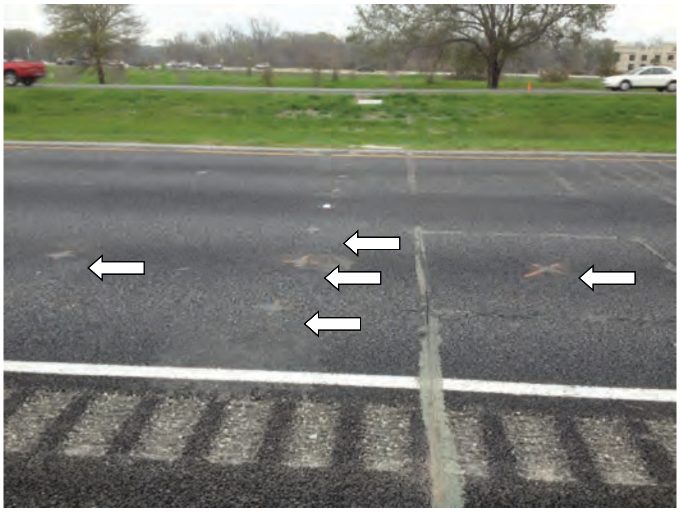


Figure 3. Wireless magnetometers installed in SH 6.

Figure 5. Motorcycles approaching detection zone on SH 6.

with the Peek system was faster than watching recorded video, but the research team usually provided redundant ground truth data in case one system or the other malfunctioned. The operation of the Peek system was a little less predictable during some of the early tests following reinstallation, so recorded video became more critical. This Peek system intermittency was due to replacement of its four inductive loops per lane at the same time as other loops (because of pavement resurfacing).

Figure 3 is a photograph of the wireless magnetometer sensors immediately following installation in the southbound lanes. Figure 3 indicates the positions of the sensors relative to the ADR-6000 loops. White arrows indicate the one-three-one pattern of the magnetometers in all four lanes. Figure 4 shows the multi-technology detector mounted on the pole at this site. Figure 5 shows the motorcycles approaching the SH 6 site in the right lane, forming a staggered pattern. Figure 6 shows the IR Classifier installed behind a guardrail on State Highway 21 (SH 21) in College Station, Texas. Figure 7 and Figure 8 show the New Ulm sites, and Figure 9 shows the Daytona Beach data collection site.

Field Data Analysis

A major component of the data analysis was the determination of performance measures to determine the detection accuracy of the selected detection devices. This activity is essentially a problem in signal detection, and the basics of

Figure 4. Multi-technology detector mounted at SH 6.

Figure 6. IR classifier test site on SH 21 near College Station, Texas.

Figure 7. Data collection site in New Ulm, Texas, May 18, 2012, looking east.

Figure 8. Data collection site at New Ulm, Texas, May 19, 2012, looking east.

Figure 9. Data collection site for IR classifier at Daytona, Florida, October 20, 2012, looking east.

Table 3. Signal detection.

Actual Condition	Response = Detected	Response = Not Detected
Motorcycle present	A: Correct detection	B: Miss
Motorcycle absent	C: False Alarm	D: Correct rejection

signal detection are that every detection event can be classified under one of the four possible outcomes shown in Table 3.

Because the primary emphasis of this research was motorcycles, the Table 3 values were applied specifically to motorcycles. The research team investigated using these four outcomes to calculate the overall detection accuracy of each detection system according to Equation (2), which calculates the probability of a correct response:

$$\text{Overall Detection Accuracy: } \frac{(A+D)}{(A+B+C+D)} \tag{2}$$

where:

A = Correct detection (The detector correctly detected and classified a motorcycle at the time a motorcycle passed through the detection zone.)
B = Miss (A motorcycle passed through the detection zone but nothing was detected).
C = False alarm (The detector registered a motorcycle detection, but the vehicle passing through the detection zone was a non-motorcycle or nothing passed through the zone.)
D = Correct rejection (The detector detected a non-motorcycle vehicle and classified it as anything but a motorcycle.)

After calculation of the overall detection accuracy for several data collection sessions, analysts realized that this metric was not appropriate for this purpose. Analysis indicated that if A (correct detections) and D (correct rejections) are large compared to B (misses) and C (false alarms), the resulting value would always be near 1.0. For sites with high traffic volumes (e.g., SH 6 and the Daytona Beach site), the resulting value was always near 1.0 with little sensitivity for misses and false alarms. Therefore, the overall detection accuracy calculation was abandoned in lieu of calculating the simple detection accuracy, as shown by Equation (3):

$$\text{Simple Detection Accuracy: } \frac{\begin{array}{c}\textit{Classification Count}\\ \textit{by Test System}\end{array}}{\begin{array}{c}\textit{Classification Count}\\ \textit{by Ground Truth}\end{array}} \tag{3}$$

CHAPTER 3

Findings and Applications

Literature and Internet Review

The organization of the literature and Internet findings presented in this chapter begins with existing technologies for motorcycle detection. For each technology, an explanation is given regarding how it is used and its advantages and disadvantages in relation to motorcycle data collection. Findings from research projects that test and evaluate applications for improving motorcycle detection accuracy are discussed within the applicable technology section. New and/or promising technologies for improving the accuracy of motorcycle detection and classification follow. The final section in this chapter summarizes methodologies for estimating motorcycle VMT when motorcycle count data are unavailable.

Sensors used for vehicle detection are generally classified as intrusive (in-roadway sensors) and non-intrusive (beside and/or over-roadway sensors). Intrusive sensors are installed directly on the pavement surface, in saw-cuts or bores in the road surface, by tunneling under the surface or by adhering directly to the pavement surface. Examples of intrusive detectors are pneumatic road tubes, piezoelectric sensors, inductive loop detectors, and magnetometers. Non-intrusive sensors are mounted above the lane of traffic they are monitoring or on the side of a roadway where they can monitor multiple lanes of traffic. Examples of non-intrusive sensors are video image processors, microwave radar, laser radar, passive infrared, passive acoustic array, and combinations of sensor technologies such as passive IR and Doppler microwave sensors (*17*).

Several of these technologies are used by state DOTs to collect motorcycle travel data for HPMS reporting. As Table 4 shows, most states reported using pneumatic road tubes to conduct short counts for motorcycles and piezoelectric sensors to conduct continuous counts. Several states also reported testing several technologies for motorcycle counts and data collection (*18*).

Detection and Classification Challenges

Achieving a successful motorcycle travel monitoring program involves two primary objectives: (1) finding and implementing technologies that can accurately detect motorcycles, and (2) determining where to count motorcycles and how often. These two objectives might be thought of as defining the basic technology and methodology of detection and classification. Some of the challenging detection and classification issues that arise in a motorcycle travel monitoring program are (*19*):

- Motorcycle definition
- Spatial and temporal factors
- Lane discipline
- Vehicle size
- Vehicle occlusion

Motorcycle Definition. FHWA defines motorcycles in two categories: (1) larger motorcycles with two or three wheels, and (2) motorized bicycles, which include mopeds and scooters that require registration. Some states have adopted FHWA's definition of motorcycles, but others define motorcycles in other ways. Some states define them as vehicles with two or three wheels in contact with the ground, a seat or saddle for passengers with a sidecar or trailer, a steering handlebar, and no enclosure for the operator. Several states also have identified criteria to differentiate motorcycles from mopeds based on vehicle speeds, engine displacement or horsepower, or wheel diameter. Given the discrepancies in definition, FHWA proposed to provide additional guidelines on the definition of motorcycles from mopeds and scooters (*4*). The April 28, 2011 issue of the *Federal Register* contains a Notice announcing the revision to FHWA's guidance regarding state reporting of motorcycle registration information (*20*).

Spatial and Temporal Factors. Accurate travel monitoring of motorcycles requires knowing where and when they

Table 4. Data collection technology used for motorcycle travel.

Number of States Reporting (n=24)	Short Counts		Continuous Counts	
Technology	**Tested**	**Used**	**Tested**	**Used**
Intrusive				
Road tubes	13	20	-	-
Piezoelectric cable	3	4	9	17
Conventional inductive loops	6	2	4	8
Piezoelectric film	1	0	4	3
Inductive loop signatures	1	0	2	1
Quadrupole loops	1	0	1	0
Magnetometers	1	0	2	0
Non-Intrusive				
Manual	0	1	-	-
Radar	7	3	4	5
Video	1	2	2	1
Infrared (IR, including TIRTLs)	5	0	4	3
Acoustic	1	0	2	0

Source: Reference (*18*, p. 3-2).

travel. The locations and times most appropriate for counting motorcycles are not necessarily the same as those for other vehicle types. The counting methods currently used by most states are only partial solutions and reflect a set of assumptions about motorcycle ridership that may not be stable and valid for all situations. One goal of NCHRP Project 08-81 was to identify a method, or methods, to better select sites and times for monitoring motorcycle travel to better reflect the spatial and temporal behavior of motorcyclists during the week and on weekends.

Lane Discipline. Because motorcycles only cover part of a traffic lane, piezoelectric sensors, inductive loops, and other detectors that also cover only part of a lane might not detect them. In some areas, motorcyclists may operate between lanes or even on paved shoulders for short distances when the road is congested, also avoiding detection. In order to maximize the probability that the wheels of a Class 1 vehicle will be detected by a piezoelectric sensor, the sensor should extend, as nearly as possible, across the entire lane (*18*). This means replacing the 6 ft sensors now commonly used for traffic counting with full lane-width sensors.

Vehicle Size. Existing sensors often cannot reliably distinguish motorcycles from subcompact automobiles on the basis of axle spacing. The axle spacings of current Harley-Davidson motorcycles, for example, are between 63 in. and 66 in. These spacings are only a few inches shorter than those of the recently introduced Smart ForTwo car, which has an axle spacing of only 73.5 in.; and they are only 2 ft to 3 ft shorter than those of several more conventional subcompacts.

It is easier to distinguish motorcycles from subcompact autos on the basis of magnetic length (as measured by inductive loops) than on the basis of axle spacing. This is partly because the vehicles' differences in physical length are greater than the differences in axle spacing, and partly because—for vehicles with low metal content—magnetic length is shorter than physical length. Motorcycles generally have a magnetic length that is at least 3 ft shorter than their physical length (*18*).

Vehicle Occlusion. For roadside detection systems, large vehicles in a lane closer to the detector may prevent detection of smaller vehicles in the adjacent lane(s). Wheel occlusion is a similar concept, but it applies specifically to occlusion of vehicles in closer lanes for detection systems designed to detect tire/wheel systems.

Intrusive Detection Technologies

Many states use intrusive detection technologies to obtain motorcycle counts for continuous and short duration counting and HPMS reporting requirements. Intrusive detectors include:

- Pneumatic road tubes
- Inductive loops
- Piezoelectric sensors
- Magnetic sensors

These sensors represent applications of mature technologies to traffic surveillance, but all have limitations when they are used to count and classify motorcycles. The major drawbacks of using intrusive devices are traffic disruptions for installation and repair, system failures associated with installations in poor road surfaces, and use of substandard installation procedures (*21*). Resurfacing of roadways and utility repair also can damage sensors and force the operating agency to reinstall these types of sensors (*22*).

Pneumatic Road Tubes. Pneumatic road tubes are anchored directly to the pavement surface. A vehicle passing over the tube causes a burst of air pressure to travel through the rubber tube. Road tubes detect volume and speed and classify vehicles by axle count and spacing. They differ from the other three types of detectors in that pneumatic road tubes typically are used for short-term traffic counts of 1 or 2 days on roads with low to moderate traffic volumes (*17*). Even so, pneumatic tubes require close surveillance to ensure proper performance.

Road tubes are one of the main types of sensors used for conducting short-term counts of traffic, including motorcycles. Certain limitations of this technology can lead to both undercounting and overcounting of motorcycles. In particular, road tube systems may undercount motorcycles because they have trouble distinguishing groups of motorcycles and detecting very lightweight motorcycles or because motorcyclists may choose to steer around the tube, avoiding detection altogether. On the other hand, because road tube systems have difficulty differentiating between subcompact vehicles and larger motorcycles, many subcompact vehicles (e.g., the Smart ForTwo and the Mini Cooper) may be incorrectly classified as motorcycles. When road tubes are used with an 8 ft threshold (as is the current practice in at least some states), such misclassifications may result in appreciable overcounting of the number of motorcycles (*17*).

Advantages of pneumatic road tubes include that they are quick to install for temporary recording of data and they are relatively inexpensive and easy to maintain. Negative attributes of road tubes include limited lane coverage and the fact that their efficiency is subject to weather, temperature, and traffic conditions (*17, 21*).

Inductive Loops/Piezoelectric Sensors. Inductive loop detectors consist of the following primary components:

- One or more turns of insulated wire placed in a shallow slot sawed in the pavement
- An electronics unit located in a nearby cabinet or weatherproof housing
- Lead-in cable from the edge of the roadway to the roadside electronics

The electronics unit transmits energy to the wire loops, and the system behaves as a tuned electrical circuit with the loop wire and lead-in serving as inductive elements. When a vehicle passes over or stops within the wire loop, the conductive metal induces eddy currents in the wire, which reduces the loop inductance (*23*). The reduction is measurable within the electronics unit and signals a detection. Inductive loop detectors provide vehicle passage, presence, count, speed, and occupancy data, and newer versions can provide vehicle classification based on specific metal detected within the vehicle (*17*).

Many states use an additional sensing component with inductive loops for classification purposes and for detecting smaller vehicles like motorcycles—piezoelectric sensors (sometimes called piezos). Installers must cut a slot in the pavement, typically at a 90 degree angle to the direction of traffic and covering the full lane-width. Application of a force like a vehicle tire crossing the sensor generates an electrical charge that is proportional to the pressure exerted on the sensor. Piezoelectric sensors provide vehicle counts, detect vehicle weight and speed, and classify vehicles based on axle count and axle spacing (*17*). One caveat for using piezoelectric sensors for weight is that Class 1 piezoelectric sensors are required for generating weight data, whereas the cheaper and less accurate Class 2 sensors are typically used for classification. The installing agency must decide before purchasing whether the sensors will be used for collecting weight data or classification data.

Many jurisdictions combine inductive loop detectors with piezoelectric sensors in varying combinations for continuous and short classification counts. The most common configurations are the LPL or PLP (piezo-loop-piezo) configurations. Using a pair of loops without piezos facilitates continuous classification of vehicles by length. The Virginia DOT adopted standards for loops and piezoelectric sensors to improve the detection of motorcycles. The Virginia DOT specification calls for installing loops with four turns of wire and no splices, and two piezos stacked one above the other in a single sawcut to cover the entire lane-width (*18*).

Certain characteristics of motorcycles and actions of motorcyclists make accurate detection and classification difficult using these technologies. Motorcycles are smaller and lighter and contain less metal than other vehicles, which results in undercounts of motorcycles. Motorcycles traveling in groups and especially in certain staggered patterns are particularly challenging for inductive loop/piezoelectric sensor detection systems (*24*).

Motorcyclists often avoid riding in the middle part of the lane because of debris, oil, coolant, and other slick fluids. Detectors that cover only part of a lane might not detect motorcycles that pass over the part of the lane that is not covered.

Some motorcyclists even operate between lanes ("lane splitting") or on shoulders and similarly avoid detection. The use of wide loops and full lane-width piezos (or wide loops alone) helps reduce errors in counts of motorcycles (*18*). However, the difficulty in detecting motorcycles that travel side-by-side and/or between lanes or on shoulders likely will continue to result in undercounts.

Some advantages of using piezoelectric sensors with loops over using inductive loops alone are improved speed accuracy, the ability to determine the classification of the vehicle based on axle spacing, and the ability to determine and monitor the weights of vehicles when used with weigh-in-motion (WIM) electronics (*17*). The down side is that piezoelectric sensors are subject to failure with little or no warning, especially if installed in poor pavement. The detection accuracy of light vehicles such as motorcycles is reduced as these sensors age (*17*). Piezos, loops, and other detectors that cover only part of a lane may fail to detect motorcycles and have difficulty detecting motorcycles in groups. Advantages of using inductive loops alone include:

- Flexible design (shape and number of wire turns) to satisfy a large variety of applications
- Well-understood technology with a large experience base
- Insensitive to inclement weather such as rain, fog, and snow
- High accuracy for count data as compared with other commonly used techniques

Research is underway at the University of Oklahoma to test and evaluate a microprocessor-based system that uses a sensor consisting of a single metal strip fitted over piezoelectric ceramic/quartz disks. Installation in the roadway requires placement of this assembly at a diagonal to provide complete detection between road shoulders. Based on the diagonal installation, a vehicle with four wheels generates four distinct pulses, whereas a motorcycle only generates two. The system includes the roadway sensors, a multi-channel charge power amplifier, an analog-to-digital converter, and a computer. The computer acquires and analyzes the sensor pulses to obtain classification, speed, and weight of traveling vehicles, and then communicates the information in real time to a database housed on a remote server (*25*).The research team did not expect the system to be in production in time to include it in the field testing for NCHRP Project 08-81.

Magnetic Detectors. Magnetometers are passive devices that detect perturbations in the earth's magnetic field due to the magnetizable components of vehicles as they pass through a detection zone. Magnetometers detect cars and trucks, but they are less effective in detecting and classifying motorcycles and bicycles because smaller vehicles have low magnetizable masses (*17, 18*).

There are two types of magnetic field sensors: (1) dual-axis and three-axis magnetometers, which detect changes in the vertical and horizontal components of the earth's magnetic field produced by a ferrous metal vehicle and (2) induction magnetometers, sometimes called *magnetic detectors*, which measure changes in the magnetic flux lines when metal components in a vehicle travel past the detection zone (*26*).

Advantages of dual-axis or three-axis magnetometers include that they are less susceptible than are induction loops to the stresses of traffic and pavement flexing so they are useful in places where loops are not feasible (e.g., bridge decks). Some induction magnetometers transmit data over a wireless radio frequency link. Some models also can be installed under the roadway without the need for pavement cuts. The down side is that induction magnetometers cannot detect stopped vehicles, and some models have small detection zones (*17*).

Recent research on magnetic detector technology has resulted in the development of a wireless magnetic sensor network based on magneto-resistive sensor technology that can detect vehicles, including motorcycles (*27*). The developers claim that the sensor is able to achieve high accuracy for motorcycle detection because the magnetic length of motorcycles is clearly distinguishable from other vehicle types.

Non-Intrusive Detection Technologies

Non-intrusive detection technologies are sensors mounted to the side of the roadway, above the roadway, or installed beneath the pavement. Non-intrusive technologies cause minimal disruption to normal traffic operations during installation, operation, and maintenance compared to conventional (intrusive) detection methods. Some viable non-intrusive technologies for motorcycle detection are:

- Video-based detectors
- Microwave radar detectors
- Laser radar detectors
- Passive IR detectors
- Passive acoustic detectors
- Combinations of sensor technologies

In general, these sensors measure vehicle counts, presence, and passage. Some sensors also provide vehicle speed, vehicle classification, and multiple-lane, multiple-detection zone coverage (*17*).

Video-Based Detectors. Video-based detectors use a computer to analyze the image input from a video camera based on different approaches. Some detectors analyze the video image of a vehicle that passes through a target area and determines detection based on the change in pixels within the detection zone. This type of system is sometimes called a *tripwire detector.* Other video detectors determine when a target vehicle enters the field of view and track the vehicle through this field of view. "Tracking" video systems usually offer more output options but also involve more processing than tripwire systems (*26*).

Video cameras can be mounted on the side of the road, in the median, or directly over the roadway (*18*). Depending on the type of video detector used, the cameras can collect data about vehicles' volume, speed, presence, occupancy, density, queue length, dwell time, headway, turning movements, acceleration, lane changes, and classification (*26*).

Video is useful for collecting classification counts of motorcycles and other vehicles but it can only classify based on vehicle length. Detection accuracy depends on the truck and motorcycle volumes on monitored roadways or lanes. At locations with higher volumes of tall vehicles, video detectors are likely to undercount motorcycles because of vehicle occlusion. Overhead video cameras do not encounter as much side-to-side occlusion as side-mounted cameras, but they are still subject to front-to-back occlusion. However, their need for large overhead structures for mounting and artificial lighting for nighttime counts may limit their application in motorcycle detection (*18*).

Advantages of video-based detectors include their ability to monitor multiple traffic lanes and detection zones/lanes, process a rich array of data from multiple cameras, and add or modify detection zones with ease. Major disadvantages of video detectors include:

- Vulnerability to viewing obstructions
- Inclement weather
- Shadows
- Occlusion
- Light transitions (e.g., day to night)
- Vehicle/road contrast
- Water, salt grime, icicles, and other debris on the camera lens

Also, some video-based detectors are susceptible to distortion from the camera motion caused by strong winds (*23*).

Researchers have investigated various performance aspects of video-based detectors. Middleton and Longmire (2008) tested a tripwire video system on a road with 10 percent trucks for several hours a day over two 3-day periods, finding that motorcycles were undercounted by about 17 percent (*28*).

The performance aspects of new detectors are improving, making them viable replacements for inductive loops in some cases. Middleton, Parker, and Longmire (2007) conducted research on video detectors to investigate performance aspects of newer detectors. As part of this effort, the researchers conducted field tests that compared count, speed, and occupancy outputs from selected new detectors against an accurate baseline system, the Peek ADR-6000. Their research tested promising non-intrusive vehicle detector technologies, including video detectors, acoustic, magnetic, inductive loops, and microwave radar (*29*).

Kanhere et al. at Clemson University (2010) tested a tracking video detection system with their algorithm to count motorcycles at two sites during a motorcycle rally held in Charleston, South Carolina (*30*). At one site, researchers mounted the video camera in the median of a four-lane divided highway; at the other, they mounted the camera on the side of a road carrying two lanes of traffic in a single direction. Motorcycles accounted for 56 percent of vehicles at the first site and 69 percent at the second.

Overall, the Clemson system overcounted motorcycles in the departing direction by 4.4 percent at the first site, undercounted them in the approaching direction by 2.6 percent at that site, and undercounted them by 6.2 percent at the second site. Reportedly, undercounts occurred because of motorcycles sharing a lane and because of occlusion. The next stage of research involved improving the robustness of the system in those situations, as well as extending the work to handle motorcycles at nighttime and in low ambient lighting conditions. Based on the literature, the developers planned further research to augment the algorithm by incorporating pattern-based and shape-based descriptors to better differentiate motorcycles in difficult and ambiguous situations (*30*). The Clemson system became a market-ready product, sold under the name of TrafficVision™, and was eligible for testing as part of NCHRP Project 08-81.

Microwave Radar Detectors. Typical mounting structures and locations for microwave radar detectors are poles located adjacent to the roadway or over the lanes to be monitored. When vehicles pass through the antenna beam, a portion of the transmitted energy reflects back toward the antenna. The energy then enters the receiver, which detects and calculates the desired data (*17*). Radar detectors have similar performance characteristics as video-based detectors in terms of occlusion. However, they do not require artificial lighting and microwave radar detectors are virtually unaffected by weather (*18*). As with video, the detection accuracy of radar detectors depends on the truck and motorcycle volumes on the monitored roadway or lane(s). At locations with larger volumes of tall vehicles, microwave radar detectors are likely to produce significant undercounts of motorcycles because of vehicle occlusion (*18*). Advantages of microwave radar detectors include:

- Insensitivity to inclement weather at relatively short ranges
- Allowance for direct measurement of speed
- Coverage of multiple lanes (up to 10 lanes)

A study of frequency-modulated continuous-wave microwave radar systems produced an overall motorcycle undercount of about 19 percent (as opposed to 17 percent for video), with particularly large (and unexplained) undercounts observed on two of the six days of testing (*17*).

Active and Passive IR Detectors. Active IR sensors transmit low-energy laser beams to a target area on the pavement and measure the time for the reflected signal to return to the sensor. The corresponding reduction in time for the signal to return indicates the presence of a vehicle. Active IR sensors provide vehicle presence at traffic signals, volume, speed measurement, length assessment, queue measurement, and classification (*17*).

The strength of active IR detectors is that they transmit multiple beams for accurate measurement of vehicle position, speed, and classification. Also, multiple units can be installed at the same intersection without interference from transmitted or received signals, and multi-zone passive sensors measure speed (*23*).

Passive IR sensors detect the energy that is emitted from vehicles, road surfaces, other objects in their field of view, and from the atmosphere, but they transmit no energy of their own (*17*). Passive IR sensors with a single detection zone measure volume, lane occupancy, and passage.

The Transportable Infrared Traffic Logger (TIRTL) is an active IR traffic counting and classification system. Because TIRTLs are designed to detect tires, unlike most other non-intrusive classifiers, they are capable of axle classification instead of length classification. A TIRTL consists of a tire-height transmitter placed on one side of a roadway and a receiver placed on the other side. The transmitter generates two parallel IR beams at a 90-degree angle with the roadway and two additional beams at a diagonal angle. Thus, the four beams consist of two parallel beams and two beams in a criss-cross pattern.

The occlusion problem applied to the TIRTL in the context of motorcycle detection could be less than that found with length-based classification technologies because of the TIRTL's detection of tires instead of the entire vehicle. In concept, TIRTLs may be installed permanently for use as continuous counters or temporarily for the collection of short counts. However, it is important that the devices be securely located for protection against vandalism and so that vibrations caused by truck traffic do not cause beam misalignment. The accuracy of TIRTL classification counts and TIRTL counts of motorcycles, in particular, varies inversely with roadway width.

Testing of TIRTLs on two-lane roadways with an overall width (including shoulders) of 39 ft or less indicates that TIRTLs tend to overcount motorcycles. The overall net overcounting rate is about 5 percent, suggesting that TIRTLs may warrant further evaluation for use on two- and three-lane roadways (*18*).

Another detector product using technology similar to the TIRTL is Peek Traffic's AxleLight laser sensor. The literature search found limited information on this detector and found no sources indicating its accuracy for motorcycles. Research sponsored by the Minnesota DOT (Minge, Kotzenmacher, and Peterson 2010) included the AxleLight but results did not report its accuracy for motorcycle detection (*31*). Positive attributes of both the TIRTL and the AxleLight include their non-intrusive nature and their ability to detect axles. They are the only known non-intrusive detection systems that can classify vehicles according to FHWA's Scheme F. However, their negatives include:

- High cost (AxleLight retails for $31,580; TIRTL is similar)
- Being subject to vandalism and theft (mounted low to the ground)
- Difficulty of installation in northern states in winter with snow/ice accumulation alongside the roadway
- Potential for increased detection errors in rainy weather due to the spray causing false detections

Passive Acoustic Detectors. Passive acoustic detectors can detect volume, speed, occupancy, and classification. They measure the acoustic energy or audible sounds produced by a variety of sources that are generated by a passing vehicle. Sound energy increases when a vehicle enters the detection zone and decreases when it leaves. A detection threshold determines the termination of the vehicle presence signal. Sounds from locations outside the detection zone are attenuated (*17*). Performance tests conducted at TTI indicate that acoustic detectors are not as reliable or accurate as some other non-intrusive detectors (e.g., microwave radar) (*29*).

Literature Summary and Conclusions

The literature and Internet search produced several useful resources on existing technologies to detect and classify motorcycles. New technologies and sensors continue to emerge as manufacturers respond to the expanding needs of integrated and mobile motorcycle detection systems. No single device is best for all applications. Each detector has strengths and limitations that make them suitable for some purposes but not for others. To that end, the successful application of detector technologies depends on proper device selection to meet specific needs. Many factors, including data type, data accuracy, installation and calibration, cost, and reliability, impact the selection and performance of detector technology (*22*).

The existing technologies that have the most promise for accurately classifying motorcycles for long-term classification counts are active IR (TIRTL), inductive loops/piezoelectric sensor systems (with full lane-width piezos), tracking video, and magnetic detectors. Of the prominent magnetic detectors, one is intrusive but considered worthy of consideration.

Table 5 provides a summary of strengths and weaknesses for these promising technologies based on the literature and Internet review.

New and Promising Technologies for Motorcycle Detection

Some of the technologies discussed in the previous section may have been installed for other purposes but are viable for motorcycle detection. Given that resources for purchasing new systems may be scarce at the state level, the research team began its selection of candidate systems by considering the following existing technologies:

- Inductive loop/piezoelectric sensor systems (with full lane-width piezos)
- Multi-beam IR sensors such as TIRTL
- Microwave radar detectors
- Tracking video detectors
- Magnetometers

However, there were also reasons for looking beyond the traditional technologies. These reasons included the following:

- Some detectors involve traffic disruptions during installation.
- Some systems do not cover the full lane-width (e.g., some piezoelectric sensors).

Table 5. Summary of technology strengths and weaknesses.

Technology	Strengths	Weaknesses
Pneumatic road tubes	• Inexpensive • Quick installation for temporary data recording • Easy to maintain • Mature technology	• Undercounts motorcycles in groups • Difficulty distinguishing subcompact vehicles and motorcycles • Difficulty detecting very light motorcycles • Motorcyclists intentionally avoid in light traffic • Accuracy subject to weather and traffic conditions • Appropriate only for short-term counts
Piezoelectric sensors	• Accurately detects motorcycles when new and covers full lane-width • Mature technology	• Unpredictable failure
Magnetometers	• Less susceptible than loops to stresses of traffic • Can be used where loops are not feasible (e.g., bridge decks) • Not sensitive to weather	• Single magnetometers undercount motorcycles
Microwave radar detectors	• Non-intrusive • Quick and easy setup • Side-fire covers up to 12 lanes • Immune to weather and light • Reasonable cost	• Undercounts groups of motorcycles • Occlusion causes undercounts
Tracking video detectors	• Non-intrusive • Reasonably good counts where truck volumes are low • Easy to modify detection zones • Provides view of roadway for verification purposes	• Undercounts when truck volumes are high • Requires lighting at night or IR camera • Accuracy reduced during some light and weather events
Multi-beam infrared (IR) detectors	• Non-intrusive • Scheme F classification by detecting axles	• Vandalism and theft potential • Accuracy compromised by weather • Installation causes minor traffic interference • High cost for some sites
Acoustic detectors	• Non-intrusive • Multiple-lane detection • Insensitive to precipitation	• Temperatures affect data accuracy • More time for setup than other systems

- Some technologies have not been sufficiently tested for motorcycle detection.

Promising technologies for motorcycle detection should be able to address several detection and classification issues that are unique to motorcycles. These issues include the ability to distinguish motorcycles from subcompact cars and the ability to count motorcycles in groups. The combination of one or more detector systems (multi-technology) may better address motorcycle detection where size is critical. Following are some salient points regarding new technologies that might be candidates for field testing. One of the options is a viable multi-technology system. Some of the technologies discussed in the next sections were not included in the testing conducted for NCHRP Project 08-81 but may merit additional research in the future.

Inductive Signature Technologies. As part of a project sponsored by the Arizona DOT, TTI had requested information on an alternate ground truth system offered by Inductive Signature Technologies, Inc. (IST) (*32*).At that time, some uncertainty existed about the IST system's perceived lack of maturity compared to another system using similar technology. Since that time, the IST system has been involved in an FHWA-sponsored research project on length-based classification (*33*). However, the IST system is still not market ready as it requires special knowledge for interpretation of results and special skills to install the system in the roadway. For these reasons, the research team elected not to test the IST system as part of NCHRP Project 08-81.

Segmented Piezoelectric Axle Sensor. Recent tests of a segmented sensor for high resolution detection show high potential for detection and classification of motorcycles. However, this sensor is still in the development stage, with the Florida DOT sponsoring early proof-of-concept tests of prototypes (*34*). The concept involves multiple sensing elements housed in a single long channel. The finished product will probably look like a standard piezoelectric sensor in most ways, with the exception that along its length it will have several independent sensing elements. The length of each sensing element will determine the accuracy of the sensor in establishing tire widths, tire separation in dual tire configurations, and detecting motorcycles. Early prototypes were 8.0 ft in length. Researchers used a modeling approach to determine optimum segment dimensions. They varied segment lengths from 0.5 in. to 4.0 in. in increments of 0.05 in. Results indicated that a length of less than 0.9 in. can result in 100 percent discrimination between dual and single tires. The research report did not comment on whether this length would be feasible (*35*).

Field test results of the segmented sensor indicated that it can differentiate between single and dual tires and that such distinction can significantly improve vehicle classification accuracy. Additional research is needed to improve polymer materials for better conductivity and to improve the electronic interface to increase the speed and accuracy of segment closure detection. Additional research on optimum segment lengths for other applications not included in the initial field tests (e.g., super single tires, motorcycles, and bicycles) also is needed (*34*). Independent information from both the developer of the sensor and the Florida DOT in October 2011 indicated that the Florida DOT will continue funding to support further development of the segmented sensor. However, this sensor was not ready for field testing in NCHRP Project 08-81.

Modified Radar Detector. In 2010, TTI tested a modified Wavetronix SS-125 High Definition (HD) radar detector, which is designed for motorcycle and bicycle detection (*36*). Results from a local high speed freeway (SH 6) in College Station, Texas, provide an indication of the HD detector's performance during heavy rain on 1 day compared to a similar period on the following day with no rain. Its overall count accuracy for all vehicles during this 50-minute period was 99.4 percent both during the heavy rain and 99.4 percent during a dry period of the same length. An evaluation to determine the number of motorcycles that would be detected assuming length bins of less than 10 ft and less than 8 ft (with the latter bin intended to contain only motorcycles) revealed that lanes nearer the HD had greater propensity to overcount vehicles of the selected lengths.

Results from a 2010 study at one of TTI's controlled test facilities indicate that detection accuracy of motorcycles in a staggered pattern was 96.1 percent, and the average speed difference between the HD and a baseline GPS unit was 0.33 mph with a standard deviation of 1.49 mph. Similar results were obtained with motorcycles side-by-side as long as they were separated by about one lane-width (*36*). The research team made repeated attempts to contact the manufacturer of this radar detector without success. The FHWA contact on the SBIR test pertaining to this sensor recently divulged that the manufacturer had declined the opportunity to enter Phase 2 testing. Given that the current modified detector had been tested already, the research team did not pursue further tests in NCHRP Project 08-81.

Wireless Magnetometers. Early tests using single wireless Sensys Networks magnetometers for detection of a mix of vehicles resulted in reasonable performance, which has since improved. Since these early tests, the manufacturer has added sensitivity settings that should improve the detector's motorcycle detection. The manufacturer also has recommended installing two or three detectors in a side-by-side configuration to increase the detection area of these detectors, making it less likely that motorcyclists can avoid the detection area.

The most recent evaluation of Sensys Networks magnetometers (prior to NCHRP Project 08-81) occurred at the TTI test facility in College Station in 2011, although this test still did not specifically target motorcycle detection. The testing used three physical magnetometer configurations and various extension times to determine the best count accuracy. This research used contact closure cards and a vehicle classifier to receive input from the magnetometers and compared detections to a high end classifier using inductive loop signatures. Findings indicate that a single wireless magnetometer sensor can produce excellent count accuracy for the full range of vehicle types when the proper extension time is used (especially with a significant number of large combination trucks). The research explored the recommended settings, finding that when the proper extension time was implemented, wireless magnetometers provided consistent count accuracy greater than 99 percent when compared to the accurate baseline system. Based on early tests and a local representative who could provide technical support, this detector was selected as a viable candidate technology for NCHRP Project 08-81.

Multi-Technology System. Prior to its testing in NCHRP Project 08-81, an earlier test in 2011 of a new multi-technology system produced by Migma Systems, Inc. also showed promise to accurately detect motorcycles, although it was not in full production during the research timeframe of NCHRP Project 08-81. With funding through an SBIR project, Migma Systems, Inc. developed a multi-technology system using an IR visible light stereo camera, an IR thermal camera, and an acoustic sensor. Each of these components had a specific detection role to play. The developers designed the system around these three components:

1. They used the IR camera to identify the riders on two- and three-wheeled vehicles.
2. They used the IR thermal camera to distinguish cars and motorcycles from bicycles.
3. They used the acoustic sensor to distinguish classes of motorcycles (*37*).

The first step in the detection process is to use the IR thermal camera to distinguish bicycles from other vehicles, keying on the unique thermal signature of bicycle wheels. Next, the distinction between motorcycles and cars comes from their different thermal signatures, with each exhibiting its own shapes and characteristics. The operator can select a subarea of the image and look at its thermal threshold and shape to determine the vehicle that generated the image. Because the IR camera technique sometimes confuses cars with motorcycles, the system offers a second source of input—the visible light (stereo) camera. Its primary source of input is the vehicle wheels. To distinguish motorcycles from cars, it searches the shape of the area around the front wheel. For a motorcycle, the front wheel area is distinct and different from that of a larger vehicle (*37*).

At this point in the classification routine, only vehicles classified as motorcycles remain. The next step is to determine if the vehicle is a motorcycle, a moped, or a scooter. These three vehicle types have distinct sound signatures, so the system uses the acoustic detector to distinguish between the three vehicle types. The research team uses digital signal processing with phase analysis of the sound to measure the spectrum features of the vehicle classes.

Migma researchers conducted an outdoor test as the Phase 1 project development concluded to determine the accuracy of the multi-technology system.

Table 6 shows the results, indicating some classification errors. Out of 12 cars, the system classified one as a heavy motorcycle and one as a light motorcycle. Out of 14 heavy motorcycles, the Migma system classified three as cars. Out of four light motorcycles, it classified one as a car; and of

Table 6. Summary of classification results from Migma detection system.

Vehicle Class	Bicycle	Heavy Motorcycle	Light Motorcycle	Car	Moped	Scooter
Bicycle	**8**	0	0	1	0	0
Heavy Motorcycle	0	**11**	0	3	0	0
Light Motorcycle	0	0	**3**	1	0	0
Car	0	1	1	**10**	0	0
Moped	0	0	0	0	**3**	0
Scooter	0	0	1	0	0	**2**

Source: Reference (*37*).

nine bicycles, it classified one as a car. It classified all three mopeds correctly, but it classified one of three scooters as a light motorcycle (*37*).

The Migma research team identified reasons for the inaccuracies and has worked to improve the weaknesses. The team is continuing this refinement in the SBIR Phase 2 project, which is currently underway. Phase 2 includes testing the system with motorcycles traveling in a group and testing in inclement weather. Given that Migma Systems, Inc. promised to provide a detection system and technical support during the field tests for NCHRP Project 08-81, the research team included this multi-technology system in field testing.

Estimating Motorcycle VMT

Six states currently use seasonal and day-of-week factors derived solely from continuous counts of Class 1 vehicles to convert short counts of Class 1 vehicles to estimates of AADT. Because the use of Class 1 vehicles is subject to substantially greater seasonal and day-of-week variation than the use of vehicles in other classes, use of factors derived solely from continuous counts of Class 1 vehicles is usually a prerequisite for producing reasonable AADT estimates for these vehicles. One additional state was expected to start deriving factors solely from continuous counts of Class 1 vehicles in 2009, and two more plan to do so in the future (*38*).

Ten states develop VMT estimates for Class 1 vehicles without using factors derived solely from counts of Class 1 vehicles. These states did not indicate any plans for changing this procedure. Another option for producing improved estimates of motorcycle crash and fatality rates is to implement procedures for estimating the VMT of Class 1 vehicles that do not require vehicle counts (*18*).

Additional sources are available from which to obtain data on the number of motorcyclists riding on which roads. This section summarizes current methodologies for calculating incident and fatality rates when the available motorcycle volume and VMT data are less than comprehensive. It also covers adjustment factors that are available for use in related calculations.

Motorcycle Registration Data. Registration data contain demographic data and data about motorcycles. However, there are issues that obscure the connection between registration data and exposure data. These issues include:

- Some motorcycles may not be registered (though unregistered motorcycles are probably untagged and therefore not ridden on public roads).
- Some riders own and register multiple motorcycles (but can ride only one at a time).
- The registered owner may not be the person riding a motorcycle.
- At least one state offers lifetime motorcycle registration.

The U.S.DOT re-baselined its motorcycle fatality rate measure for FY 2008 to reflect a change of focus from fatalities per 100 million VMT to fatalities per 100,000 registrations (*39*). VMT is considered the best measure for exposure because it measures actual miles traveled and is U.S.DOT's preferred method of measuring fatality rates. Measures of effectiveness of highway safety trends must include exposure to be meaningful. For example, fatality rates based on population, the number of registered vehicles, or the number of licensed drivers are of little value as analytical tools due to lack of exposure data.

Motorcycle Sales Data. Data are available on the number of motorcycles sold in the United States every year. These data help provide a rough estimate of the number of motorcycles that may be on the road, but they are not particularly helpful in understanding the number of miles ridden or demographic data on riders. For example, motorcycle sales data do not reflect miles ridden on older motorcycles or miles ridden by non-owners. Also, many motorcyclists own more than one motorcycle, which potentially skews the data.

Motorcycle License Data. All states require motorcyclists to have a separate motorcycle license or endorsement. However, research shows that a high proportion of riders have not obtained motorcycle licenses. There is also possibly an equally high population of licensed motorcycle riders who do not ride.

Highway Usage Data. States are required to keep data on the number and nature of vehicles using major highways. These data may give some insight into the number of motorcycles on these roads and the numbers of miles being ridden, but the data might not come from highways where most motorcyclists are traveling.

Travel Demand Data. States maintain data on the extent of road usage so that they can make forecasts of future needs and they can determine the effects of traffic on the environment. These data may not contain information about how much of this traffic consists of motorcycles.

Surveys of Motorcyclists. It may be possible to determine information on motorcycle travel by surveying motorcyclists. The advantage of this approach would be gathering a large amount of information on riders. The disadvantages would be the same disadvantages of survey research discussed above, plus the fact that all data would be self-reported and self-reported exposure data may not be accurate. Potential surveys include:

- National Household Traffic Survey (NHTS): This survey samples households by telephone (including cell phones) from all regions across the country. The data collected include demographic characteristics of households, people, vehicles, and detailed information on travel for all purposes by all modes (5 percent owned motorcycles, 3.6 percent of all vehicles were motorcycles) (*40*).
- Origin and destination (O & D) surveys: These surveys gather travel information and often are used by agencies to determine future traffic patterns.
- Driver exposure surveys: These surveys examine the relative safety of the road transport system by asking drivers to provide information about distance and duration traveled as well as "opportunities for accidents"—the drivers' exposure to the possibility of accidents.

Roadside Counts. One way to determine the number, and to some extent the nature, of motorcycles on a particular roadway is to manually count motorcycles through visual observation. The results can include estimates of motorcycle size and type (e.g., sport bikes, cruisers) and determination of riders' helmet status (e.g., type of helmet or no helmet). Helmet type (e.g., no helmet, novelty helmet, or full-face helmet) could determine whether the observer could determine driver age, race, and gender.

Recorded Video from Traffic Cameras. Many states and local jurisdictions have traffic cameras that are capable of recording traffic for subsequent analysis. This option would be similar to roadside counts except that the camera locations might not be optimum for capturing motorcycle travel, and the orientations and positions of the cameras might preclude capturing certain critical details.

Insurance Company Data. Insurance companies keep records that may contain information on number of motorcycles in a household, number of riders, and percentage of use of each motorcycle by each rider. Data would also include demographic data and may include crash data. However, insurance companies do not generally make data available for research purposes, and the data are often not sufficiently detailed for research purposes.

Agency Engagement

The information in this section comes from a survey of 10 state DOTs that responded to questions about the technologies and methodologies they used (successfully or unsuccessfully) to detect motorcycles. DOTs in the following states were surveyed:

- Arizona
- California
- Colorado
- Florida
- Minnesota
- New York
- Ohio
- Oregon
- Virginia
- Washington

Technology Used by State DOTs

Arizona

The Arizona DOT found that using inductive loops and piezoelectric sensors in combination is effective in detecting motorcycles in most cases. The rating that the Arizona DOT personnel gave for other technologies (inductive loops alone, magnetometers, and radar) was "poor." For video, their rating was "good with manual classification," apparently meaning that they recorded video and conducted a subsequent off-line manual classification. The Arizona DOT has experienced an average life expectancy of the loop/piezo system of 7 years. Loops cost the Arizona DOT about $1000 installed and piezos cost about $900 each (length not specified). Assuming two piezos and one loop per lane, the system installation cost would be about $2800 per lane.

The Arizona DOT included some comments about the strengths and weaknesses of each technology. The strength of the inductive loop was that it works well in all traffic conditions. Its weakness is that it needs piezoelectric sensors to detect motorcycles. A strength of an older magnetometer is that the user can adjust the sensitivity, but the weakness is the high cost of installation (which includes boring under the roadway). The strength of piezoelectric sensors is their accuracy, but their weakness is that they need inductive loops for presence detection.

California

The California DOT (Caltrans) has considered a number of different technologies to detect vehicles in general and motorcycles in particular. Technologies used by Caltrans have included:

- Inductive loops
- Piezoelectric sensors
- Magnetometers

- Radar
- Video

Caltrans has recently created a policy of minimizing the presence of personnel on the roadway for installation and maintenance of detectors. Caltrans engineers are actively evaluating newer technologies with an emphasis on non-intrusive technologies while maintaining accuracy, cost, and ease of use. Based on experience, Caltrans has found that a combination of inductive loops and piezoelectric sensors provides the most accurate and most cost-effective technology to count vehicles and motorcycles. Some districts within Caltrans are experimenting with magnetometers. However, details pertaining to their accuracy were not available. Caltrans has encountered numerous issues with radar accuracy for counting motorcycles, including occlusion of motorcycles due to larger vehicles. Caltrans also has found video detection to be expensive and not very accurate.

Like other states, the objective of the Caltrans vehicle monitoring program is to collect data on all vehicles, including motorcycles. In addition, Caltrans routinely sets up temporary detector stations using pneumatic tubes at locations with observed higher proportions of motorcycles. These temporary count stations typically include 1 week of data.

The primary metrics used to select technologies are accuracy, cost, ease of setup, and vendor support. However, the agency has not conducted a formal analysis of the accuracy of technologies for detecting motorcycles. The cost of installation and maintenance of a detector station is an important factor for Caltrans. Caltrans spends approximately $50,000 for an inductive loop/piezoelectric sensor system on four lanes, which typically requires 1 night to install. If the installation is done properly, the only required maintenance is an occasional calibration of the counter.

Colorado

The Colorado DOT has found that inductive loops alone are not accurate in detecting motorcycles, so the Colorado DOT uses piezoelectric sensors along with loops to improve motorcycle detection. Evaluation metrics were accuracy and cost, supplemented by the fact that the Colorado DOT already uses piezos and loops for volume and classification data collection (for all vehicles). The Colorado DOT has not formally tested the accuracy of this system or other detection technologies for motorcycles.

Florida

The Florida DOT considered inductive loops and piezoelectric sensors to be the most accurate for detecting motorcycles, although there had been no formal evaluation specifically targeting motorcycles. The Florida DOT loops are spaced 16 ft apart lead to lead with a 6-ft piezoelectric sensor between the two loops covering one wheel-path. Even though the Florida DOT had not tested this system for motorcycle detection, their spokesman said it “seems to detect most of them if they do not intentionally avoid the sensors.”

According to the Florida DOT spokesman, the problem with this system in detecting motorcycles is in classification since the number of small cars with a similar wheelbase has increased. The inductive loop/piezoelectric sensor system cannot distinguish between them, so there is a fair amount of misclassification. The Florida DOT also uses pneumatic tubes for short-term counts, and they appear to detect almost everything that crosses them.

The Florida DOT has investigated other technologies such as video, radar, and magnetometers. The radar was not very accurate for vehicle classification although the Florida DOT did not conduct a formal test of its accuracy for motorcycles. It overestimated the number of trucks by a large factor at one site over a 1 month period. The Florida DOT also tested wireless magnetometers placed two per lane, and they counted accurately but could not classify length well enough to meet the state DOT’s needs. The same was true of Mio-Vision video in a Miami test—the video counted well, but it was not sufficiently accurate at classification.

Life-cycle costs are a function of the life of each component of the system (loops and piezos). The Florida DOT experiences about a 5 to 6 year life with piezoelectric sensors. Inductive loops usually last twice as long—10 to 12 years. The major factor in the life of in-pavement systems is the care during installation used by the installation contractor. The Florida DOT did not provide information about actual costs, just the time they last. The actual installation time for the inductive loop/piezoelectric sensor system is about 2 hours, but adding in traffic control setup and removal and epoxy cure time plus loop sealant cure time takes a full day for a two-lane site.

The Florida DOT has not found a satisfactory non-intrusive detection system to cover all vehicle types. For that reason, the agency continues to use inductive loops/piezoelectric sensors for long-term counts and pneumatic tubes for short-term counts.

Minnesota

The Minnesota DOT uses one non-intrusive detector for motorcycle detection: side-fire radar. The Minnesota DOT also uses two intrusive systems for motorcycle detection—one with piezoelectric sensors and loops and the other with quartz weigh-in-motion sensors and inductive loops. The Minnesota DOT also uses pneumatic tubes for short-term counts.

The Minnesota DOT has found that the radar detectors are very good for motorcycle detection in free-flow conditions. Road tubes, piezoelectric sensors, and sensors using quartz technology are only accurate if they cover the full lane-width. For cost of each detector type, the Minnesota DOT specified a first cost and a cost per year to maintain. The initial cost of the radar is $6000, with an additional cost of about $600 per year. Road tubes cost the Minnesota DOT $2000 initially plus $200 per year, piezos cost $1200 per lane and $200 per year, and quartz sensors cost $25,000 per lane and $5,000 per year per lane.

A negative feature of radar is the need for a bucket truck for installation and maintenance, plus it does not detect as well in stop-and-go traffic. Occlusion is also a factor that affects its accuracy for motorcycles and some other vehicles. A negative feature of road tubes is they are not appropriate for high volume sites due to risk to installers. A problem with piezoelectric sensors and quartz sensors is their higher cost and they miss motorcycles if the motorcycles are near the centerline.

New York

The New York State DOT uses inductive loops with piezoelectric sensors for long-term counts involving motorcycles and two pneumatic tubes with portable counter for short-term counts. The agency's desired accuracy is 95 percent, and the state believes their detectors achieve that accuracy. The New York State DOT spends about $40,000 for each two-lane classification site using inductive loops and piezoelectric sensors.

Ohio

The Ohio DOT reported that the LPL configuration has been the mainstay for its overall permanent classification program. The Ohio DOT found inductive loops and piezoelectric sensors arranged in this configuration to be the most reliable and accurate sensors for collecting vehicle classification data. According to an Ohio State University (OSU) research project conducted at one of the Ohio DOT's permanent count stations, the LPL counter properly recorded motorcycles 96 percent of the time. OSU conducted the study over a 4-hour period on one lane using a video recorder and manual data verification. This was part of an overall classification study at one permanent count station in Columbus, Ohio.

The Ohio DOT reported that a LPL site currently costs approximately $10,300 per lane to install. To reinstall sensors only, the cost is approximately $4,900 per lane. Depending upon pavement conditions, sensors need to be replaced every 4 to 5 years. The strength of this technology is that it is fairly accurate across all vehicle classes. A weakness of this technology is that it fails quickly mainly due to pavement conditions. In addition, it is expensive to install, requiring lane closures to install and/or maintain.

Oregon

The Oregon DOT uses inductive loops and piezoelectric sensors for motorcycle detection and has found that it provides acceptable results, verified by video recordings. Whereas some states have reported using piezos covering only one wheel-path, the Oregon DOT uses a longer piezoelectric sensor to cover the full lane-width. Oregon DOT personnel did not report either the life-cycle cost or the initial cost of any technologies. Of other technologies that the Oregon DOT investigated, radar required less time in the road, which represented a safety and mobility improvement. Also, radar handles lane changes better than other technologies.

Virginia

The Virginia DOT has found that inductive loop and piezoelectric sensor systems are accurate at detecting motorcycles. However, the Virginia DOT has developed an improved system for collecting classification data as well as a post-processing methodology to improve detection of light vehicles. Starting on the data collection side, the Virginia DOT developed a specification for a high performance inductive loop board. The loop board is a 4-channel board, which reduces crosstalk by scanning channels. The manufacturer described the better performance of this board as follows: "the detector puts out a higher signal on the loops to increase signal-to-noise ratio." Also, the Virginia DOT has pretty exacting standards for installing loops that likely contribute to better performance. Components of these standards include:

- All loops installed with 4 turns of wire
- No wire splices allowed
- Wire meets International Municipal Signal Association (IMSA) 51-7 specification
- 4 in. deep installation (primarily to survive milling)

Similar to the inductive loop board, the Virginia DOT's piezoelectric sensor board is not an off-the-shelf item. Several years ago, the Virginia DOT worked with a supplier to gather a large number of waveform signals that might typically be found in Virginia. They developed a piezoelectric card with the capability to analyze complex waveforms rather than one that was simply a threshold detector. This board can handle a wide voltage range and also rejects adjacent lane energy.

The Virginia DOT's piezoelectric sensor installation standard is different from that of some states. The Virginia DOT does not use single wheel-path installations—it only uses full lane-width piezos. The Virginia DOT tried several different approaches (e.g., high output piezos, various grout materials) to improve the longevity of the installation. Current practice involves the installation of two piezoelectric sensors per lane, stacked in a single sawcut. The stacked configuration places a piezo at 2.5 in. below the surface and another at 1.5 in. below the surface in the same sawcut. The Virginia DOT results to date have been very good, with optimum motorcycle classification accuracy as high as 98 percent.

With regard to the data processing component, a basic understanding of the Virginia DOT system is essential. In the early morning hours of each day, the Virginia DOT autopolls its count stations and uploads the data to its database. During the upload of data, its system completes a number of automated checks based on established performance criteria. It outputs informational and error messages based on these checks. Upon arriving at work later that morning, the Virginia DOT's continuous count station (CCS) data analysts review the messages from previous day(s) and assign a quality rating to the data. Some messages relate specifically to the settings, programming, and maintenance of the loop. Such messages may also trigger specific actions, such as an information service call to a contractor, a site visit, or scheduling and prioritizing repair of a count station.

With the assistance of vendors, the Virginia DOT developed a unique loop/piezo system for monitoring motorcycle travel. It involves a 21 bin table for capturing motorcycles as degraded piezoelectric sensors start missing hits of lighter vehicles like motorcycles (*see* Table 7). Even though it works well for most detections of motorcycles, the system still misses Class 1 vehicles that straddle lanes or that ride side-by-side or in tight packs. The Virginia DOT also stated that there are issues to be addressed in concrete pavement with significant rebar and missed detections of smaller motorcycles (mopeds, scooters, etc.). In general, the Virginia DOT has observed that its system accurately classifies full-size motorcycles as Class 1 or Class 21, depending on the piezo signal.

Table 7. The Virginia DOT 21 bin classification table.

Vehicle Class	Description
1 through 15	Standard vehicle classification
16 and 17*	1 axle detected Class based on magnetic length
18 and 19*	Zero axles detected Class based on magnetic length
20	Zero or 1 axle detected Magnetic length over 22 ft
21	Zero or 1 axle detected Magnetic length less than 7 ft

* Equivalent to FHWA (Scheme F) Class 2 and Class 3.

Figure 10 indicates how the Virginia DOT results change with replacement of a failing piezoelectric sensor, indicating that motorcycles are detected even as the sensor's signal degrades. With the old failing sensor (prior to the swap in April 2008), significantly more vehicles were recorded as Class 21 vehicles than afterward with the new sensor. Basically, Class 1 vehicles replaced Class 21 vehicles. In either case, the Virginia DOT system generally counted the motorcycles correctly as either Class 1 or Class 21.

The cost of the Virginia DOT system is about $20,000 for a two-lane installation of two inductive loops and one piezoelectric sensor per lane. The Virginia DOT reports that properly installed loops can last indefinitely, while piezo sensors have a shorter life. The Virginia DOT reports a cost of $9,000 (in the context of a two-lane system) for replacing piezoelectric sensors, which is considerably higher than other states reported.

Finally, the Virginia DOT emphasizes that, even with the implemented enhancements, motorcycles remain a difficult class to monitor. Ridership patterns (e.g., weekends, fair weather) increase the difficulty of this class even when equipment works optimally.

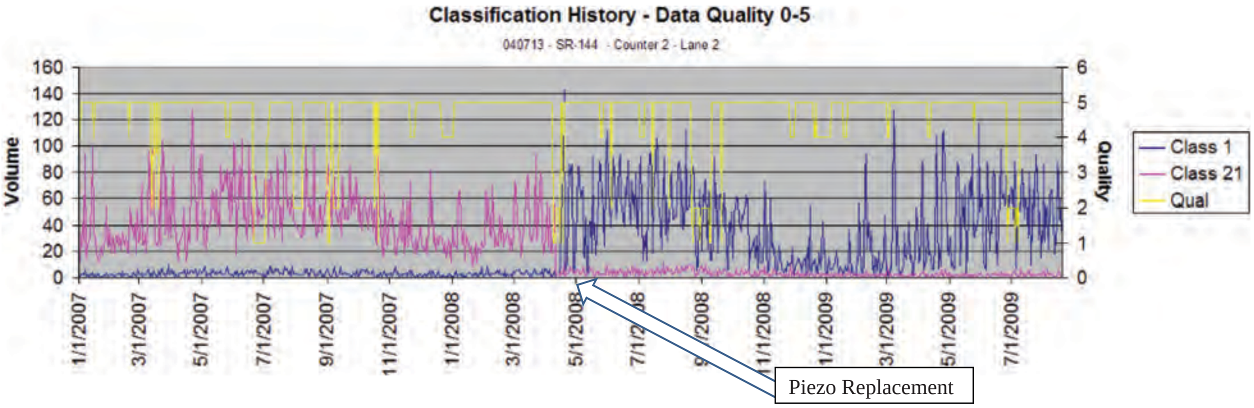


Figure 10. The Virginia DOT classification results change with new piezoelectric sensor.

Washington State

The Washington State DOT has investigated using inductive loops, magnetometers, radar, and piezoelectric sensors. The metrics used to evaluate the sensors include:

- Accuracy (using manual verification counts).
- Cost (compared to similar equipment).
- User interface: The DOT ensures that the equipment interfaces well with its own software and checks hardware compatibility as well. The agency wants its technicians to be able to learn the system quickly.
- Vendor support: The DOT needs to easily contact the vendor, to get questions answered quickly, to get quick turnaround on hardware orders, and to have materials delivered quickly.

The Washington State DOT found that radar was reasonably good for motorcycle detection but that its classification accuracy was not as good. Magnetometers and video were less accurate, but inductive loops and piezoelectric sensors could be excellent with proper setup.

Life-cycle costs were not available. The initial cost of an inductive loop was $1,600, and a loop typically lasts from 5 to over 30 years. The initial cost of a piezoelectric sensor was $1,200, and a sensor might last 3 to 5 years.

According to the Washington State DOT, the pros and cons of each technology are as follows:

- Inductive loops/piezoelectric sensors
  - Pros:
    - Proven technology
    - Very accurate speed and length classification
    - Inexpensive installation costs
    - Loops can be used in conjunction with piezoelectric sensors for 13 bin axle classification
  - Cons:
    - Static position
    - Dependent on road conditions
- Magnetometers
  - Pros:
    - Quick and easy installation
    - Reasonably accurate counts
    - Inexpensive to add lanes
  - Cons:
    - Poor interface with customer-supplied equipment
    - Poor speed data
    - Poor length data
    - No 13 bin classification
- Radar
  - Pros:
    - Non-intrusive technology
    - Accurate when using higher level equipment
    - Accurate counts in areas where there is a lot of lane shifting
  - Cons:
    - Poor vehicle lengths
    - Speeds just averaged
    - No axle classification
- Video
  - Con:
    - Does not meet minimum standards for vehicle count and classification data

Table 8 summarizes the technologies used by state agencies that were contacted by the research team. In some cases, state DOTs reported on technologies not currently used but evaluated using non-formal procedures. The comments generally emphasize motorcycle detection but also consider other vehicle types.

Methodology Used by State DOTs

The Arizona DOT submits motorcycle data to meet the HPMS requirement by aggregating motorcycle data on a statewide level. The only other comment that Arizona DOT provided about this reporting was that they ". . . count [motorcycles] based on general observations as we do with other vehicles."

Alternatively, state DOTs have the option of reporting disaggregated data by highway class, urban area (or urban/rural), roadway segment, or other. Agencies that choose disaggregate reporting have the opportunity to describe how they determine locations to monitor motorcycle travel.

The Caltrans data collection group collects the data at designated count stations, runs it through data checks, and provides the data to the HPMS group in Caltrans. These data come from both the permanent count stations and the temporary count stations. HPMS then applies certain factors to the data to generate motorcycle counts for reporting purposes.

The Colorado DOT monitors motorcycle travel at the same locations where permanent count stations are located and where 24- to 48-hour counts are available.

The Florida DOT investigated and established the sites for all traffic data collection about 20 years ago (not specifically targeting motorcycles). The state has 300 CCSs to cover 12,000 miles of roadway across the state. The Florida DOT wants at least one classification site on each roadway section per county, although some districts have more than the minimum.

The Minnesota DOT counts motorcycles at the same classification sites as other vehicles. The detection equipment used is piezoelectric sensors and loops or quartz sensors and loops.

Table 8. Summary of technologies and assessments by state agencies.

Agency	Technology	Pros	Cons
Arizona DOT	Inductive loops/piezoelectric sensors	Good in all traffic conditions	N/A
	Video with manual classification	Good (with manual classification)	Poor by itself
	All others	N/A	Poor
Caltrans*	Inductive loops/piezoelectric sensors	Most accurate detector Cost effective	
	Radar	N/A	Poor motorcycle detection
Colorado DOT*	Inductive loops alone	N/A	Poor motorcycle detection
	Inductive loops/piezoelectric sensors	Accuracy and cost acceptable	
Florida DOT*	Inductive loops/piezoelectric sensors (sequence: LPL)	Most accurate detector	Cannot distinguish subcompacts
	Radar	Count accuracy acceptable	Class accuracy poor
	Other non-intrusive sensors	N/A	None found acceptable
Minnesota DOT	Radar	Accurate in free-flow	Need bucket truck to install
	Road tubes	OK if full lane-width	Short-term counts only
	Piezoelectric sensors	OK if full lane-width	N/A
	Quartz WIM**	OK if full lane-width	N/A
New York State DOT	Inductive loops/piezoelectric sensors	Use for long term	N/A
	Road tubes (two)	Use for short term	N/A
Ohio DOT	Inductive loops/piezoelectric sensors (sequence: LPL)	Primary for all class counts 96% accurate for motorcycles	N/A
Oregon DOT	Inductive loops/piezoelectric sensors (full lane-width)	Acceptable accuracy for motorcycles	N/A
Virginia DOT	Inductive loops/piezoelectric sensors (full lane-width) -High performance loop board -High output piezos -21 bin class table	Highly accurate for motorcycles	N/A
Washington State DOT	Inductive loops/piezoelectric sensors	Accurate, low cost	Static position, longevity a function of pavement condition
	Radar	Accurate if high level equipment Accurate for lane changing	Poor vehicle lengths and speeds
	Magnetometers	Accurate counts, easy to install	Poor vehicle lengths and speeds
	Video	N/A	Poor length and class

*No formal analysis conducted specifically for motorcycles.
**WIM = weigh-in-motion.

The New York State DOT collects data for HPMS on a statewide aggregated level. The agency estimates statewide motorcycle travel data based on growth factors.

The Ohio DOT reports motorcycle travel on a disaggregated level by highway class and by urban or rural categories. The Ohio DOT does not currently select sites based specifically on motorcycles, but uses the statewide data collection plan based on roadway groupings.

The Oregon DOT collects enough samples and breaks state roadways into enough segments to satisfy its own decision-makers. The agency also collects data on non-state roadways, but it does not specifically target motorcycles. The Oregon DOT counts motorcycles based on general observations as it does with other vehicles. The Oregon DOT does not go to extra lengths to obtain motorcycle data because the benefits would not be worth the additional cost.

The Virginia DOT reports HPMS data in disaggregate form by roadway segment. The agency breaks every road into traffic links. On all roadways functionally classified as collector and above, the Virginia DOT includes sampling sections of collected classification data. Site selection is based on locations that are perceived to be best for all vehicles. The Virginia DOT collects motorcycle data at almost all locations where classification data are needed using the LPL configuration for continuous count sites and pneumatic tubes at the remaining sites (about one-third of the total sites).

The Washington State DOT does not report motorcycle data from its short count program. In its permanent count program, the agency counts motorcycles based on general observations as it does with other vehicles. The Washington State DOT collects data 365 days a year from 162 permanent locations and reports the data to FHWA by hour and by direction.

None of the state agencies contacted uses a special procedure for locating the motorcycle classification count locations. They consider motorcycles like all other vehicles and count them on the same basis. Some state DOTs aggregate motorcycle data on a statewide basis and report data by highway class and/or urban versus rural, and so forth. No agencies contacted offered special spatial or temporal considerations for motorcycles. This finding led the research team to use crash data to provide the necessary guidance on data collection protocols.

Crash Data Collection Protocols

The research team obtained information on crash data collection protocols from Michigan, Montana, Texas, and Wisconsin.

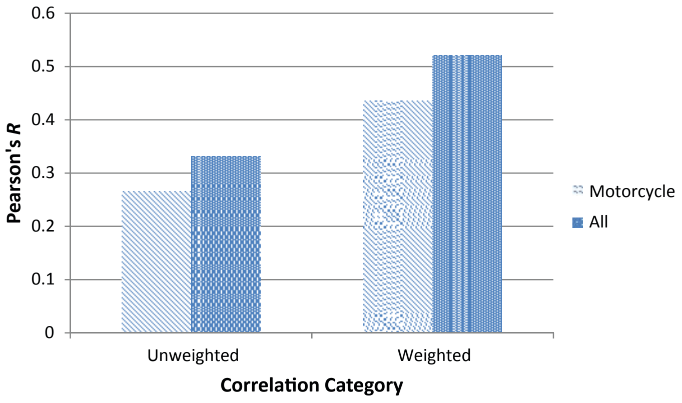


Figure 11. Correlation of motorcycle crash frequency and the traffic volume at the nearest count station to the crash (Michigan data).

For the transportation agencies at these four states, calculation of the data collection protocols used correlation coefficients (Pearson's R) to measure the association between crash frequency (unweighted and weighted) and traffic volume (motorcycle and total traffic) at the count stations nearest the crashes. Calculation of weighted crash frequency is done using Equation (1), which appears in Chapter 2 of this report as part of the discussion of the methodology used to determine the correlation coefficients.

Michigan Analytical Results

Figure 11 and Table 9 show the correlation coefficients (Pearson's R) for Michigan data measuring the association between crash frequency (unweighted and weighted) and traffic volume (motorcycle and total traffic) at the count stations nearest the crashes.

Weekday and Weekend Motorcycle Crashes in Michigan. Figure 12 and Table 10 show the Michigan crash frequency and volume count correlations separately for weekday and weekend crashes.

Table 9. Correlation of motorcycle crash frequency and the traffic volume at the nearest count station to the crash (Michigan data).

Traffic Volume Counts	Motorcycle Crash Frequency		Sample Size (N)
	Unweighted	Weighted	
Motorcycle	0.266*	0.436**	101
All	0.332**	0.521**	101

$^*p < 0.005$; $^{**}p < 0.001$

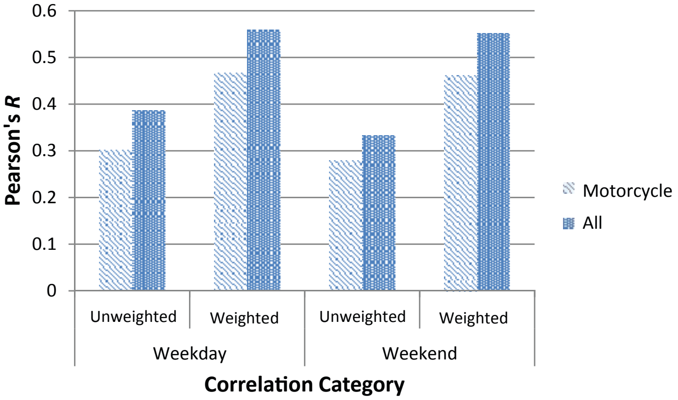


Figure 12. Weekday and weekend crash frequency (weighted and unweighted) correlated with motorcycle and total vehicle counts at the nearest count station (Michigan data).

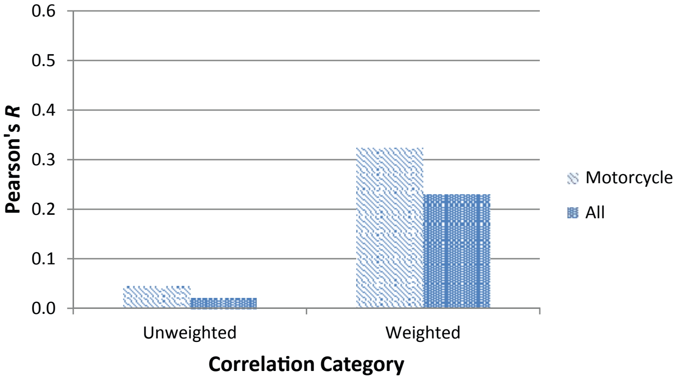


Figure 13. Correlation of motorcycle crash frequency and the traffic volume at the nearest count station to the crash (Montana data).

Montana Analytical Results

Figure 13 and Table 11 show the correlation coefficients (Pearson's *R*) for Montana data measuring the association between crash frequency (unweighted and weighted) and traffic volume (motorcycle and total traffic) at the count stations nearest the crashes.

Texas Analytical Results

Figure 14 and Table 12 show the correlation coefficients (Pearson's *R*) for Texas data measuring the association between crash frequency (unweighted and weighted) and traffic volume (motorcycle and total traffic) at the count stations nearest the crashes.

Wisconsin Analytical Results

Figure 15 and Table 13 show the correlation coefficients (Pearson's *R*) for Wisconsin data measuring the association between crash frequency (unweighted and weighted) and traffic volume (motorcycle and total traffic) at the count stations nearest the crashes.

Table 10. Weekday and weekend crash frequency (weighted and unweighted) correlated with motorcycle and total vehicle counts at the nearest count station (Michigan data).

Time Period	Crash Frequency	Traffic Volume Counts		Sample Size (N)
		Motorcycle	All	
Weekday	Unweighted	0.302*	0.387*	51
	Weighted	0.467**	0.559**	
Weekend	Unweighted	0.279*	0.333*	50
	Weighted	0.462**	0.552**	

* $p < 0.05$; ** $p < 0.001$

Weekday and Weekend Motorcycle Crashes in Wisconsin. Figure 16 and Table 14 show the Wisconsin crash frequency and volume count correlations separately for weekday and weekend crashes.

Interpretation

The purpose of this analysis was to determine if motorcycle crash locations are distributed geographically in a pattern that reflects the geographic distribution of traffic volume. The researchers first approached this analysis based on an initial mapping of crash and traffic volume data for the state of Michigan, which showed on casual observation that the two seemed to track well geographically. The goal of this analysis was to determine to what extent a state DOT might be able to rely on the spatial distribution of motorcycle crashes when attempting to determine where best to count motorcycle traffic. It was also important to identify an analysis that most states could perform in making these siting decisions for improved motorcycle count installations.

Table 11. Correlation of motorcycle crash frequency and traffic volume at the nearest count station to the crash (Montana data).

Vehicle Type	Motorcycle Crash Frequency		Sample Size (N)
	Unweighted	Weighted	
Motorcycle	0.045*	0.324**	118
All vehicles	0.020*	0.229**	289

*$p > 0.05$; **$p < 0.001$

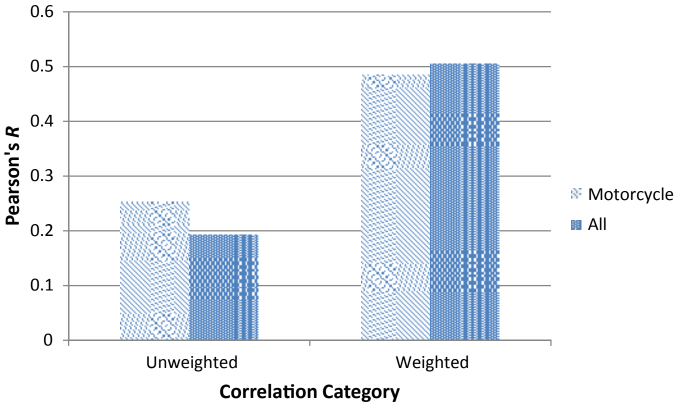


Figure 14. Correlation of motorcycle crash frequency and the traffic volume at the nearest count station to the crash (Texas data).

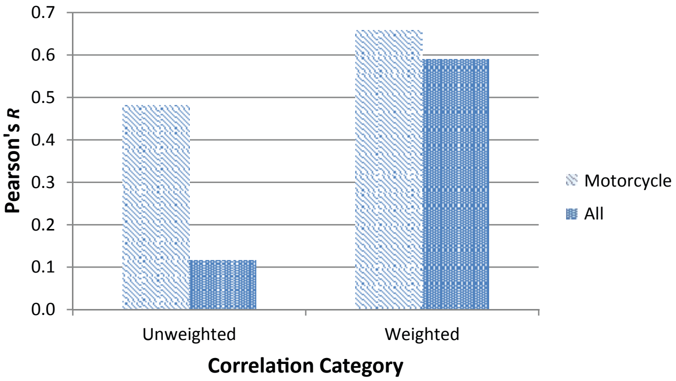


Figure 15. Correlation of motorcycle crash frequency and the traffic volume at the nearest count station to the crash (Wisconsin data).

Table 12. Correlation of motorcycle crash frequency and traffic volume at the nearest count station to the crash (Texas data).

Vehicle Type	Motorcycle Crash Frequency		Sample Size
	Unweighted	Weighted	(N)
Motorcycle	0.253*	0.485*	545
All vehicles	0.193*	0.505*	545

*p < 0.001

The research team then added data obtained from Texas, Montana, and Wisconsin and found similar results. However, the Wisconsin data using straight-line distances were not as useful as using crashes on the same roadway as the count site and measuring the distances along that roadway.

Two other findings are of interest. First, it is clear that the spatial distribution of motorcycle crashes is associated with the spatial distribution of traffic (and vice versa) to the point that a state can be confident in using crash location as an indicator of where (geographically) it should invest first in improved motorcycle count setups. Second, the logical extension is that

Table 13. Correlation of motorcycle crash frequency and the traffic volume at the nearest count station to the crash (Wisconsin data).

(a) 2007 to 2009

Traffic Volume Counts	Crash Frequency	2007		2008		2009	
		Correlation	N	Correlation	N	Correlation	N
Motorcycles	Unweighted	0.156***	40	0.853*	32	0.641*	21
	Weighted	0.425*		0.914*		0.797*	
All	Unweighted	0.174**	193	0.146**	197	0.058***	198
	Weighted	0.622*		0.626*		0.566*	

(b) 2010 to 2011 and average

Traffic Volume Counts	Crash Frequency	2010		2011		Average
		Correlation	N	Correlation	N	Correlation
Motorcycles	Unweighted	0.276***	11	--	--	**0.481**
	Weighted	0.497***		--		**0.658**
All	Unweighted	0.137**	197	0.068***	206	**0.117**
	Weighted	0.602*		0.535*		**0.590**

*p < 0.01; **p < 0.05; ***p > 0.05

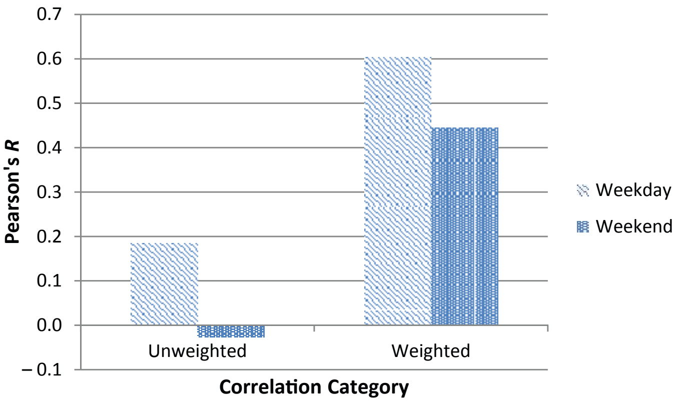


Figure 16. Weekday and weekend crash frequency (weighted and unweighted) correlated with motorcycle and total vehicle counts at the nearest count station (Wisconsin data).

the methodology works equally well for weekends and weekdays. That is, the locations of weekend motorcycle crashes can be used to determine where to conduct weekend counts just as the location of weekday crashes can be used to determine where to conduct weekday counts.

A further implication of these results is worth exploring although unproven in this research. The correlation between crash counts (weighted by the inverse distance of crashes from the nearest count station) and the total counts of all vehicles at those count stations may form the basis of a surrogate measure of motorcycle traffic volume. Because this association is a moderate level (with correlation values at about 0.50), such a surrogate measure would not have high precision; however, it would allow a state to quickly develop an estimate of the expected minimum and maximum values of overall (statewide) motorcycle traffic volume.

The goal of this part of the project was to determine if motorcycle traffic (or total traffic) and crash frequency are spatially distributed in similar ways. If they are, it is reasonable to expect that states can avoid the expense of developing separate count programs for motorcycles versus all other vehicles. The count stations can be sited in similar spots for all vehicles, including motorcycles. This is indeed what the results of this analysis indicate.

Crash Prediction Model

The research team conducted the crash data analysis while attempting to understand how to locate motorcycle count sites. The model described in Equation (4) has motorcycle crashes as the dependent variable, and the total traffic volume and motorcycle volume as the explanatory variables. Given that many non-flow related factors are known to affect the frequency of crashes, this model likely suffers from an omitted variables bias. However, the empirical assessment carried

Table 14. Weekday and weekend crash frequency (weighted and unweighted) correlated with motorcycle and total vehicle counts at the nearest count station (Wisconsin data).

(a) 2007 to 2009

Traffic Volume Counts	Crash Frequency	2007		2008		2009	
		Correlation	N	Correlation	N	Correlation	N
Weekday	Unweighted	0.248*	191	0.245*	192	0.108***	184
	Weighted	0.605*		0.658*		0.566*	
Weekend	Unweighted	0.032***	180	-0.034***	188	-0.054***	185
	Weighted	0.513*		0.442*		0.465*	

(b) 2010 to 2011 and average

Traffic Volume Counts	Crash Frequency	2010		2011		Average
		Correlation	N	Correlation	N	Correlation
Weekday	Unweighted	0.208*	190	0.114***	196	**0.185**
	Weighted	0.636*		0.551*		**0.603**
Weekend	Unweighted	-0.027***	175	-0.043***	181	**-0.025**
	Weighted	0.372*		0.432*		**0.445**

*p < 0.01; **p < 0.05; ***p > 0.05

Table 15. Estimates of the negative binomial model.

Variable	Estimate	Standard Deviation	t-statistic
Constant (β_0)	-8.0134	1.064	-7.53
$TotVol\,(\beta_1)$	0.8050	0.117	6.88
$MCVol\ (\beta_2)$	0.7671	0.391	1.96
Dispersion parameter (α)	0.6262	0.112	5.58
Log-likelihood	-320.5		
Akaike information criterion AIC	649.1		
Pearson χ^2	113.8 ($\chi^2_{0.05,107} = 132.1$)		
Sample size (N)	111		

† Standard error

out in this work will still provide valuable insights and potential applicability because the model can be easily recalibrated and applied to other states.

$$\text{MC Crashes} = e^{\beta_0} \times SegLength \times TotVol^{\beta_1} \times e^{\beta_2 \times MCVol/1000} \quad (4)$$

where:

$SegLength$ = Length of segment in the vicinity of count site (5 miles either side of the count site is considered).
$TotVol$ = Total volume at count site.
$\beta_1, \beta_2, \beta_3$ = Model coefficients derived from state database.
$MCVol$ = Motorcycle volume at count site.

The crash prediction model relied on the Wisconsin dataset and used crash data collected from 2007 to 2011. Because of the large variability in traffic flows between different years, model development considered each year separately. Table 15 summarizes the results of the negative binomial (NB) model. The Pearson χ^2 statistic for the model is 113.8, and the degrees of freedom are 107 (= $n - p$ = 111.4). As this statistic is less than $\chi^2_{0.05,107}$ (= 132.1), the hypothesis that the model fits the data cannot be rejected.

The coefficient for total traffic volume is below 1.0, which indicates that motorcycle crash risk increases at a decreasing rate as traffic flow (all vehicles) increases. It should be noted that the 95% confidence intervals for each of the coefficients did not include the origin, meaning all the coefficients in the model are significant at the 5% level.

Figure 17 shows the estimated crashes with the change in motorcycle volume when the total traffic flow changes from 20,000 vehicles per day to 100,000 vehicles per day. This figure illustrates that the motorcycle crash risk increases at an increasing rate as the motorcycle volume increases.

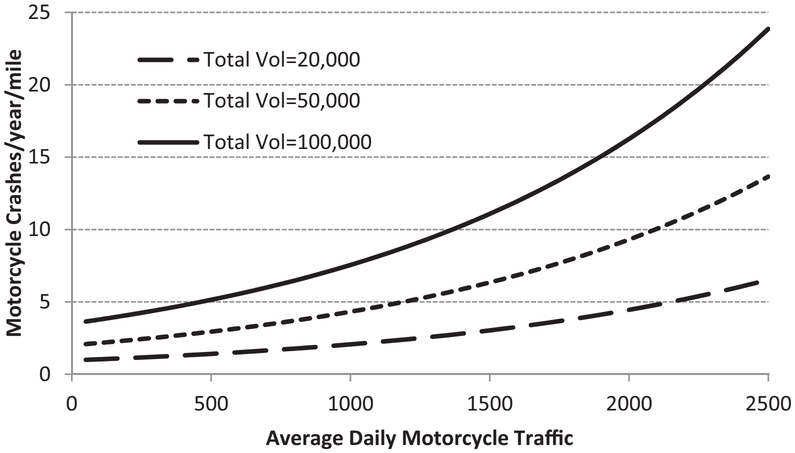


Figure 17. Relationship between motorcycle traffic volume and motorcycle crashes.

Field Data Findings

This section presents results for each of the five selected detection systems, one by one, followed by a summary. The discussion addresses the following key components to help properly interpret the results:

- Description of test conditions (e.g., road geometry, traffic volume, speed)
- Performance in detecting motorcycles
- Initial cost of the system
- Whether portable or fixed
- Technology advantages and disadvantages
- Appropriate applications of the technology

Under the category of technology advantages and disadvantages, one aspect that might not be well understood is how each detector determines vehicle classification. Detectors normally do this in one of two ways: either they detect a length or they detect axles and spacing between axles to determine the vehicle classification. The exception is the multi-technology detector, which relies on three technologies (acoustic, IR, and a stereo camera) to determine a vehicle class. The measurement using axles and spacings typically leads to a classification using FHWA Scheme F, which has 13 vehicle classes. Of the technologies tested in this research, only the inductive loop/piezoelectric sensor systems and the IR Classifier have the ability to classify directly according to FHWA Scheme F. For vehicle classification reporting purposes, the FHWA allows some states to collect data according to length but requires results to be reported as Scheme F classes. Large motorcycles (Class 1 vehicles in Scheme F) are generally less than 7 ft in length (unless they have been modified) and the smallest Class 2 vehicles start at about 7 ft in length.

Detectors that measure only vehicle length can do so based on either a physical length estimate or a magnetic length estimate, but states that use these systems must be able to create length bins that tie directly to one or more vehicle classes within Scheme F. Of the five technologies tested in this research, magnetometers and the tracking video classify vehicles based on vehicle length alone. Inductive loops (if used alone) and magnetometers use magnetic length as an estimate of physical length. The magnetic length of motorcycles is usually less than the physical length and often is even less than the wheelbase.

For each of the five test systems discussed, tabulated results are included. In the fourth column of each table is a ratio that shows the number of motorcycles detected by that system divided by the ground truth count. (Each table also indicates what technology was used to establish the ground truth). In each case, the ratio in the fourth column is converted to a percent to establish the simple detection accuracy. The last column to the right indicates that the available data were provided as per vehicle (PV) records as needed. Hourly bins were used depending on output options available from each system.

Infrared Classifier

Testing of this system involved two motorcycle rally sites: one in New Ulm, Texas, on May 18, 2012, and the other in Daytona Beach, Florida, on October 20, 2012. The New Ulm site used a two-lane roadway with width of about 18 ft with no shoulders or pavement striping so vehicles often traveled in the center of the road instead of on the right side. The speeds on this road were between 30 and 45 mph and the traffic volume was very low. The US-92 test site used for the Florida data collection was a four-lane divided highway with depressed grass median and speeds ranging from 50 mph to 60 mph. Data collection only involved the two eastbound lanes, and the traffic was always free-flowing with no interruptions. The overall traffic volume was relatively high, and the number of motorcycles passing the test site was high.

Table 16 summarizes the results of testing of the IR Classifier. Notice the ratio in the fourth column—the number of motorcycles detected by the IR Classifier divided by the actual (ground truth) count. For example, in Table 16, for May 18, 2012, the detected motorcycle count of 163 is the number classified by the IR system as motorcycles or Class 1 vehicles, and the actual (ground truth) count is 134. Converted to a deci-

Table 16. Data collection summary for the IR classifier.

Date and Location	Time Span	Ground Truth	Motorcycles Detected/Actual	Simple Detection Accuracy	Bin
May 18, 2012 Texas	13:00–18:46	Video	163/134	121.64%	PV[a]
Oct. 20, 2012 Florida	07:30–09:30	Video	709/744	95.30%	PV

[a] PV = per vehicle

mal, the simple detection accuracy on May 18 was 121.64%. The available data were provided as PV records as needed.

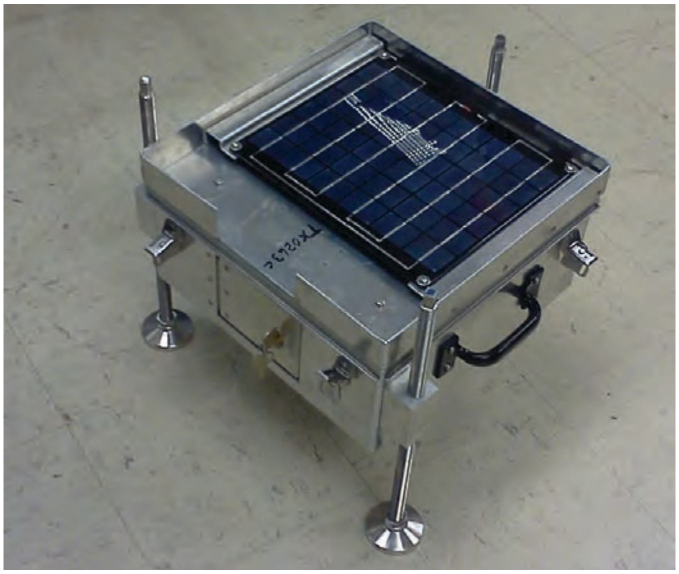
The IR Classifier motorcycle detection results at the Texas rally are clearly not as good as those at the Florida rally. Setup difficulties in Texas were likely a factor in these results. A critical factor guiding site selection in both Texas and Florida was that neither the Texas DOT nor the Florida DOT allowed placement of the IR Classifier units near high speed travel lanes without guardrail protection. Also important to site selection were the pavement cross-slope and crown. These factors are critical to getting good results given that the IR beams cross the roadway underneath the vehicle and must not be interrupted by anything but vehicle tires.

Closer scrutiny of the IR Classifier results indicated 34 false alarms at the Texas rally compared to only 5 false alarms in Florida in a much larger dataset, leading to a relatively large number of overcounts in Texas. The difference might be due to site-specific conditions, such as very slow speeds at the Texas rally on May 18 or differences in the setup. The false alarms at the Texas rally were due largely to the presence of Class 9 vehicles (5-axle tractor-semitrailers) and the incorrect classification of tandem axle groups as motorcycles. However, the Florida dataset included several Class 9 vehicles as well, and they were all classified correctly.

Based on conversations with early users, the IR Classifier was not as accurate during certain inclement weather conditions, such as heavy rain. Based on recent comparisons during a rainy season in Australia, the effects of rain seem to have been mitigated; however, the Australian results need to be verified by local tests that might include a variety of weather conditions besides just rain.

The manufacturer of the IR Classifier provided cost information based on the Indiana DOT contract prices. The cost is $23,190 for the system (transmitter/receiver, software, laser site, and power and communication cables). Portable cabinets (two each) for enclosing the electronics at the roadside cost $3,660 per set. Included in the cost are the two cabinets, a solar panel, a solar regulator, leveling legs/feet, rechargeable harness, locking lid, and battery compartment for two 12V 7Ah batteries. Figure 18 is a photo of the cabinet offered by the IR Classifier distributor. The distributor does not sell the portable tripod setup that was used for this research but uses it strictly for demonstration purposes. The total cost for the complete package, including the transmitter/receiver with its components and the two portable cabinets would be $26,850. This system has sufficient power to collect data for 48 hours. An external battery pack (additional cost of $1,050) can extend the data collection time to 7 days.

The distributor insisted that only trained personnel be used to set up the unit at all sites for this project, so researchers were unable to obtain a good understanding of how difficult or easy setup might be. All setups except one used two trained persons. With two persons, one person was stationed on each side of the monitored roadway to make adjustments to the aim of the sender-receiver system via an iterative process. The exception was the October 20 setup in Florida, where only one person was available to perform the setup.



Source: Control Specialists, used by permission.

Figure 18. Photo of IR classifier cabinet with solar panel.

Both the transmitting and receiving components of the IR Classifier system have built-in sights to assist in the aiming procedure. The lead person also has access to software on a laptop that guides the setup to optimize the aim of each component. Even then, monitoring the passage of several vehicles followed by additional adjustments appears to be required to get the best results. Setup required about 30 minutes on both October 19 and October 20, but the Texas setups took longer. Overall, the setup appears to be fairly complex, especially with portable units like the ones used for this research; however, a 30-minute setup time is certainly acceptable. Setup of a permanent site (for long-term data collection) requires a site survey and permanent enclosures on both sides of the roadway to ensure initial and continuous alignment of the beams. The manufacturer was developing an improved user's guide to assist in setup of the system, but the guide was not available as of February 2013.

Strengths of the IR Classifier are as follows:

- It can classify according to FHWA Scheme F (13 classes).
- Its accuracy for motorcycle detection is good.
- It is non-intrusive and highly portable.
- The portable unit is self-contained with its own power supply, and newer fixed units are Ethernet-equipped for direct firmware upgrades and other communication needs.

- The cost of a portable system like the one used on this project ($26,850) is acceptable given than it is reported to cover as many as four or more lanes.
- Its user interface, while likely complicated for a new user, is obviously adequate for expert users to get acceptable results.

Weaknesses of the IR Classifier are as follows:

- Site selection for portable TIRTL installation is critical for getting good results.
- Sites for permanent installations require an extensive site survey and likely additional cost.
- Battery power (without the add-on batteries) is limited to 48 hours.
- Setup by a novice user will likely be difficult and require a lengthy learning period.
- Vandalism could be an issue because the portable units are at ground level and vulnerable.

The portable IR Classifier appears to have a wide range of applications, but site selection is critical to achieving good results, especially for portable units. The distributor has stated that the Illinois DOT is using one permanently installed IR Classifier system to cover eight lanes on a high volume freeway and is satisfied with the results. The research team has not verified this claim with the DOT. The configuration tested in this research has excellent portability; it can be dismantled in a matter of minutes and placed in a compact box for transfer to the next site.

Inductive Loops/Piezoelectric Sensors

Testing of the inductive loop/piezoelectric sensor system occurred at one site, the SH 6 test facility in College Station. This roadway had an AADT of about 50,000 vehicles per day and had a speed limit of 70 mph. Texas DOT reinstalled this system in an LPL configuration in January 2012 at the same time it reinstalled the ADR-6000 inductive loops following a new hot mix asphalt overlay. The inductive loops and piezoelectric sensors are connected to an IRD TRS Rack II classifier, which is normally programmed to collect data in 15 vehicle classes and store them in 1-hour bins. Modifying the data collection parameters was a source of problems, so some of the test results are reported as hourly summaries and others are PV results.

Table 17 summarizes the data collection results for the inductive loop/piezoelectric sensor system. Appendix B shows a data sample to indicate the original format.

Results indicate a simple detection accuracy ranging from a low of 0 percent to as high as almost 90 percent. After researchers discovered the low detection accuracy of this system and alerted Texas DOT, an investigation into the issue began. Texas DOT could not correct the problem in time to redo the data collection and perhaps achieve better results.

According to Texas DOT, the initial cost of installing a four-lane inductive loop/piezoelectric sensor system like the one at College Station would be about $61,000, but cost would vary depending on the length of road bores, number of ground boxes, and length of conduit runs. Components included in the referenced cost are the controller, electronics, modem, and an 80W solar panel.

Advantages of full lane-width piezoelectric sensors with inductive loops include:

- The system is able to collect 13 vehicle classes consistent with FHWA Scheme F.
- The technology is mature.
- Necessary components are widely available.

Table 17. Data collection summary for inductive loop/piezoelectric sensor system.

Date	Time Span	Ground Truth	Motorcycles Detected/Actual	Simple Detection Accuracy	Bin
June 30, 2012	11:00–12:00 09:00–10:00	Video/ ADR-6000	5/6 2/3	88.3% 66.7%	Hourly
July 1, 2012	11:00–12:00 09:00–10:00	Video/ ADR-6000	0/3 0/4	0% 0%	Hourly
July 3, 2012	11:00–12:00 11:00–12:00	Video/ ADR-6000	4/24 10/20	16.7% 50.0%	Hourly
July 21, 2012	00:00–24:00	ADR-6000	104/191	54.45%	Hourly
July 22, 2012	00:00–24:00	ADR-6000	76/154	49.35%	Hourly
July 23, 2012	00:00–24:00	ADR-6000	41/73	56.16%	Hourly
Feb. 8, 2013	13:00–15:00	Video/ADR	20/102	21.05%	PV[a]

[a] PV = per vehicle

- How to install the components is common knowledge.
- The system is immune to weather and light conditions.

Disadvantages of inductive loops/piezoelectric sensors include:

- Sawcutting the pavement compromises pavement integrity.
- Piezoelectric sensors can fail prematurely and unexpectedly, sometimes with no warning.
- The installation places workers in close proximity to traffic.
- Installation and maintenance can cause traffic delays.
- Underground components are sometimes damaged by other roadside construction.
- Once installed, the system is not as flexible as some other systems.
- The life-cycle cost of loops and piezos could be higher than that of competing systems (e.g., if installed in weak pavement).

Applications of inductive loops and piezoelectric sensors are fairly widespread on free-flow roadways in both rural and urban areas, although many jurisdictions still use 6 ft piezos instead of those that cover the full lane-width. The inductive loop/piezoelectric sensor results from this research pertaining to motorcycles would likely be worse with 6 ft piezos. Loops alone are still used by many agencies for traffic signal detection and on freeways for collecting data such as vehicle speeds, counts, and occupancies. Given the disadvantages noted for this technology and the availability of other detection systems today, many agencies are abandoning inductive loops, at least as they fail, and are replacing them with less-intrusive devices.

Magnetometers

Testing of the wireless magnetometer system involved one site, the SH 6 test facility at College Station. SH 6 has an AADT of about 50,000 vehicles per day and has a speed limit of 70 mph. A manufacturer's representative reinstalled this system in January 2012, while Texas DOT had the lanes closed for reinstallation of the ADR-6000 inductive loops and the inductive loop/piezoelectric sensor system following a pavement resurfacing project.

Table 18 summarizes the results of magnetometer testing. The ground truth for these tests was established using a combination of recorded video and the Peek ADR-6000 classifier. Magnetometer components include the four sensor nodes in all lanes, an Access Point (AP) for communication and data storage, and electronics in the cabinet. Communication from each of the sensor nodes is wireless to the AP at the roadside, with node power provided by an internal battery. The most common usage involves simple on and off signals (vehicle present or not) much like inductive loops. The research team downloaded data for test purposes via the Internet by accessing the Sensys Networks server in Berkeley, California. Appendix C shows the original data format. The vehicle length in ft is the key value for matching these data with ground truth data. This sample is sorted by length (short to long), indicating a number of short vehicles as estimated by each vehicle's magnetic length.

The manufacturer does not market the wireless magnetometer system as a motorcycle detection system, so this research is the first known effort to quantify the accuracy of these detectors for motorcycles. The positioning of the sensor nodes at SH 6 was intended to accommodate the widest variety of uses for current and future research purposes, not just for this project. This research kept all five nodes turned on in each lane for all tests; however, only motorcycles traveling in the center of the lanes generated a speed and vehicle length (i.e., due to the 1-3-1 pattern, motorcycles centered in the lane crossed three center sensor nodes).

Because this was the first motorcycle test for this detector, its detection attributes were not well understood at first, either by the researchers or by the manufacturer's representative. For that reason, perhaps, and also because there might be unwanted adjacent lane detections with higher sensitivity, the manufacturer was hesitant to adjust the sensitivity to improve

Table 18. Data collection summary for magnetometers.

Date	Time Span	Ground Truth	Motorcycles Detected/Actual	Simple Detection Accuracy	Bin
July 1, 2012	10:00–11:00	ADR-6000	2/3	66.67%	Hourly
Feb 8, 2013	13:30–15:00	Recorded video	76/97	78.35%	PV[a]
Feb 22, 2013	15:00–16:00	Recorded video	11/16	68.75%	PV

[a] PV = per vehicle

motorcycle detection. As data collection and evaluation continued, analysts hypothesized that motorcycles needed to pass closer to the sensor nodes than originally thought (i.e., to within about 1.0 ft) to achieve consistent and predictable results. Close scrutiny of the February 8, 2013, data for a test in which selected riders were instructed to ride in the wheelpaths indicated that the outside sensor nodes detected motorcycles almost every time, but the center nodes did not. Randomly passing motorcyclists usually pass in the wheelpaths as well, leading to what appeared to be a high percentage of missed detections.

This finding led to another test on February 22, 2013, during which selected riders were instructed to travel over the nodes in the center of the lane. This dataset indicated that the magnetometers detected motorcycles about 70 percent of the time when passing through the established detection zone. Some riders might have missed the tiny (2 ft-wide) detection zones, and the detection rate could be even higher with better understanding of how to establish the sensor spacings and sensitivities.

Like most other systems, the magnetometer system measures vehicle length by calculating a speed, then determining vehicle length based on the speed and presence time. To do this requires two stations positioned a known distance apart. Detection of each vehicle occurred with single magnetometers on each end of the 1-3-1 pattern. A better configuration for motorcycles would be two (or three) nodes at each of the two endpoints to ensure improved detection in the wheelpaths, with the endpoints at least 12 ft apart. The research team has found that this system's accuracy for larger vehicles is similar to that of inductive loops.

Portability of this system could be improved by using a surface-mount sensor node, but the manufacturer currently has no known plans to market such a sensor. A few years ago, the manufacturer provided a few prototype surface-mount sensors for research purposes, but the manufacturer did not want them used where motorcycles might travel. Their concern was that motorcyclists could lose control if their tires struck the raised sensors.

Batteries in the depressed sensors last about 10 years, so an operating agency could install the depressed sensors as part of a semi-mobile system in which other components are moved from site to site. The agency could mount the other components on a mobile platform such as a trailer with a telescoping pole and a solar panel for power. This scenario could use the mobile components for as many sites as needed while placing the fixed sensor nodes to be used only when data collection is needed. The cost of six sensor nodes per lane (at $480 each), epoxy, extension card in the cabinet, the AP with Ethernet ($3,400), and other components (excluding the trailer) would total $15,964 for a four-lane system and $10,204 for a two-lane system. The most common option for data storage is for the manufacturer to push data to a client server, but another option is to store data on a data server in Berkeley for an additional cost. The manufacturer now provides a 5-year warranty for major components of its system.

The data results from the tests at the TTI facility on SH 6 indicate that the sensor configuration was not optimized for motorcycle detection and could probably be improved.

This magnetometer system has the following positive attributes:

- It takes less time to install than inductive loops and is less damaging to pavements.
- Its accuracy is similar to inductive loops, especially for larger vehicles.
- It uses wireless communication, so damage by other roadside work is minimized.
- The cost to cover four lanes is $15,964, and for two lanes, $10,204 (with 6 sensors per lane).

Disadvantages of magnetometers include:

- The system requires special configuration to detect motorcycles accurately.
- It is placed in the pavement, so traffic control is required.
- Pavement milling and resurfacing would destroy the sensor nodes (although they can be removed in advance of the milling operation and reused).

Applications of wireless magnetometers have become widespread in both urban and rural areas. Early concerns with battery life have been addressed, and the AP has been modified recently to be much more amenable to solar power. Magnetometers are used by many agencies for traffic signal detection and on freeways for collecting data such as vehicle speeds and counts.

Multi-Technology System

Testing of this system involved two sites—the SH 6 test facility and the motorcycle rally in New Ulm, Texas. Table 19 indicates a few of the count periods used to test this detector. Following the rally, the manufacturer modified the detector and later returned it to the researchers for further tests. In its initial form, the detector stored an image of the detected vehicle, and the storage process apparently overwhelmed the processor at high speeds. Following the September 2012 tests at SH 6, the manufacturer continued to improve the detector for future tests. For this research, the simple detection accuracy for several days and the overall detection accuracy for May 19, 2012, at the Texas rally indicate that it needs improvement. Its performance was modestly better at the rally, where speeds were slower—in the range of 30 mph to 50 mph. Considering individual hourly results for September 21, the best 1-hour

Table 19. Data collection summary for the multi-technology detector.

Date	Time Span	Ground Truth	Motorcycles Detected/Actual	Simple Detection Accuracy	Bin
May 19, 2012	09:00–12:00	Video	143/206	69.42%	PV
Sept. 5, 2012	09:20–10:30	ADR-6000	26/45	57.80%	PV
Sept. 21, 2012	17:00–22:00	ADR-6000	21/46	45.65%	PV
Sept. 22, 2012	17:00–20:00	Video	13/22	59.09%	PV
Sept 23, 2012	17:00–20:00	Video	6/21	28.57%	PV

[a] PV = per vehicle

detection rate for the Migma system was 77.78 percent (correctly detected 7 of 9 motorcycles).

None of the tests of the multi-technology sensor involved inclement weather. For this detector, the research team would anticipate a decline in performance during heavy rain or fog. Motorcyclists do not normally ride during heavy rain, so this might not be a significant factor. As noted before, however, traffic speeds were a challenge, as were traffic volumes with the earlier version of the detector. The setup of this detector was probably more difficult because of its newness and complicated user interface.

Advantages of the multi-technology detector are:

- It has a low initial cost (estimated by the manufacturer to be about $6,000).
- It is non-intrusive—it can be mounted on a pole beside the roadway.
- It has a compact size.

Disadvantages of the multi-technology detector are:

- Its accuracy for motorcycle detection must be improved.
- It is not designed to detect anything but motorcycles, so a user would have to install a second device to detect non-motorcycles.
- Its user interface needs further development.
- In its current configuration, it can only cover one or two lanes.

The multi-technology sensor has considerable potential for future data collection in situations for which a low-cost, non-intrusive sensor is needed. However, it is not ready for widespread use at this time. The manufacturer has secured additional development funding through the SBIR program. The technology appears to be conducive to solar/battery power, and its communication needs can be met with a low-bandwidth solution.

Tracking Video System

Testing of the tracking video detector involved two sites—the SH 6 test facility and the motorcycle rally in New Ulm, Texas. Table 20 shows representative results of field testing. The mounting system for the rally was a van owned by Clemson University that was driven to the site for this purpose. Its telescoping pole was about 35 ft high and its offset from the road at both data collection sites at New Ulm was about 15 ft at the May 18 site and about 25 ft at the May 19 site. However, there were no occlusion issues at the rally because of the low traffic volume. Tests in College Station involved mounting the FLIR®

Table 20. Data collection summary for tracking video.

Date	Time Span	Ground Truth	Motorcycles Detected/Actual	Simple Detection Accuracy	Bin
May 18 (day)	15:00–20:40	Video	111/168	66.07%	PV [a]
May 18 (night)	20:40–21:00	Video	9/12	75.00%	PV
May 19, 2012	09:00–12:00	Video	211/236	89.41%	PV
June 30, 2012	10:00–12:00	Video	14/18	77.78%	PV
July 1, 2012	11:00–12:00	Video	2/3	66.67%	PV
July 3, 2012	09:00–12:00	Video	46/50	92.00%	PV

[a] PV = per vehicle

camera on a 5-ft riser supported by the lower pole mast arm. This mounting location placed the camera height at about 25 ft with an offset from the nearest (southbound) lane of about 20 ft. Tests in College Station used only the southbound lanes.

Most of the testing occurred during daylight, although the period on May 18 at the New Ulm rally from 8:40 p.m. until 10:00 p.m. was after dark. Statistical tests using the IR camera comparing day versus night detections revealed that day detections were biased toward false alarms whereas night detections were biased toward misses. Nighttime errors were more prevalent with the standard camera, so the nighttime analysis only used the IR camera results. All tests at SH 6 used the standard camera because of a wavy image from the IR camera. Researchers attempted to troubleshoot the problem but were unable to find a solution in a timely manner and were under pressure to return the FLIR camera. The simple detection result indicates that nighttime detection using the IR camera was not too different from the daytime, although the sample size was small. In all cases of night detection using recorded video for ground truth either at this rally or in College Station, there was insufficient lighting to accurately determine vehicle type with a high degree of certainty.

There are two use-cases for the tracking video technology in terms of how data might be collected/processed:

- Recorded video post-processing (generally off-site)
- Real-time processing in the field where data storage occurs on-site

Overall, the cost to the consumer regarding the technology would be the same for both scenarios, but the ancillary equipment, such as the camera and the power and communication needs, would differ. For both scenarios, the user would have a field-hardened laptop PC with software loaded. The system used in this research retails for $12,000 and includes two video streams simultaneously being processed by the laptop and 1 year of hardware warranty and software add-ons and bug-fixes at no additional charge. Users also have the option of adding third and fourth “channels,” at an additional cost of $3,000 each, to allow simultaneous processing of three or four video streams. The unit costs are one-time fees, and there are no monthly or hourly usage, data processing, or user license charges.

In-office post-processing would involve two costs—one for the initial camera cost ($500 to $1,500, or higher for IR cameras) and the other for camera power and possible cost for data communication. IR (or thermal) cameras cost at least $2,500. In lieu of communication costs, an agency might choose to record its own video stream using a digital video recorder (DVR). The DVR cost might range from $1,000 to $3,000, depending on available features. However, the DVR is needed only if the agency wants to record video as opposed to recording classification counts. The laptop can store a maximum of about 1 hour of video internally without a DVR. An agency might want to store some video for verification purposes while simultaneously storing classification counts.

Real-time processing in the field would again involve two costs—one for the initial camera cost ($500 to $1,500, or higher for IR cameras) and the other for camera power (assuming no data communication). The laptop battery life should be sufficient for several days of data collection depending on the amount of processing, but it would require an auxiliary power source for longer periods. Communication methods for the laptop can vary depending on the network architecture. It can output data to agency personnel on-site in real time as well as over fiber or wireless networks. The unit comes with a mobile broadband card built into the laptop but would involve user fees.

The setup of the tracking video system was reasonably easy, and the system is reasonably portable. Moving it from one site to another could probably be accomplished by using a trailer and telescoping pole provided the pole could be stabilized to minimize camera movement during data collection. Setup for the tracking video system was easier than that for most other video systems encountered by the research team and only required setting markers (e.g., traffic cones) at predetermined locations within the viewing area.

The tracking video detector’s strengths include:

- It is a non-intrusive system.
- Video tracking is considered more accurate than tripwire video systems for difficult vehicles like motorcycles.
- The basic cost for the video system to cover four lanes (or possibly six lanes, depending on the layout) would require one laptop unit ($12,000), IR camera ($2,500), plus ancillary cables and mounting equipment (about $500), for a total of about $15,000.
- As with any video detector, this system provides a view of the roadway that can be used for verification purposes.

The tracking video detector’s weaknesses include:

- Its performance is likely to be affected by some weather conditions, such as heavy rain and fog (although this research did not confirm this assumption).
- Camera mounting situations may occur for which glare and day/night transitions cause diminished performance (a flaw that is common with most video detection systems).
- It would need to use existing stationary poles, or it could be mounted on a trailer with a telescoping pole.
- Vehicle classification is based on length, with five classification bins available.

Applications of this technology include both rural and urban count sites where adequate poles or other supports already exist. Purchasing a new pole at each site would increase the overall cost substantially. The system could potentially be trailer-mounted for monitoring remote areas. In that case, the trailer would need to provide power to the laptop, the camera, and the DVR, potentially via solar/battery power.

Summary of Field Data Findings

Table 21 summarizes the results of all systems tested that were provided individually above.

Classification of Non-Motorcycles

All of the selected detectors except the multi-technology detector have the ability to classify vehicles besides motorcycles. However, only two can classify vehicles based on axle detection using all 13 classes contained in FHWA Scheme F: the inductive loop/piezoelectric sensor system and the IR Classifier. Given that motorcycles typically are only a small proportion of total vehicles, when choosing a detector it is important that decision-makers know the classification accuracy for vehicles other than motorcycles in order to make the best overall choice.

Table 21. Summary of results for all five detectors.

Date	Time Span	Ground Truth	Motorcycles Detected/Actual	Simple Detection Accuracy	Bin
Infrared (IR) Classifier					
May 18, 2012	13:00–18:46	Video	129/134	96.27%	PV [a]
Oct. 20, 2012	07:30–09:30	Video	709/744	95.30%	PV
Inductive Loop/Piezoelectric Sensor System					
June 30, 2012	11:00–12:00 09:00–10:00	Video/ ADR-6000	5/6 2/3	88.3% 66.7%	Hourly
July 1, 2012	11:00–12:00 09:00–10:00	Video/ ADR-6000	0/3 0/4	0% 0%	Hourly
July 3, 2012	11:00–12:00 11:00–12:00	Video/ ADR-6000	4/24 10/20	16.7% 50.0%	Hourly
July 21, 2012	00:00–24:00	ADR-6000	104/191	54.45%	Hourly
July 22, 2012	00:00–24:00	ADR-6000	76/154	49.35%	Hourly
July 23, 2012	00:00–24:00	ADR-6000	41/73	56.16%	Hourly
Feb. 8, 2013	13:00–15:00	Video/ADR	20/102	21.05%	PV
Magnetometers					
July 1, 2012	10:00–11:00	ADR-6000	2/3	66.67%	Hourly
Feb 8, 2013	13:30–15:00	Rec. Video	76/97	78.35%	PV
Feb 22, 2013	15:00–16:00	Rec. Video	11/18	61.11%	PV
Multi-technology Detector					
May 19, 2012	09:00–12:00	Video	143/206	69.42%	PV
Sept. 5, 2012	09:20–10:30	ADR-6000	26/45	57.80%	PV
Sept. 21, 2012	17:00–22:00	ADR-6000	21/46	45.65%	PV
Sept. 22, 2012	17:00–20:00	Video	13/22	59.09%	PV
Sept 23, 2012	17:00–20:00	Video	6/21	28.57%	PV
Tracking Video Detector					
May 18 (day)	15:00–20:40	Video	111/168	66.07%	PV
May 18 (night)	20:40–21:00	Video	9/12	75.00%	
May 19, 2012	09:00–12:00	Video	211/236	89.41%	PV
June 30, 2012	10:00–12:00	Video	14/18	77.78%	PV
July 1, 2012	11:00–12:00	Video	2/3	66.67%	PV
July 3, 2012	09:00–12:00	Video	46/50	92.00%	PV

[a] PV = per vehicle

Table 22. Classification of non-motorcycles by inductive loops/ piezoelectric sensors.

Vehicle Class*	Time	Non-Motorcycles Detected		Loop/Piezo Accuracy
		Video	Loop/Piezo	
Group 2 (Class 2 and Class3)	10:00–11:00	24	4	16.67%
	11:00–12:00	20	10	50.00%
Group 3 (Class 4 and Class 5)	10:00–11:00	1036	1074	103.67%
	11:00–12:00	1186	1232	103.88%
Group 4 (Class 6 to Class 13)	10:00–11:00	83	90	108.43%
	11:00–12:00	1186	1232	103.88%

*Group 1 (Class 1) is not included in this table.

Infrared Classifier

Analysis of non-motorcycle detection by the IR Classifier did not reveal any particular weaknesses for any vehicle class. The analysis used about an hour of the Florida data collected on October 20, 2012. Within this period, the IR Classifier detected a total of 798 Class 2 through Class 9 vehicles. Based on manual observation of the recorded video used to establish ground truth for the same period, the IR Classifier correctly classified 783 of these vehicles for a simple detection accuracy of 98.12 percent.

Inductive Loops/Piezoelectric Sensors

Table 22 summarizes the hourly totals for non-motorcycles from the inductive loop/full lane-width piezoelectric sensor system installed by Texas DOT in January 2012. This analysis combines FHWA classes 2 through 13 into three groups for simplicity. Results are better for larger vehicles than for Class 2 and Class 3, but the analysis reveals problems with the system part way through the data analysis. Properly operating inductive loop/piezoelectric sensor systems typically perform much better.

Magnetometers

The research team compared the magnetometer hourly data with classification counts from the Peek ADR-6000. Table 23 summarizes hourly totals summed to form a daily (24 hr) comparison. These results indicate that daily sums are very close to the ground truth values, differing by no more than 2 to 3 percent. Appendix C indicates the original data output format from the magnetometers.

Multi-Technology System

The multi-technology system currently classifies only motorcycles.

Tracking Video System

The tracking video system classifies vehicles according to the following length or vehicle bins:

- Motorcycles
- Cars and pickups
- Single-unit trucks and buses

Table 23. Classification of total traffic by the magnetometers.

Date	Lane 1[a]	Lane 2	Lane 3	Lane 4
April 17, 2011	-1.08%	-1.82%	-0.94%	-0.19%
April 18, 2011	-1.06%	-1.99%	-1.28%	0.01%
April 19, 2011	-1.00%	-2.03%	-1.18%	-0.08%
April 20, 2011	-1.01%	-2.63%	-1.12%	-0.03%
April 21, 2011	-1.97%	-2.45%	-1.60%	0.05%

[a] Lane 1: northbound right lane, Lane 2: northbound left lane, Lane 3: southbound left lane, Lane 4: southbound right lane.

- Combination trucks
- Other/unknown

Using the dataset for July 3, 2012 (daylight only and good weather conditions), analysts found that the tracking video detection accuracy was best for the car/pickup bin but overcounted single-unit trucks/buses and undercounted combination trucks. Observations of the video indicated that most of the errors were due to either occlusion or not being able to distinguish between two vehicles in close proximity.

Table 24 summarizes these results.

Table 24. Classification of non-motorcycles by the tracking video system.

Vehicle Type	Number by TrafficVision™	Ground Truth (Video)	Percent Correct
Cars and pickups	3,336	3,396	98.23%
Single-unit trucks/buses	201	159	126.42%
Combination trucks	170	218	77.98%

CHAPTER 4

Conclusions and Recommendations

Improving VMT estimates for motorcycles involves both of the following:

- The methodology of establishing locations where counts should be conducted
- Selecting the best technology to correctly classify motorcycles at those sites

The conclusions and recommendations presented in this chapter come from an investigation of data collection protocols and from extensive field data collection efforts.

Data Collection Protocols

Based on the results obtained from the four states, the authors believe that states should consider locating classification sites, at least initially, based on the spatial distribution of motorcycle crashes. This process can be expedited by using latitude/longitude coordinates from crash records (if available) and by employing GIS software. Not all states have motorcycle crash locations available in the format necessary for this process, so the first step would require modifying crash reports and computerized forms to accommodate this change. Even without the availability of latitude/longitude data, or until they become available, states could use a more simple observational method to characterize crash distributions and determine whether their current classification sites generally provide adequate coverage. The data from the four states support this notion of basing count sites (at least the first cut) on mapping the distribution of crashes.

In the absence of other reliable data sources, this is a method that a state could use to determine if it has existing count locations that are likely to be useful for counting motorcycles or if it has large geographic areas or specific highways where large numbers of motorcycle crashes are happening but where few (or no) resources are dedicated to motorcycle traffic counts. A state may also use this analysis to determine whether counts are needed on weekends versus weekdays.

Field Data Collection and Analysis

Table 25 summarizes the major findings related to the field data collection efforts. Because most of the detectors exhibited a range of detection accuracy, the tabular values for accuracy are a bit subjective. The accuracy metric used is simple detection accuracy, which is the number counted by the test system divided by the actual count, expressed as a percent. Decision-makers are not likely to rank the importance of each category equally, but these results are offered as a guide in the decision process with the option of applying weighting factors based on local experience and perhaps using a summing process to compare each category against the others.

The accuracy metric is viewed as very important as accurate VMT estimates require accurate detection. However, the reader is cautioned that direct comparison of all five detectors would be inappropriate, given that not all were tested at the same site and under exactly the same conditions. The exception was a limited subset of data for the inductive loop/piezoelectric systems, the magnetometers, and the tracking video that used the same traffic at SH 6 on some of the data collection dates. Also, the IR Classifier and the tracking video used the same traffic at the Texas motorcycle rally on May 18 (a setup error occurred with the multi-technology system).

Following are some factors that should help in interpreting these results. Both the multi-technology sensor and the tracking video systems were new and have already undergone improvements since the data collection effort for NCHRP Project 08-81 concluded. The authors anticipate that properly functioning full lane-width loop/piezo systems should detect well over half of the motorcycles that pass by based on experience in a few other states. The Texas DOT is in the process of troubleshooting the problem with the system.

Table 25. Overall technology summary.

Technology	Motorcycle Accuracy	Non-Motorcycle Accuracy	Initial Cost		Portability	Skill Level for Setup [a]
			Two-lane	Four-lane		
Infrared (IR) classifier	95%	98%	$26,850	$26,850	Fixed/Portable [b]	Expert
Inductive loop/piezoelectric sensors	45%	95%	$33,000 [c]	$61,000 [c]	Fixed	Field Tech.
Magnetometers	80%	95%	$10,204	$15,964	Fixed [d]	Field Tech.
Multi-technology sensor	50%	N/A	$6,000	$12,000	Fixed [d]	Field Tech.
Tracking video system	75%	90%	$15,000	$15,000	Fixed [d]	Field Tech.

[a] Setup skill level—expert required versus field technician (with proper training).

[b] TIRTL is available as either portable or fixed.

[c] Estimated by Texas DOT: $61,000 total for four-lane site and $33,000 total for two-lane site.

[d] Some components could be portable, or detector could be portable with modifications.

For non-motorcycle detection, results from all four detectors are in the expected range, and all are deemed acceptable. The only detector in the group that is likely to be affected significantly by inclement weather such as rain and fog is the tracking video, although these weather conditions did not occur during this research. The use of an IR camera could improve tracking video performance in some conditions as compared to a standard camera. In northern climates with potential for snow/ice accumulation, the IR Classifier performance would likely be affected as long as the accumulation remains. As noted elsewhere in this report, ad hoc evidence from Australia indicates that rain is not as likely to affect IR Classifier performance now as it once did.

The cost of each system is an important variable, but portability is considered a component of cost because a highly portable system can serve many sites instead of only one. A good example is the IR Classifier, for which the initial cost for four lanes is almost twice the cost of loops/piezoelectric sensors, magnetometers, or the tracking video system. The discrepancy is even greater for two-lane sites, but the portability of the IR Classifier is higher than the portability of the other three systems. The multi-technology sensor is the least expensive option and is highly portable, but its accuracy is not sufficient for it to be a viable contender at this time. The tracking video system could be made portable by using a trailer-mounted camera and power supply. It also could use fixed cameras that are used for surveillance or other purposes as long as their pan/tilt/zoom capability is available during the data collection period. In that case, data collection/storage could occur on-site with the laptop (e.g., in a roadside equipment cabinet) or, if the proper communication medium were available, the laptop could do the processing anywhere. Some components of the magnetometers could be portable, but the sensor nodes in the pavement are fixed.

Recommendations

Data Collection Protocols

This research offers states a tool that can assist them in either identifying count sites for motorcycles or identifying gaps in current count programs. NCHRP Project 08-81 presents preliminary results from four states that need to be vetted by similar analyses in other states; however, this research provides sufficient evidence that this approach is appropriate for its intended purpose. Patterns of data may vary in each state, but these findings suggest that it is likely that some or even most other states can improve their motorcycle count programs using this method. An easily conducted analysis will very quickly show states if their existing counters are located in the right places.

This research validated the early hypothesis that crash locations are reasonable predictors of traffic volume for motorcycles. States that lack good count data may wish to examine their motorcycle crash locations to see if their existing count locations have the potential (if upgraded) to provide better data on motorcycle traffic volume. That is the essence of the finding—that crash locations and volume are associated, so they can be used as generally good predictors of each other. In summary, a state could:

- Check whether or not its existing count sites provide effective coverage for the motorcycle crash locations based on the crash data, and
- Run a correlation analysis once they have better count data.

Some states might also need to implement weekend rural counts based on observed riding characteristics. Special weekend rural counts might only be needed if:

- The spatial distribution of weekend motorcycle crashes are radically different from that for weekdays, and

- The correlation of spatially weighted crash frequency to traffic counts was demonstrably lower for weekends than for weekdays.

Otherwise (i.e., if the correlation is high for weekends), the implication is that the count program is adequately capturing motorcycle travel.

Technology Selection

Recommendations pertaining to the five detectors tested in NCHRP Project 08-81 address each detector individually rather than by ranking them. Direct comparison would not be appropriate given that:

- This research did not test all the detectors simultaneously under the same conditions.
- Different technologies have their own inherent strengths and weaknesses.
- Environmental conditions affect some technologies more than others.

IR Classifier. Setup of this system appears to require an expert and site selection is critical to a proper setup, but its accuracy for all vehicle types and ability to classify vehicles in all of the FHWA Scheme F classes is a strong positive attribute. The portable version of the IR Classifier can provide data at a lower cost per lane compared to many alternatives.

Inductive Loops/Piezoelectric Sensors. Many states already use inductive loops and piezoelectric sensors, but the low detection rate for motorcycles plus their other negative factors should encourage states to replace these legacy systems with non-intrusive detectors that are more accurate. At the very least, it is suggested that states replace existing 6 ft piezoelectric sensors with full lane-width piezos for detection of motorcycles.

Magnetometers. The data collected in this research indicates that covering the full lane-width in a way to avoid gaps in coverage will require at least two (and perhaps three) magnetometers at each station in a 2-2 or 3-3 configuration separated by at least 12 ft longitudinally. Magnetometers appear to overestimate the length of motorcycles, so future research is suggested to verify length estimates. The research for NCHRP Project 08-81 did not investigate detector sensitivity settings and their impact on Class 1 detections or length estimates.

Multi-Technology Sensor. This sensor is already undergoing improvement through the SBIR program and will be evaluated again with rigorous field testing following modifications. Changes known to be underway include an improved user interface and the ability to detect non-motorcycles. It is suggested that the user community wait until these new features are incorporated and full testing shows the multi-technology sensor to be a reliable sensor.

Tracking Video. Planned improvements by the manufacturer that are already underway suggest that the tracking video system has the potential to be even better than this research has indicated. Future testing of this technology needs to include a variety of environmental conditions using both IR and traditional cameras.

Suggestions for Future Research

Data Collection Protocols

- Test data from more states to determine if crash data (or other factors) are an appropriate predictor of count station locations for motorcycles.

Technology Selection

- Test the effects of a variety of weather and lighting conditions on the following technologies:
  - IR Classifier
  - Multi-technology sensors
  - Tracking video
- Test magnetometers using two sensor nodes at each station (2-2), then three sensor nodes at each station (3-3) to determine detection characteristics for motorcycles and how well they distinguish motorcycles from subcompact cars. Investigate the effects of sensitivity settings and station spacings on the length estimates and on classification accuracy.
- Determine the number of lanes and cross-slope characteristics that a multi-beam IR Classifier can cover before serious degradation of results occurs.
- Conduct additional rigorous testing on the newest detectors tested in this research—the multi-technology system and the tracking video.
- Investigate promising new detectors not included in this research because they were not yet market ready or were not available when this research began. Such detectors include:
  - Segmented axle sensors, for which early tests of two separate products were funded by the Florida DOT and the Oklahoma DOT.
  - High resolution, full lane-width inductive loops such as the "blade" from IST.
- Investigate the accuracy of newly introduced detectors that claim to be good motorcycle detectors (e.g., hybrid technology products from Iteris and Traficon).
- Investigate the pros and cons of using thermal imagers for tracking video detection to determine if the performance gains offset the additional cost.

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APPENDIX A

Guidance for States to Determine Motorcycle Count Locations

Data Elements

Crash Database (filter to select motorcycle-involved crashes only):

Crash Data Variable List:

- **Crash ID**
- **Latitude** (needs to be validated)
- **Longitude** (needs to be validated)
- **Roadway ID** (matched to state route number designations as used in the traffic count database)
- **Crash date**
- **Crash day of week** (if separately coded, otherwise can be decoded from date)
- **Direction of Travel for the Motorcycle** (nice to have but not critical)

Traffic Count Database (Match the YEAR to the year of crash data provided):

Traffic Count Variable List (NOTE: GIS expert should review and revise as needed):

- **Count Station/Location Unique ID**
- **Latitude** (of the count location)
  Longitude (of the count location)
- **Roadway ID** (state route number designations, especially useful if this is the same information coded in the crash data)
- **Direction/Side of Roadway** (if relevant to ensure accurate placement of the counts on a spatial network and roadway)
- **Annual Average Daily Traffic (AADT)-- Motorcycles** (must have)
- **AADT--All Vehicle Types** (must have)
- **Weekday versus Weekend** (States with counts that separate weekdays from weekends can refine the estimates even more by calculating weighted comparisons for weekdays and weekends separately.)

Data Format and Filtering Notes:

1) The crash data can be in raw crash databases if a state prefers to use a data extract of all motorcycle crashes. The analysis only needs to use the crash-level data table.
2) In general, most database formats are acceptable but the state should check the options first. An Excel file is acceptable if there is one record per crash or per count location. If significant manipulation of the data is necessary, some other format might be easier for the state.
3) States *could* make use of multiple years of data; however, it is important to match the crash year to the traffic count year, so states would need both types of data in separate files for as many years as desired.

How to Process the Data

1) **GIS:** Locate the count sites (including displaying them on a map as desired for the report).

2) **GIS:** Locate the crash sites (including mapped displays along with count locations).

3) **GIS:** Compute the linear distances from each crash site to:

   a) The nearest count station ON THE SAME ROADWAY.
   b) The nearest count station spatially without regard to roadway (i.e., straight line distance).

4) **Statistician:** Create data files as follows:

   a) For each count station, the number of crashes that are nearest to that site ON THE SAME ROADWAY.
   b) For each count station, the number of crashes that are nearest to that site without regard to roadway (i.e., straight line distances).
   c) Create data files (a) and (b) separately for weekday and weekend crashes (i.e., four files instead of just two).

5) **Statistician:** Perform the following analyses (all use Pearson's R):

   a) Unweighted correlation between crash frequency and
      i. Total vehicle AADT
      ii. Motorcycle AADT
   b) Weighted correlation between crash frequency weighted by inverse distance measure and
      i. Total vehicle AADT
      ii. Motorcycle AADT (In past analyses, the weighting factor used a multiplier just to have the units be in a “normal” range. The distance measures were calculated in meters in the previous files, so if that changes, the multiplier might also change.)

These steps may be done separately for weekday and weekend data as well as overall, depending on what data are available.

APPENDIX B

Texas DOT Data Sample

No.	Year	Mo.	Day	Hour	Min.	Sec.	Lane	Class	Speed	Num. Axles	WB	Spc1	Spc2	Spc3	Spc4
1	13	2	8	0	0	24	4	9	73	5	52.8	15.5	4.3	29.1	3.9
2	13	2	8	0	0	38	4	2	77	2	8.9	8.9			
3	13	2	8	0	1	7	1	2	68	2	9.6	9.6			
4	13	2	8	0	1	29	2	2	71	2	8.5	8.5			
5	13	2	8	0	1	34	4	3	84	2	14.1	14.1			
6	13	2	8	0	1	35	4	2	74	2	8.9	8.9			
7	13	2	8	0	1	37	1	2	75	2	7.6	7.6			
8	13	2	8	0	1	59	3	2	77	2	8.9	8.9			
9	13	2	8	0	2	1	1	2	77	2	8.7	8.7			
10	13	2	8	0	2	2	4	2	69	2	8.6	8.6			
11	13	2	8	0	2	7	4	2	68	2	8.8	8.8			
12	13	2	8	0	2	9	2	3	74	2	11.9	11.9			
13	13	2	8	0	2	22	1	3	72	2	11.9	11.9			
14	13	2	8	0	2	29	4	2	69	2	8.9	8.9			
15	13	2	8	0	2	43	4	2	63	2	9.3	9.3			
16	13	2	8	0	2	58	4	2	77	2	8.4	8.4			
17	13	2	8	0	3	5	1	9	67	5	54.7	16.5	4.3	29.8	4.1
18	13	2	8	0	3	20	1	2	72	2	8.4	8.4			
19	13	2	8	0	3	24	4	3	69	2	13.3	13.3			
20	13	2	8	0	3	33	1	2	65	2	10.3	10.3			
21	13	2	8	0	3	45	1	5	60	2	22.4	22.4			
22	13	2	8	0	3	45	4	2	75	2	9.8	9.8			
23	13	2	8	0	3	57	1	5	61	2	20.6	20.6			
24	13	2	8	0	4	8	1	8	58	4	50.1	13	33.8	3.3	
25	13	2	8	0	4	8	4	2	58	2	9.2	9.2			
26	13	2	8	0	4	30	4	2	63	2	9.6	9.6			
27	13	2	8	0	4	36	1	3	64	2	12.1	12.1			
28	13	2	8	0	4	48	4	2	62	2	9.4	9.4			
29	13	2	8	0	4	53	4	2	74	2	9.8	9.8			
30	13	2	8	0	5	0	4	2	77	2	8.4	8.4			
31	13	2	8	0	5	9	4	9	72	5	62.8	17.6	4.3	30.9	10
32	13	2	8	0	5	13	1	9	65	5	59.6	19.1	4.3	32.2	4
33	13	2	8	0	5	16	1	2	67	2	9.5	9.5			

APPENDIX C

Sensys Networks Data Sample

Time	AP / Sensor Zone	Speed (mph)	Length (ft)	Gap (ft)
2/8/2013 11:00	APCC455 / L1	60.1	9.4	0.25
2/8/2013 12:13	APCC455 / L4	66.5	9.5	0.25
2/8/2013 12:15	APCC455 / L3	69.9	9.6	1.59
2/8/2013 11:21	APCC455 / L4	62.6	9.7	0.18
2/8/2013 13:14	APCC455 / L4	71.2	9.7	0.29
2/8/2013 13:01	APCC455 / L2	68.7	9.8	0.27
2/8/2013 12:12	APCC455 / L4	66.5	9.9	4.16
2/8/2013 13:20	APCC455 / L4	83	9.9	3.73
2/8/2013 14:11	APCC455 / L3	66	10	0.41
2/8/2013 11:06	APCC455 / L4	66.5	10.1	16.2
2/8/2013 11:48	APCC455 / L4	66.5	10.1	0.26
2/8/2013 14:00	APCC455 / L1	63.5	10.1	1.09
2/8/2013 14:15	APCC455 / L1	72.2	10.1	4.39
2/8/2013 13:16	APCC455 / L2	73.7	10.2	0.2
2/8/2013 11:50	APCC455 / L1	67.9	10.3	0.2
2/8/2013 12:00	APCC455 / L2	73.7	10.3	0.91
2/8/2013 14:50	APCC455 / L1	64.4	10.3	3.48
2/8/2013 13:00	APCC455 / L4	76.2	10.4	2.49
2/8/2013 13:19	APCC455 / L2	68.7	10.4	0.82
2/8/2013 11:05	APCC455 / L3	70.6	10.5	0.73
2/8/2013 11:04	APCC455 / L1	67.9	10.6	0.2
2/8/2013 12:00	APCC455 / L4	71.2	10.6	4.6
2/8/2013 12:39	APCC455 / L3	74.9	10.7	4.76
2/8/2013 12:48	APCC455 / L1	78	10.7	2.84
2/8/2013 13:26	APCC455 / L4	62.6	10.7	6.13
2/8/2013 13:11	APCC455 / L1	67.9	10.8	6.28
2/8/2013 14:40	APCC455 / L3	69.9	10.8	0.17
2/8/2013 12:22	APCC455 / L4	76.2	10.9	7.85
2/8/2013 14:38	APCC455 / L1	56.6	10.9	1.1
2/8/2013 13:36	APCC455 / L3	69.9	11	0.2
2/8/2013 14:06	APCC455 / L2	68.7	11	4.99
2/8/2013 14:06	APCC455 / L4	64.3	11	5.25
2/8/2013 11:32	APCC455 / L3	74.9	11.1	6.88
2/8/2013 11:53	APCC455 / L3	74.9	11.1	0.75
2/8/2013 13:32	APCC455 / L3	80.7	11.1	0.79
2/8/2013 13:37	APCC455 / L1	64.4	11.1	7.55
2/8/2013 14:10	APCC455 / L1	72.2	11.1	5.41
2/8/2013 14:15	APCC455 / L1	72.2	11.1	2.02

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation