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EVALUATING THE ACCURACY LEVEL OF TRUCK TRAFFIC DATA ON STATE HIGHWAYS

Prepared For:

Utah Department of Transportation
Research Division

Submitted By:

Brigham Young University
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February 2009

INSIDE COVER

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16. Abstract

Truck traffic significantly alters the amount of user costs incurred by delays caused by work zones and incidents. Truck traffic also plays an important role in many aspects of UDOT's daily activities, including transportation planning, highway operational analysis, and design of pavement and bridges. The level of accuracy of truck traffic data was not clearly known by UDOT engineers. This research first studied methods for estimating truck traffic on state highways with a desired level of accuracy, and then evaluated the level of accuracy of the current truck traffic data by a statistical sampling of automatic traffic recorder (ATR) stations (so called, permanent count stations). As it turned out, the accuracy level of the current truck traffic data was not at the level acceptable to UDOT. Although total traffic counts at ATR stations were statistically equivalent to the ground truth count data (only 0.12% difference), trucks larger than 30 ft were undercounted by 21.13% on average and vehicles shorter than 30 ft were over-counted by 5.73% on average. It was found that identifying vehicles in the 30-ft length group (16.1 ft to 30 ft) was the most problematic with the currently used vehicle counting methods. Development of new data collection and reduction methods was recommended for improving the overall accuracy of truck traffic on UDOT's highways.

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Executive Summary

Truck traffic significantly alters the amount of user costs incurred by delays caused by work zones and incidents. Truck traffic also plays an important role in many aspects of UDOT's daily activities, including transportation planning, highway operational analysis, and design of pavement and bridges. The level of accuracy of truck traffic data was not clearly known by UDOT engineers. This research first studied methods for estimating truck traffic on state highways with a desired level of accuracy, and then evaluated the level of accuracy of the current truck traffic data by a statistical sampling of automatic traffic recorder (ATR) stations (permanent count stations).

Major findings from the literature review and the best practice survey of the state DOT's on truck traffic count are the following:

- Typical desired tolerance (standard error): 5% to 10%
- Targeted accuracy level (error rate): 90% ~ 95% (10% ~ 5%)
- Traffic data collection method: inductive loop detectors and microwave sensors
- Classification type: volume only, volume by length, and volume by class
- Method of collecting ground truth count data: visual counts by lane and by direction (freeway and main arterial),
- Collection time: every 3 months to 3 years

In the best practice survey, state DOT employees in charge of traffic counts in other state DOT's cited sensor problems (sensor configuration, calibration, location, and limitation), vehicle classification algorithms, and environmental problem (weather) as their major reasons that would lower the accuracy level of truck traffic counts.

Knowing the major intrastate truck routes will help UDOT improve design and operation of highway facilities for trucks, utilize intelligent transportation systems, improve signing system, help regulatory changes in allowed vehicle size or configuration, enhance enforcement and compliance, and identify truck-related highway investment needs.

As for the commodity flow pattern survey, the number of responses was too small to make any in-depth analysis in commodity flow pattern. These responses are only a handful of all the trucking companies in Utah. Nevertheless, the findings from these responses will benefit UDOT in conducting a freight flow study in the future. Using the main ATR stations for truck counting and intermediate nodes, the truck route to and from each main truck counting station by direction was identified by using the ArcGIS Network Analysis Tool. Even though the truck routes identified in the pilot study may not be exact, the result from this analysis should help UDOT designate certain highways as truck routes.

Main factors for designing a stratified sampling of permanent traffic count station (ATR stations) were identified as follows:

- Hardware factor: type of data, collection method, tolerance, and targeted accuracy level (error rate);
- Location factor: highway functional class, regional characteristics, and availability of space for placing traffic count equipment;
- Time factor: time period to collect, and day of the week; and
- Other factors: traffic volume and traffic condition (congestion and construction).

Ground truth traffic data were collected in the field in two stages: a pilot study and a full-scale study. For conducting a stratified sampling, a statistician from BYU's Center for Statistical Consultation and Collaborative Research (CSCCR) was consulted and the opinions of the Technical Advisory Committee (TAC) members were taken into account. To achieve a systematic stratified data collection, several sampling design factors such as hardware type, station location, time of day, day of the week, etc. were used. Visual data were reduced using the DelayAnnotator software and vehicles were classified into the thirteen classes as defined by the Federal Highway Administration (FHWA). Ground truth traffic data collected in the field were analyzed and compared with the traffic data collected at the selected ATR stations using statistical analysis tools. Factors that can affect the performance of traffic counters, identified by the literature review and the state-of-the-practice survey, were used in the statistical analysis. Through various statistical analyses of error rates, the research team found the relationship between error rate (accuracy level) and vehicle groups as follows:

- Passenger car group (vehicles less than 30-ft long): over-counted by 5.73% (95% confidence interval: +3.16% to +8.31%);
- Truck group (vehicles longer than 30-ft long): under-counted by 21.13% (95% confidence interval: -25.51% to -16.75%), far greater than targeted 5% to 10% error rates;
- Total count: ATR counts were statistically equivalent to the ground truth counts. The error rate was 0.12% (95% confidence interval: -1.76% to +2.00%).

It appears that the over-counts of the passenger car group and the under-counts of the truck group cancel each other to make total counts accurate. It was also found that identifying vehicles in the 30-ft length group (16.1-ft to 30-ft) was the most problematic with the currently used vehicle counting methods.

The large undercount of trucks will significantly affect design, operation, management, and maintenance of UDOT's highways, and UDOT needs to develop procedures to reduce such a large under-count caused by the existing traffic count equipment.

In order to improve truck traffic counts, the following recommendations are made:

- Check regularly the accuracy level (error rate) with a well-designed stratified sampling of ATR stations,
- Establish an efficient and economical ground truth data collection and analysis method,
- Explore the possibility of synthesizing truck and freight related data obtained by the WIM program and at the Ports of Entry with the truck counts obtained at the ATR stations to improve the overall accuracy level (lowering error rate) of truck traffic counts, and

- Explore the possibility of using truck traffic count data obtained at ATR stations that produce high accuracy truck counts to adjust the traffic count data obtained at other ATR stations that produce truck counts at a lower accuracy level.

Besides the recommendations given above, the following recommendations related to hardware and vehicle classification algorithms are made:

- Change the boundaries for vehicle length groups and make them commensurate with the FHWA's vehicle classes or reflect the vehicle lengths specified in the AASHTO's Green Book,
- Use the inductive loop length detector until microwave detectors can classify vehicles with higher accuracy level (Note that UDOT at present uses only 3 microwave-based ATRs and further testing of microwave detectors is recommended), and
- Install more class-type ATR stations at locations with higher traffic volume (currently there are only three class-type ATR stations installed only at remote locations with very low traffic volume) to evaluate how correctly they can classify vehicles into FHWA's thirteen classes.

1 Introduction

1.1 Background

When the principal investigator (PI) of this project worked on the development of user cost estimation procedures for work zones (Saito et al., 2005) a few years ago, he realized that the truck traffic data currently gathered by the Utah Department of Transportation (UDOT) might not be as accurate as they wished to conduct a user cost analysis.

Truck traffic significantly alters the amount of user costs incurred by delays caused by work zones and incidents. Truck traffic also plays an important role in many aspects of UDOT's daily activities, including transportation planning, highway operational analysis, and design of pavement and bridges. At planning level, movements of trucks on the state highway system will help UDOT properly allocate their highway funds; at the operational level, truck traffic is essential for evaluating the capacity and level of service of highways; and at the design level, truck traffic is one of the main factors for designing pavement structure and, superstructures and substructures of bridges. Therefore, it is essential that UDOT has a clear idea about the accuracy level of their truck traffic data.

The level of accuracy of truck traffic data was not clearly known by UDOT engineers. This proposed research first studied methods for estimating truck traffic on state highways with a desired level of accuracy, and then evaluated the level of accuracy of the current truck traffic data by a statistical sampling of automatic traffic recorder (ATR) stations (permanent count stations). As it turned out, the accuracy level of the current truck traffic data was not at the level acceptable to UDOT, and future data collection and reduction methods were recommended for improving the overall accuracy of truck traffic data on UDOT's highways.

1.2 Objectives

Three objectives of the study were the following:

- Prepare a summary of the state-of-the-art and state-of-the-practice of truck traffic data collection, reduction, accuracy level maintenance, and estimation methods;
- Determine the accuracy level and confidence interval of the truck traffic data collected by the existing method; and
- Recommend directions and methods for improving the level of accuracy of truck traffic data if the analysis showed the current accuracy level of truck traffic data being inadequate.

1.3 Scope of the Study

This study focused on the ATR stations owned by UDOT. A random sampling of location and time of day was made to carry out traffic data collection by video recording equipment. Truck traffic counts taken from the videotaped field data were compared with the truck traffic counts obtained from the ATRs in UDOT's Traffic Monitoring Program to determine the accuracy level of truck traffic data.

1.4 Organization of the Report

Chapter 1 presents the background, objectives, and scope of the study. Chapter 2 summarizes the results of an extensive literature review. The literature review focused on state-of-the-art methods for collecting, reducing, and estimating truck traffic by permanent count stations. First, general characteristics of truck traffic are described. Truck traffic data collection method, Truck VMT, accuracy level and truck traffic counting data error, relation between truck traffic and pavement, and statistical analysis on truck traffic are then reviewed.

Chapter 3 presents the results of analysis on responses to a survey of the state department of transportation (DOTs) to evaluate the state-of-the-practice of truck traffic data collection methods and their efforts to improve the accuracy level of truck traffic data. The contents of the survey included truck traffic counting method (extent and data collection equipment type), methodology for evaluating the accuracy level of truck traffic data, and the level of compliance to mechanistic-empirical pavement design guide (M-EPDG) and DOT's response to the guide.

Chapter 4 discusses major commodity flow patterns on Utah's highway system. In order to find main corridors (routes) of truck traffic on Utah's highway system, a commodity flow pattern survey, the geographic information system (GIS) methodology, and the shortest path algorithm were used. The information of commodity flow by trucks will help improve identify strategic locations for truck traffic counts.

Chapter 5 provides the methodology and procedure for collecting ground truth truck traffic data. Due to the differences in truck traffic volumes among the different highway classes where ATRs are located, stratification of ATR stations is essential. Factors including functional classification, annual average daily traffic (AADT), and other relevant factors were considered to set up a data collection plan. First, a small-scale pilot survey was carried out prior to a full-scale data collection to obtain information on the magnitude of classification errors by consulting a statistician at BYU and Technical Advisory Committee (TAC) members. Based on the outcome of the pilot study, a full-scale data collection based on a stratified sampling of ATR stations was carried out.

Chapter 6 presents the results of statistical analyses for determining the error rate (accuracy level) of the current truck traffic data. The ground truth traffic data, obtained by video analysis, were compared with the traffic count data obtained at the ATR stations. The statistical analysis procedure consisting of six steps was introduced, including 1) data entry and sorting, 2) determination of main analysis factors, 3) estimation of accuracy rate and difference, 4) statistical analysis, 5) consultation with a statistician, and 6) review and evaluation of statistical results.

Chapter 7, Conclusion and Recommendations, summarizes the tasks carried out in this study and the findings of the statistical analyses performed, together with the recommendations for implementing an optimal spatial spread of ATRs for improving the accuracy level of truck traffic data up to the level targeted by UDOT. Recommendations for future directions for data collection, reduction, and estimation for improving the accuracy level of truck traffic data are then presented.

2 Literature Review

This chapter discusses general characteristics of truck traffic, truck traffic data collection methods, and findings from the previous research studies on the accuracy level of truck traffic data. The main purposes of the literature review were to evaluate the state-of-the-art methods for collecting, reducing, and estimating truck traffic and to inquire statistical methods that would improve the overall accuracy level of truck traffic data.

2.1 General Characteristics of Truck Traffic

2.1.1 Characteristics of Truck Traffic

As truck traffic on highways has rapidly increased, problems and challenges related to truck traffic planning and operation have arisen. Challenges resulting from the rapid increases of truck traffic on highways include traffic congestion, transportation system deficiencies, safety, infrastructure deterioration, inter-modal connections, environmental impacts, quality of life, economic development, losses in productivity, and so forth. While primary problems most prevalent for state DOTs are congested urban highways, insufficient truck parking, and pavement deterioration, those for metropolitan planning organizations (MPOs) are congestion, environmental issues (air quality and noise), and economic issues (transport costs and productivity).

Douglas (2003) suggested the following solution methods for those challenges and problems related to truck traffic. Expected benefits of these projects primarily include improvements in safety, reductions in congestion, and increases in productivity.

- A wide range of planning activities for dealing with truck traffic: large-area freight planning (state, region, or corridor), local-area freight planning (inter-modal facilities or truck-related land use), and goods movement forecasting;
- A wide range of potential strategies for managing increasing truck traffic: improved highway design, special roadway facilities for trucks, operational improvements, intelligent transportation systems, improved signing, regulatory changes in allowed vehicle size or configuration, enhanced enforcement and compliance, and investments in alternative infrastructure; and,
- Other management strategies for dealing with truck traffic: pavement improvement or rehabilitation, climbing lanes, lane restrictions, and weigh-in-motion.

Also, Wang et al. (2006) discussed several factors that influence the level of impacts of trucks and heavy vehicles on traffic operations and control. They were summarized below together with the results of other related research studies:

- Because of their heavy weight and large turning radii, long vehicles (LVs) have very different moving characteristics than short vehicles (SVs), which are mostly passenger cars. These characteristics affect roadway's geometric design factors, such as horizontal alignment and curb heights.
- The heavy weight of LVs is also an important factor in pavement design and maintenance, as truck volumes influence both pavement life and design parameters (AASHTO, 2004).
- Roadway performance is influenced by the presence of large and/or low-performance vehicles in the traffic stream because they reduce roadway capacity (Cunagin and Messer, 1983).
- The Highway Capacity Manual explicitly stipulates that passenger-car equivalents of LVs under different conditions should be used for highway design. Safety is also influenced by LVs (TRB, 2000).
- A recent study found that eight percent of fatal vehicle-to-vehicle crashes involved large trucks, although only three percent of all registered vehicles were large trucks (NHTSA, 2004).

- Recent studies (Peters et al., 2004; Kim et al., 2004) also found that particulate matter (PM) is strongly associated with the onset of myocardial infarction and respiratory symptoms. Heavy duty trucks that use diesel engines are major sources of PM, accounting for 72 percent of traffic-emitted PM (EPA, 2001).

All these facts illustrate that good speed and truck volume data are extremely important for accurate analysis of traffic safety, traffic pollution, and flow characteristics in transportation planning, operation, management, and engineering. Data are also important inputs for advanced traffic management systems (ATMS) and advanced traveler information systems (ATIS). Additionally, truck traffic data are needed by federal and state transportation organizations to adequately monitor and analyze our nation's freight movements.

As implicated by the characteristics of truck traffic mentioned above, the importance of the accuracy of truck traffic on highways has significantly increased in the area of planning and design, and operation and management.

2.1.2 Truck Classification

According to the Electronic Code of Federal Regulations (e-CFR, 2006), the federal axle load limits on the Interstate Highway system are grouped by three categories, that is, single axle (20,000 pounds), tandem axle (34,000 pounds), and gross vehicle weight (80,000 pounds).

According to FHWA's Vehicle Classification (AASHTO, 1992), vehicles including trucks are categorized into thirteen vehicle classes based on the number and configuration of the axles as shown in Figure 2-1. By AASHTO trucks are classified into ten types according to the configuration of the trailer unit, the number of axles, and the number of trailers.

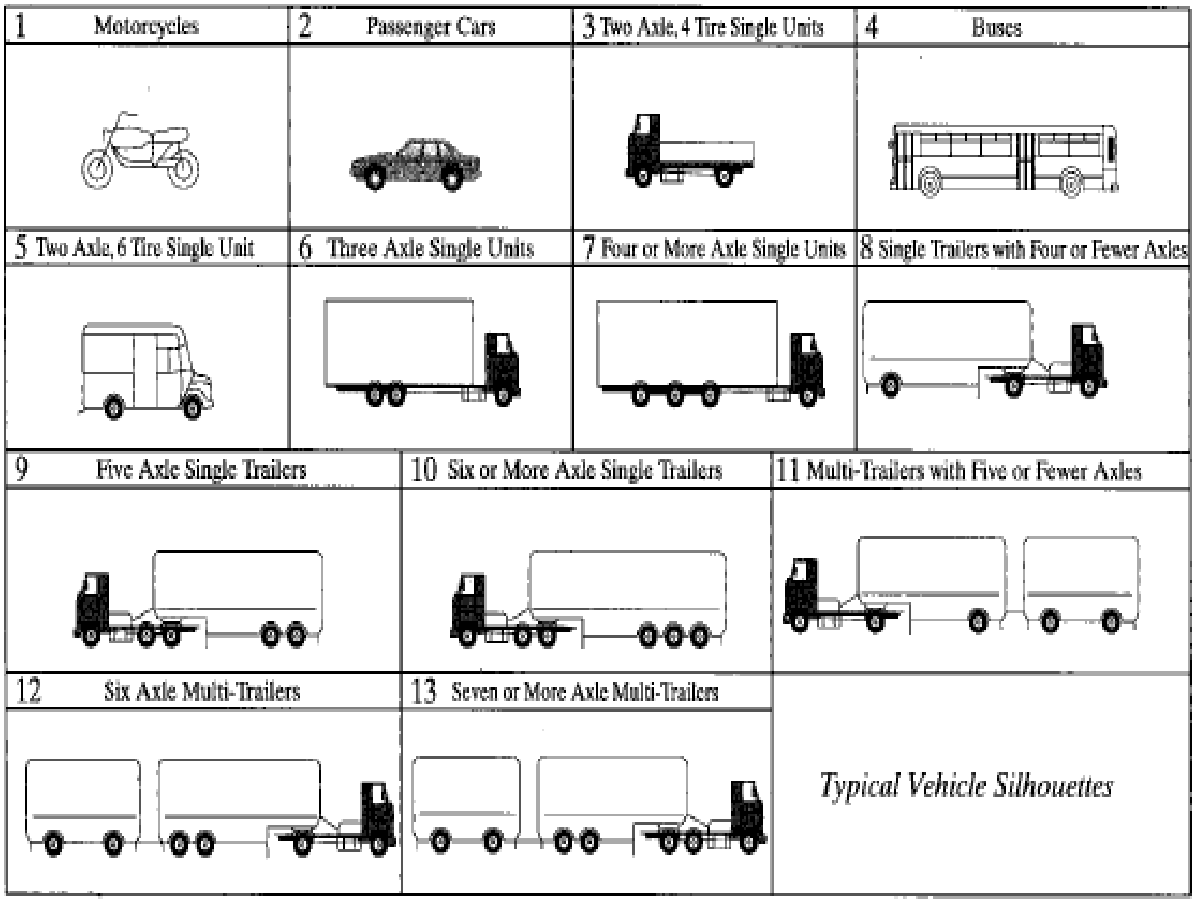

Figure 2-1 Thirteen Vehicle Classes by FHWA (AASHTO, 1992)

2.2 Truck Traffic Data Collection Methods

Volume and vehicle classification data of trucks are collected automatically or manually. Most popular techniques include pneumatic counters (e.g. tube counters or road tubes), inductive loop detectors, video sensors, microwave sensors, weigh-in-motion (WIM) equipment, and visual observation.

FHWA's TMG (2001) discusses available vehicle classification technologies including use of axle, vehicle length, and machine vision classifiers. New technologies are rapidly evolving. Victoria and Walton (2004) summarized the characteristics of truck traffic collection methods as shown in Table 2-1.

Table 2-1 Characteristics of Truck Traffic Collection Methods

Technique	Advantages	Disadvantages
Automated or electronic traffic counts (pneumatic detectors, inductive loop detectors, vehicle classification recorders, WIM equipment	• No traffic disruption • Able to collect traffic counts at many sites efficiently with low labor requirement	• Wide variance in truck counts or classifications by pneumatic detectors due to a low quality calibration method, vehicle speed, and traffic density • Potential for equipment failure • Pneumatic detectors present problems in term of staff safety • No information regarding commodity classification, commodity type, shipment details, and routing details,
Video surveillance	• No traffic disruption • Better information on type of commodity hauled compared with automated electronic counters	• Not a cost-effective option in most situations • Potential for equipment failure or recording failure during adverse weather
Visual classification counts (tally sheets mechanical counting boards, electronic counting boards)	• No traffic disruption • May be more accurate than automated or electronic traffic counts	• High personnel requirement • Potential for human error • Staff safety and operational problems • No information regarding commodity classification, commodity type, origin-destination pair, shipment details and routing details

Source: Victoria and Wanton (2004)

Also, many studies showed that good techniques for classifying trucks include a combination of data acquisition technologies. Truck data collection methods are divided into three general categories: 1) Category 1 – automated vehicle classifiers (AVCs) and manual counting, 2) Category 2 – WIM systems and automated traffic recorders (ATRs), and 3) Category 3- mixing two or more data collection methods. The following subsections summarize the characteristics of each category.

2.2.1 Category 1: AVC and Manual Counting

Kwon et al. (2002) discussed the characteristics of category 1. They stated that an AVC usually used technologies such as inductive loops and bending plate or piezo sensors, or more sophisticated technologies such as video imaging, laser and night vision systems, or acoustic signal analysis. These systems produce online counts of traffic in different vehicle types. But they were costly to install and suffer various limitations.

When manual counting is used, a person records the truck traffic distribution for a short sampling period (usually a day or two) and the counts are extrapolated to get an estimate for a whole year. This estimate could have a large margin of error, even after adjusting for seasonal and day-of-week trends. Improving accuracy by increasing the frequency and time duration of manual counts is costly.

2.2.2 Category 2: WIM System and ATR

Texas DOT (2001) and Hallmark (2002) discussed the characteristics of category 2 data collection methods. WIM equipment determines vehicle weights while vehicles are moving over the equipment. It collects traffic volumes by vehicle class and weight as it determines vehicle weights. The data collected also include date, time, vehicle length by axle spacing, speed, and axle weight. There are two types of WIM systems: bending plate and piezo.

2.2.3 Category 3- Mixing Two or More Systems

In order to improve the quality of truck count and speed data, Wang et al. (2006) used the paired video and single-loop sensors. The paired video and single-loop sensor system was the truck traffic data collection system which complemented the weaknesses of the two types of detectors, single-loop and dual-loop detectors. They concluded that the video-based vehicle detection and classification (VVDC) provided a cost-effective solution for automatic traffic data collection. They concluded that the video image processing method developed for vehicle detection and classification was a viable alternative for truck data collection. The prototype VVDC system was, however, currently designed to work in the daytime only and without longitudinal vehicle occlusion and severe camera vibration

2.3 Truck VMT Accuracy Level and Data Error in Truck Traffic Counting

2.3.1 Importance of Truck VMT Accuracy

Vehicle-mile-traveled (VMT) and vehicle classification are vital inputs to the design and operation of an efficient highway system. In particular, heavy truck VMT is important as the number of heavy vehicles on a highway affects traffic operation, safety, and pavement performance (Hallmark, 2002). Research has shown that the current methods used in the estimation of heavy-vehicle VMT are often less accurate than those used for passenger vehicles. In the evaluation of existing truck VMT calculation methods, Hallmark (2002) identified deficiencies of the existing truck VMT calculation methods and made recommendations for reducing uncertainties in heavy-vehicle VMT estimates. Iowa DOT uses traffic data taken from continuous count stations to estimate AADT for two different truck groups (single-unit and multi-unit) using three methods shown below (Hallmark, 2002):

- Method 1, the truck expansion factor approach: Monthly and daily expansion factors for each truck group are developed. Truck AADTs are determined by applying truck expansion factors to short-term counts.
- Method 2, the yearly truck percentage approach: Truck percentages are determined using the annual percentage of trucks for each truck group from continuous count stations.
- Method 3, the count specific truck percentage approach: General expansion factors are developed for all vehicle classes. This method uses daily truck percentages obtained from short-term counts.

Hallmark (2002) reported the following findings about these three methods:

- For single-unit trucks, the truck expansion factor method performed the best in terms of minimum expected error.

- For multi-unit trucks, the truck expansion factor method also performed the best in terms of minimum expected error.
- The prediction error was the lowest for the method that developed expansion factors separately for the different truck groups for both single- and multi-unit trucks. This indicates that the use of expansion factors specific to heavy vehicle classes results in better estimates of AADT, and, subsequently, VMT, than using aggregate expansion factors and applying a percentage of trucks.

Hallmark (2002) also concluded that estimates of truck VMT served as vital inputs for geometric and pavement design of highways. Truck VMT is also a key factor in traffic safety. VMT estimates by vehicle class are needed to determine crash rates by vehicle class and compare them across vehicle class. A better understanding of where trucks are located in the highway system will assist in evaluating the causes of truck-related crashes and consequently in minimizing fatalities and injuries that result from such crashes. Also, reliable estimates of heavy-vehicle VMT are essential for creating accurate inventories of emissions.

2.3.2 Errors in Truck Traffic Data

According to the TMG (FHWA, 2001), two types of error are possible in collecting and analyzing traffic data. They are errors in data collection process, and errors in data reduction process. A wide range of factors including power failure, recorder malfunction, and detector malfunction are sources of invalid data or missing data from the permanent counters.

When permanent counts contain errors, there is no available correction process. The only manual step in reducing permanent counter data is to review the data set for completeness and to manually exclude data that have been rendered invalid through a power failure or machine malfunction.

The American Association of State Highway and Transportation Officials (AASHTO) guidelines (AASHTO, 2001) state that there should be a sufficient number of days of valid traffic measurements during a year to compute average traffic characteristics at the site. The number of days needed is determined by whether or not an automated editing process is used to evaluate the recorded data. If automated edits are performed, it is recommended that agencies adopt a one-day minimum of edit-accepted data for each day of the week and each month of the year. Until agencies had implemented automated edits, AASHTO recommends that a two-day minimum for each day of the week, each month of the year, be adopted. These statements from AASHTO, which were further supported by FHWA's TMG (FHWA, 2001), should be followed to ensure the quality and validity of the developed adjustment factors.

2.3.3 Accuracy Level in Truck Traffic Data

Collecting more accurate truck traffic data is important as the number of heavy vehicles on a road affects highway planning, operations, geometric design, safety, and pavement performance. In order to improve the quality of truck traffic data collected at permanent traffic count stations, researchers have experimented trial-and-error methods. Only a few studies have been conducted to evaluate accuracy levels of truck traffic data. Table 2-2 summarizes the results of the existing research studies on accuracy levels of truck traffic data that aimed at lessening the errors at permanent truck traffic data collection stations.

Table 2-2 Summary of Research Results on Accuracy Level of Truck Traffic Data

Researcher	Methodology	Accuracy Level
Wang et al. (2006)	Paired video and single-loop sensors.	The accuracy for vehicle detection was above 97 percent, and the total truck count error was lower than 9 percent for all three tests.
Fung et al. (2002)	A statistical shadow removal algorithm based upon construction of a probability map called the Shadow Confidence Score (SCS).	The algorithm achieved an error rate of 14 percent.
Lai et al. (2001)	Angle control of camera through the use of a set of coordinate mapping functions.	This method estimated vehicle lengths to within 10 percent of error margin in every instance.
Gupta et al. (2002)	Determining the relationship between the tracked regions and vehicle image based analysis.	In a 20-minute trial of the program, 90 percent of all vehicles were properly detected and tracked, and 70 percent of those vehicles were properly classified.
Hasegawa and Kanade (2005)	A system capable of detecting and classifying moving objects by both type and color.	In a test of 180 presented objects, 91 percent was correctly identified.
Graettinger et al. (2005)	Video data collected from an Autoscope Solo Pro commercial detection system to provide classifications corresponding to the 13 FHWA vehicle classes.	An overall misclassification rate of 3.4 percent was achieved.

2.3.4 Data Collection Methods for Estimating Accuracy Level of Traffic Data

In order to evaluate the accuracy level of traffic data, Lomax et al. (2001) surveyed the archived operation data collection methods of ten major cities in the United States. They summarized the archived data collection methods and data quality as shown in Table 2-3.

Table 2-3 Summaries of Archived Operations Data Collection Methods and Data Quality

City Name	Data Collection Method	Average Sensor Spacing (mile)	Speed Derivation Method	Submitted Derivation method		Average Percentage of Records Passing Quality Control Test (%)[1,2]	
				Roadway	Time Interval (min)	Volume Records (%)	Speed Records (%)
Atlanta, GA	Video image processing	0.4	Direct measurement	By lane	15	89	89
Cincinnati, OH/KY	Mainly single inductance loops; some video and radar	0.5	Estimated[3]	By direction	15	93	93
Detroit, MI	Double inductance loops	2.0	Direct measurement	By lane	1	99.7	99.7
Hampton Roads, VA	Double inductance loops	0.5	Direct measurement	By lane	2	91	91
Houston, TX	Regional AVI[4] (probe reader)[5]	2.8	Direct measurement	By link	Individual vehicle travel time	99.0	94.7
Minneapolis, MN	Single inductance loops	0.5	Estimated	By lane	5	99.9	87
Phoenix, AZ	Double inductance loops; Some passive loops	0.3	Direct measurement	By lane	5	94	84
San Antonio, TX	Mainly double inductance loops; some acoustic detectors	0.5	Direct measurement	By lane	20-30 seconds	99	99
Seattle, WA	Single inductance loops	0.4	Estimated	By lane	5	100	100

Notes:
[1] Quality control was performed on original data as submitted which varied from 20sec to 15min.
[2] Percentage of records based upon the average across all days of the year 2000. Or as otherwise noted
[3] Calculated using volume and occupancy measurements; formulae vary from city to city
[4] AVI = Automated Vehicle identification
[5] Volumes were estimated from AADTs provided by TxDOT.

2.4 Relationship between Truck Traffic and Pavement

2.4.1 Basic Concepts

The National Cooperative Highway Research Program (NCHRP) Guide for Using Mechanistic Principles to Improve Pavement Performance (NCHRP, 2003) stated that four variables including 1) pavement structural capacity, 2) environmental conditions, 3) axle load distribution and 4) rutting and fatigue cracking needed to be considered in order to improve pavement performance.

Lu et al. (2002) defined the basic concepts of interrelationship between pavement performance and truck traffic as follows:

- Under-estimation of truck traffic led to poor design and maintenance of highway facilities and pavements.
- The increasing sophistication of pavement distress models used in mechanistic pavement design methods required more detailed truck traffic information in order to take full advantage of their increased predictive capability.
- Highly detailed truck traffic information could be easily stored, organized, and readily used for pavement design.

Also, they summarized main factors considered on truck traffic analysis that is related to pavement as follows:

- Traffic distribution between day and night was an important factor in pavement design because the environmental factors (e.g., temperature) varied greatly between day and night, which led to corresponding changes in pavement material properties.
- It could be reviewed that the daytime truck percentages were similar for both directions at a given WIM site. In general, the daytime truck percentage for total truck types ranged from 55 to 75 percent, and was close to the corresponding values of special truck type.

- Seasonal distribution of traffic was also an important factor in pavement design because the same traffic loading would have different effects on pavement damage during different seasons. The analysis results showed that there was little seasonal variation in traffic volume.
- When there were two lanes in one driving direction, over 90 percent of the truck traffic will travel on the outside lane, and when there were three or more lanes in one driving direction, over 90 percent of the truck traffic would travel on the outermost two lanes.
- One of the main goals of truck traffic analysis was to produce a long-term forecast of traffic loading on the pavement being considered. Two parameters were currently used by Caltrans to estimate the traffic growth trend: average annual daily truck traffic (AADTT) and equivalent single axle load (ESAL).
- The higher points of truck occupancy occurred on weekdays and the lower points occurred on weekends. The results showed that the traffic volume annually reached its maximum value during June through August.
- Truck speed information was also useful in pavement design. It could be observed from these figures that the speed of each truck type has a narrow distribution, mainly between 50 mph and 70 mph, except for the speed distributions of special types of truck, which fell between 50 mph and 75 mph. The results showed that most of the vehicle speeds were between 50 mph and 60 mph.
- The changes in truck gross weight were directly related to the effect that truck traffic had on pavement damage. They could also reflect the economic development of an area. The legal maximum gross vehicle weight in California was 80,000 lbs (355 kN). It could be observed that the growth rates of truck gross weight were different among locations and truck types. Generally the value was between –1 and +2 percent.

2.4.2 Existing Major Research Studies on Relationship between Truck Traffic and Pavement

Oh et al. (2007) evaluated damage potential for pavements by overweight truck traffic in order to minimize expected damage. This research was required to design pavement to support overweight truck traffic by evaluating damage potential based on accurate modeling of pavement response. An attempt was made to model base and sub-grade layers as a stress-dependent cross-anisotropic material to assess pavement response using finite-element (FE) analysis.

The FHWA Long-Term Pavement Program (LTPP) sites and locations where site-specific WIM systems were justified for pavement design use piezo systems. Site-specific WIM data collection for pavement design was justified by LTPP at locations where:

- Roadway sections had large volumes of trucks that left plants full and return empty;
- Pavements were deteriorating much faster than expected; and
- Pavements were deteriorating in one direction much faster than the other.

Also, Hong et al. (2007) reviewed the pavement damage on U.S.-Mexico highway trade corridor using WIM data. Their main findings are the following:

- WIM records, for each passing vehicle, captured detailed traffic information, including date and time of passage, lane and direction of travel, vehicle class, speed, wheel/axle weight, and axle spacing.
- Selecting the WIM sites for eventually studying the potential impact of the North American Free Trade Agreements (NAFTA) truck traffic on Texas's infrastructure was made by sample load data.
- Focusing on axle load data was necessary to investigate the potential impact of NAFTA truck traffic on Texas's highway infrastructure.

The characteristics of pavement performance related to truck traffic were identified (Hong et al., 2007) as shown below:

- The axle load distributions were different for different truck classes and axle types, partly because of the differences pertaining to the distances and types of cargo moved by the different truck classes. However, the load distributions typically revealed a single mode or two modes (peaks) in the data.

- There was a significant difference in the load distributions, as well as relevant statistics, of the Class 10 truck type by travel direction.
- The researchers concluded that the load sharing facility (LSF) trend lines for the Class 10 trucks in each of the travel directions would cover truck capacities, given the current regulations and the level of weight enforcement.

2.4.3 Factors Considered for Pavement Design

Pavement is designed based on traffic loadings expected in the highway's design lane, that is, the lane expected to experience the greatest number of 18,000 pound equivalent single axle loads (18K ESALs) over the design period (usually 20 years). Traffic data required to calculate ESALs include:

- Base year average daily traffic (ADT);
- Traffic growth rate for the design year;
- Percentage of trucks, including dual-rear-tire pickups and buses, in each classification category;
- Directional distribution of traffic for the design period; and
- Lane distribution factor for the design period.

Yao (1995) also studied pavement design factors. The commercial traffic and frequency of heavy load applications played a major role in the structural design of the roadway. Damages caused by truck traffic were estimated based on the analysis of historical truck traffic weight data collected by the WIM program. The WIM data are combined with other data, including:

- Highway location,
- Highway type,
- Number of lanes,
- Directional truck traffic,

- Lane factor, and
- Equivalent truck damage factor

2.4.4 Mechanistic-Empirical Pavement Design Guide (M-E PDG)

Traffic load is an essential input to pavement analysis and design process. In the past, the impact of traffic was aggregated into ESALs and entered into the empirical regression based pavement performance equations.

The recently developed Mechanistic-Empirical Pavement Design Guide (M-E PDG) (NCHRP, 2003) characterized traffic in terms of axle numbers by type and load frequency distribution, including axle load spectra, which maintains the data by axle configuration and weight without converting the loads into ESALs.

The LTPP program is a study to establish the relationship between the traffic data collection efforts, including the combination of traffic data acquisition technologies and length of time coverage, and the predicted pavement life using the M-E PDG.

Wiser (2006) analyzed LTPP data obtained from the process of specific pavement design applications. He set up several scenarios to conduct the study, established data collection scenarios by expanding the four traffic input levels of the M-E PDG, conducted case studies to represent a wide range of layer thicknesses and AADTs for detailed simulation in the M-E PDG, and performed sensitivity analysis. His conclusions are the following:

- From a pavement design point of view, traffic underestimation was considered the most critical problem because it led to the overestimation of pavement life and could produce pavement structures with insufficient structural capacity. The lower end of the percentile range computed for each traffic input element was the most significant in the study.
- Discontinuous traffic data collection scenarios involving site-specific WIM data had significantly more potential error than continuous coverage site-specific AVC data. This was because partial WIM coverage did not yield site-specific monthly

adjustment factors, which were necessary for accurately modeling seasonal damage in the M-E PDG.

- Using continuous site-specific truck counts and classification with regional load data, engineers could predict pavement life with an error on the order of 10 percent, 16 percent, and 27 percent for confidence levels of 75 percent, 85 percent, and 95 percent, respectively.
- Continuous, site-specific truck counts combined with regional load and classification data produced life prediction errors ranging from 25 percent to 64 percent for the same confidence levels. Likewise, continuous site-specific truck counts combined with regional classification and national load data also yielded similar life prediction errors ranging from 27 percent to 68 percent.
- Using continuous site-specific truck counts combined with national load and classification data yielded life prediction errors ranging from 30 percent to 76 percent.
- Pavement design and traffic engineers could use the results from this study to establish traffic data collection scenarios considering a maximum acceptable pavement life prediction error under a selected confidence level. The data from this and subsequent analyses also could be used to implement traffic data collection procedures for given design scenarios.
- In addition, pavement designers could use these findings to better understand the effect that specific traffic data sources may have on predicted pavement life determined by the M-E PDG.

2.4.5 Special Research Results for Pavement Structures

In order to ascertain the detailed relationship between truck traffic collection technologies and pavement structure, Middleton (2002) summarized special guidelines from various sources that address required pavement structures (thickness) as follows:

- Installation of piezo sensors requires a minimum asphalt thickness of 4 inches.
- Installation of bending plate sensors requires asphalt concrete (AC) pavement that is 6 inches thick or greater.

- An unpublished LTPP specification defines a minimum pavement structure using a falling weight deflectometer (FWD) to measure maximum deflection and defection basin area.
- Install 225 ft of 12-inch thick jointed concrete pavement for bending plate sensors.
- Maximum FWD variation across the location where sensors are to be installed should not exceed ±7 percent.
- If the WIM system is to be used on a roadway with AC pavement, the AC pavement must be replaced with Portland cement concrete (PCC) pavement for a minimum distance of 50-ft before and 25 ft after the WIM sensor location.

These special guidelines for pavement thickness design are helpful for determining and setting up truck traffic collection tools which are compatible with the road environment including road pavement type and condition.

2.5 Relationship between Truck Traffic Volume and Statistics

Estimates of annual average daily truck traffic (AADTT) and vehicle classification (VC) data for individual sections of roads are required to design pavement for the truck volume they will carry. The knowledge of what percentage of traffic is made up of trucks is also a required input for determining capacity and level-of-service of a roadway section being designed.

In relation to the accuracy level of the truck volume required for pavement design, Weinblatt (1996) studied seasonal and day-of-the-week factoring to improve estimates of truck VMT. He reviewed procedures currently used in the United States for estimating AADT by vehicle classes. He found that classification counts were typically collected for a 48-hour period on weekdays (excluding Friday evenings). These counts were then used, without any seasonal or day-of-the-week adjustment, as the basis for distributing estimated AADT across vehicle classes. This procedure showed that the vehicle composition of traffic did not change with time. Since AADT was usually estimated from sample counts by applying total traffic volume factors, this procedure also implied that truck volumes could be estimated by using total traffic volume factors that might have been obtained from an ATR. Weinblatt's study (1996) indicated that the above-mentioned procedure of apportioning AADT across vehicle classes could contribute to substantial errors in VMT estimates. Finally, he claimed that significantly better estimates of VMT for all classes of trucks and of AADT for combination trucks could be developed by using modified versions of the TMG's seasonal and day-of-the-week adjustment factors. (Weinblatt, 1996) These adjustment factors, however, might be derived from ATRs reflecting total traffic variation rather than truck traffic variation.

Yao et al. (1995) studied truck damage factors using the estimation method and other statistics including mean, standard deviation, z-score, and probability. First, they calculated the cumulative 18-kip ESALs for the design lane for one year by the following equation:

$$W = AADTT \times D \times E \times LF \times 365 \qquad \text{(Equation 2-1)}$$

where

W = Design 18-kip traffic loading

D = Directional distribution factor, expressed as a ratio. For one-way, D=l.0, two-way, D=0.5.

E = Damage factor (the number of 18-kip units for the average truck on the section of highway under design) which is a function of the pavement parameters: type (rigid or flexible) and thickness.

LF = Lane distribution factor, expressed as ratio. It is calculated as

LF = (1.567- 0.0826 * Ln (one-way AADT)-0.12368 * LV)

where:

LV = 0 if the number of lanes in one direction is 2

LV = 1 if the number of lanes in one direction is 3 or more

Ln = natural logarithm

Also, they quoted basic statistics such as mean, standard deviation, z-score, and other probabilities in order to ascertain the accuracy level of truck traffic counts (Yao et al., 1995).

- μ = an average weight or mean value, in kips

- σ = the standard deviation of weights, in kips
- z = the z-score of statistics, the z-scores for all axles with weight >= 18-kip can be calculated as: $z = (18-\mu)/\sigma$.
- P(z) = the probability of single axle load exceeds the 18-kip, based on assumption that the data distribution is normal. For a normal distribution case, P(z) can be found from the table of any introductory book of statistics.
- P_{th} = the probability of single axle load exceeds the 18-kip based on Chebyshev's theory. The probability of axle weight ≥ 18-kip can be also estimated by Chebyshev's theory which states: Let k be any number ≥ 1, then at least $(1-l/k^2)100\%$ of the data (in the population) fall into $(\mu-k\sigma, \mu+k\sigma)$; the interval or equivalently, at most $(l/k^2)100\%$ of the data fall outside the interval $(\mu-k\sigma, \mu+k\sigma)$

2.6 Chapter Summary

Many problems such as traffic congestion, transportation system deficiencies, safety, infrastructure deterioration, inter-modal connections, environmental impacts, quality of life, economic development, and losses in productivity have happened as the truck traffic on highway have rapidly increased. Therefore, the importance of truck traffic on highways has significantly increased in the area of transportation planning and traffic operation according to many existing truck related researches.

FHWA classifies trucks into ten types according to the configuration of the trailer unit, the number of axles, and the number of trailers (AASHTO, 1992) (see Figure 2-1).

According to the previous studies, truck data collection methods were grouped into three categories: use of axle, vehicle length, machine vision classifiers, and new technologies. Collecting more accurate truck traffic data is important as the number of heavy vehicles on highways affects traffic operations, safety, pavement performance, design, and so forth. In order to improve the quality of truck data collected at ATR stations, many researchers have experimented trial-and-error methods.

Also, with more accurate truck traffic data collected, VMTs and VC become vital inputs in the design and operation of an efficient highway infrastructure system. A research has shown that currently used methods for the estimation of heavy-vehicle VMT were often less accurate than those used for passenger vehicles. Many research studies have been concluded to raise the accuracy level of truck traffic so as to improve the design and operation of highway systems.

The NCHRP guide for using Mechanistic Principles to Improve Pavement Performance (NCHRP, 2003) suggested the consideration of four variables: 1) pavement structural capacity, 2) environmental conditions, 3) axle load distribution, and 4) rutting and fatigue cracking. Oh et al. (2007) studied damage potential for pavements due to overweight truck traffic in order to minimize expected damage. His research concluded that a study on pavement design using an accurate modeling of pavement response would be needed, which can support overweight truck traffic for the entire service life of pavement.

Yao (1995) studied the importance of pavement design factors. He concluded that the commercial truck traffic and the frequency of heavy load applications played a major role on the structural design of the roadway. The damages caused by truck traffic were estimated using the results of an analysis of historical traffic weight data collected at WIM stations. The WIM data were combined with other data, such as highway location, highway type, number of lanes, highway direction, truck traffic, lane factor, and equivalent truck damage factor. The recently developed M-E PDG (NCHRP, 2003) characterizes traffic in terms of the axle number by type and the load frequency distribution, including an axle load spectra.

In summary, many previous studies, including the Wang et al. (2006) study on checking the truck damage factor using statistics, have tried to improve collection, reduction, and estimation of truck traffic data by permanent count stations using various methods and statistics. However, a more in-depth study utilizing systematic statistical analyses is needed to improve the accuracy level of truck traffic data.

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3 Survey of State DOTs on Truck Traffic Estimation

3.1 Outline of the State DOT Survey

3.1.1 Purposes

UDOT has 95 ATR stations (16 volume-only ATR stations, 2 volume-by-class ATR stations, and 76 volume-by-length ATR stations). At present UDOT engineers assesses the accuracy by visual counts at the station and compare the vehicle type with the readout. They also check speed to see if the loop setting is correct. The field staff visits all ATR sites yearly and the engineer in charge visits the sites as needed. An internal inquiry shows that UDOT's targeted accuracy level is 95 percents. Traffic counting experts at UDOT think that major contributing factors that lower the accuracy level of truck traffic counts below UDOT's targeted accuracy level include congestion during data collection, wrong loop layout, faulty and failed wires, and so forth. Because of these problems UDOT has not yet used M-E PDG for pavement design despite that they approved its use in 2007.

In order to evaluate the state-of-the-practice of truck traffic data collection and their efforts on improving the accuracy level of truck traffic data, a survey was prepared and sent to state DOT representatives.

3.1.2 Methodology

With the help of TAC members a survey on the state-of-the-practice in truck traffic estimation was prepared and mailed to DOTs in the US and Canada. A blank form of the survey can be found in Appendix 1. Using regular mail or electronic mail, the survey was conducted from March 21 to May 2, 2008. The main items of the survey are the following:

- Truck traffic counting method (extent and equipment type),
- Method for evaluating the accuracy level of truck traffic data,
- Level of acceptance of the M-EPDG, and
- Comments on truck traffic data collection and their efforts on improving the accuracy level of truck traffic data.

3.1.3 Survey Response Rate

Seventeen agencies (30.0 percent) (sixteen state DOTs in the United States and two provincial DOTs in Canada) responded out of the agencies contacted (fifty state DOTs in the United States and ten provincial DOTs in Canada) as shown below:

- USA (16 states): Arkansas (AR), Georgia (GA), Iowa (IA), Marine (ME), Michigan (MI), Maryland (MD), Missouri (MO), New Jersey (NJ), Pennsylvania (PA), South Dakota (SD), Tennessee (TN), Texas (TX), Utah (UT), Virginia (VA), Washington (WA), and Wyoming (WY).
- Canada (2 provinces): Alberta (AA) and British Columbia (BC).

3.2 Analysis of the Survey

This section presents a summary of the analysis of the survey for major questions including the traffic counting method, method for evaluating the accuracy level of truck traffic data, and adoption of M-EPDG. The results of the detailed analysis are found in Appendix 2.

3.2.1 Traffic Counting Methods

The DOTs of all states and provinces that responded to the survey have used inductive loop detectors. Main traffic data collected by inductive loop detectors are volume-only, and either volume-by-class or volume-by-length. Fourteen DOTs mainly collected traffic data by volume-only detector, three DOTs (WA, IA, and UT) by volume-by-class detector, and two DOTs (IA and UT) by volume-by-length detector. Among the responses to a question regarding the use of inductive loop detectors by highway class, thirteen DOTs used them on highways and five DOTs used them on major arterials.

As other traffic counting methods, VA, WA, IA, TN, MI, AR, and UT DOTs used radar or microwave sensors on freeways. Piezo electronic sensors were used in AR, ME, TX, WY in the US and in BC in Canada. Also, AA and NJ use WIM for traffic counting. Short term traffic counts are used by all DOTs. Table 3-1 shows a summary of traffic counting methods used by the seventeen agencies that responded.

Table 3-1 Traffic Counting Methods Just for Ground Truth Data

	Detailed Classification	Number of DOTs	DOTs
Methodology	Visual Counts	6	WA, GA, IA, ME, WY, UT
	Weights	1	NJ
	Manual Verification	1	MD
Data collection	By Lane	6	VA, WA, IA, MD, WY, UT
	By Direction	5	WA, GA, TX, ME, WY
	By Link	1	GA
Duration of data collection	60 minutes	1	UT
	Several Hours		NJ
	3 Hours	2	WA, WY
	4 Hours	1	IA
	4-6 Hours	1	ME
	24 Hours	1	TX
	48 Hours	1	MD
Main contributing reasons of lower accuracy level than target value	Sensor problem: configuration, calibration, location, limitation	6	NJ, IA, MD, ME, WY, UT
	Human error: reviewing, video tape	1	GA
	Software algorithm	2	NJ, IA
	Environmental problem: weather	2	MD, NJ
	Pavement condition and congestion	2	MD, UT
	Higher expected accuracy level	1	GA
	High cost of new technology and shrink in the state workforce	1	ME
Number of collection stations	GA	Freeway and Main Arterial – Less than 10	
	IA	Freeway-17, Main Arterial-44, Minor Arterial-17, Collector-12	
	MD	Arterial-16	
	TX	Total – 640	
	ME	Freeway-2, Main Arterial- 4, Minor Arterial-7, Collector-2	
	WY	Freeway-1, Main Arterial-96, Minor Arterial-26, Collector-28	
Time between data collection events	GA	Freeway and Main Arterial– Less than 10 months	
	IA	3 years	
	MD	6 months	
	TX, UT	1 year	
	ME	4 months	
	WY	3 months	

3.2.2 Methods for Evaluating the Accuracy Level of Truck Traffic Data

In the survey of methodologies for evaluating the accuracy level of truck traffic data, five state DOTs including WA, GA, MD, TX, and WY responded; the remaining DOTs did not respond to this specific question. The evaluation method of each responding DOT is different: electric counting board in WA, an extensive quality control program using approved historical data in GA, mechanical counting boards in TX, and laptop computer utilizing custom counting program in WY. MD responded but did not provide details.

To the question on tolerance and targeted accuracy level of truck traffic data, nine DOTs responded. Table 3-2 shows the summary of tolerance and targeted accuracy level of truck traffic data. Seven DOTs among the nine DOTs that responded use ± 5% tolerance levels; the remaining two DOTs use ± 10% tolerance levels. Targeted accuracy levels vary among the nine DOTs. In order to achieve the targeted accuracy level of truck traffic data, VA DOT uses a high quality traffic data collection program, WA DOT carries out a physical site evaluation and compared manual count with automatic collector count, and GA DOT uses various accuracy levels depending on the type of facility. MD DOT uses a piezo loop sensor configuration to evaluate the accuracy level. TX DOT regularly screens the classification data and compares them with previous year's counts, and WY DOT routinely reviews and analyzes the traffic count data.

Table 3-2 Tolerance and Targeted Accuracy Level

	Range	# of DOTs	DOTs
Tolerance	± 5%	7	VA, WA, NJ, MD, TX, UT, and WY
	± 10%	2	GA and TX
Targeted Accuracy Level	Over 97.5%	1	WA
	95% ~97%	3	ME, UT, and WY
	90% ~95%	3	NJ, GA, and TX
	85% ~90%	2	IA and MD

3.2.3 M-E PDG

The M-E PDG has emerged as one of the main reasons why the accuracy level of truck traffic data needs to be improved. One of the survey questions related to M-E PDG stated “Has the state approved the use of the Mechanistic-Empirical Pavement Design Guide?” Among the seventeen respondents, only three states, IA (August in 2005), MO (September in 2006), and UT (2007) approved the use of M-EPDG. Eight respondents including VA (sometime in 2011), AA, NJ, GA, PA, MI, TX, and ME, are preparing to approve M-EPDG in the near future.

On the other hand, six DOTs including SD, TN, MD, BC, WY, and AR responded that they haven’t had any consideration of M-E PDG. WA DOT didn’t respond to this question.

3.2.4 Special Issues

In order to find out if any serious issues are encountered that are related to maintaining the accuracy of truck traffic data accuracy with respect to the targeted level, opinions and concerns were solicited from DOTs’ traffic count experts. Their responses were grouped into three categories: hardware and software issues, traffic condition and environmental issues, and other miscellaneous problems.

The hardware and software issues were summarized as follows:

- Problem of adequate installation depth of a piezoelectric sensor (4 inch-depth is not adequate) (VA),
- Problem of calibrating the data obtained from WIM (AA),
- Problem related to WIM: installation site (WA, GA), calibration (AA), maintenance (WA) ,
- Equipment issue: sensor failure (NJ),
- Characteristics of quartz piezoelectric WIM sensor (GA),
- Characteristics of ATRs (TN and AR),
- Limited availability of the equipments on the process of selecting sites (TX),
- Lack of technology for classifying truck traffic (ME), and
- Adequacy of sample size for implementing M-E PDG (AR).

The traffic condition and environmental issues were summarized as follows:

- Inconsistent traffic flow or congestion (NJ and TX),
- Bad pavement condition (NJ, GA, and TX),
- Malfunction of road weather information system (TN),
- Insufficient resources for ensuring accuracy level (PA), and
- Data collection type (the difference in data collection durations by class) (MO, BC, and ME).

Maintenance (PA, MO, and AR), budget (PA), and quality and quantity of available man power (WY) were some of the issues of the other problems category.

3.3 Chapter Summary

Even though the number of DOTs that responded to the survey was small (about 30 percent response rate), this survey provided hints for setting out the direction of this study. As the results of the survey indicated, all states and provinces that responded to the survey have used inductive loop detectors on various highway classes. Some respondents indicated that their states used other traffic data collection methods including radars, microwave sensors, piezo electronic sensors, and WIM systems.

Tolerance levels of truck traffic data vary from ±5% to ±10% while the targeted accuracy levels of truck traffic data vary from 85% to 97.5%. Also, it was found that M-E PDG has not been adopted by most of the states that responded.

Issues encountered by state and provincial DOTs for maintaining the accuracy level of truck traffic data at the targeted accuracy level were grouped into three categories: hardware and software issues, traffic condition and environment issues, and other miscellaneous problems.

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4 Commodity Flow Patterns in Utah

Access to cities and freight transfer stations in Utah from other states by long-distance freight trucks is limited to certain interstate paths. For east-west movements, I-80 and I-70, I-84, US-6, and US-40, and for north-south movements, I-15, US-191, and US-89 are likely to be the major routes used by long-distance truckers. There are other state routes available but they are not major routes for typical long-distance freight trucks. There are three main coal haul truck routes, including SR-10, SR-50, and SR-28.

The information on commodity flow by trucks will help improve the identification of strategic locations for truck traffic counts. This information can be used to evaluate whether the current locations of ATR stations are adequate to maintain the accuracy level of truck traffic counts. Also, the data collected in this task can be used in a future study to identify origin-destination patterns of long-distance trucks and truck traffic assignments, and to estimate their trips through the highway systems in Utah.

To search commodity flow patterns in Utah, two methodologies were used. One method was a trucking company survey done with the help of UDOT and the Utah Trucking Association (UTA). The other was the shortest path algorithm available in ArcGIS (ESRI, 2007).

4.1 Commodity Flow Survey

4.1.1 Outline of the Survey

In order to gather the most recent information on commodity flow patterns in Utah, a trucking company survey was conducted with the help of UDOT and UTA. This survey was performed by two methods. One method used interviews during the UTA Annual Conference, which was held in St. George, Utah, on May 8 and 9, 2008, and the other was an e-mail survey. The e-mail survey was carried out from April to June, 2008 to UTA members. No UTA member responded to this e-mail survey. The main questions of the two surveys were grouped into two categories, company information and commodity flow pattern, as shown below:

- Company information: name, truck carrier type, location, terminal location, main commodities carried, number of trucks, and annual total tonnage of commodities carried
- Commodity flow patterns: peak operation time, percentage of trucks operating during peak time, and top three destination including main routes.

4.1.2 Analysis of the Survey at the UTA Conference

The number of responses (a total of 12 responses) obtained at the UTA Annual Conference was too small to conduct a commodity flow pattern analysis. Table 4-1 shows a summary of the information obtained from the interviews. Even though the number of responses was small, the information obtained through this survey will be helpful for conducting future studies on freight movements in Utah.

Table 4-1 Summary of the Responses to the Survey

	Truck Carrier Type	Major Commodities Carried	Number of Trucks Owned (Small/Large/ Trailer)	Annual Total Tonnage of Commodities Carried	Peak Operation Time	Percentages of Truck Operation During Peak Time	Top Three Destination
A	Over-the-road-carrier	Reefer carrier or anything	-/ +300/ +300	300 million Tons/year	5:00PM-6:00AM	80%	- 50 all states - St. George: Bangerter Highway in SLC* →St. George
B	Special freight carrier	Petroleum	-/-/10	4,200,000 Pounds/day	04:00AM-2:00PM	90%	- SLC - Clearfield - Provo
C	Private carrier	Food commodities	-/200/39	56,000,000 Tons/year	2:00PM-2:00AM	50%	- SLC - Ogden - Utah County
D	Less-than-truckload carrier	New products and household goods	12/57/7	11,500 tons/year	11:00AM-6:30PM	-	- SLC North - Provo - SLC
E	Private carrier	Rock products	250/20/80	-	6:00AM-2:00PM	85%	- SLC - Utah county - Summit county
F	-	US mail	15/22/-	-	3-8AM 4-8PM	100%	- SLC - Logan - Orem
G	Less-than-truckload carrier	General LTL	12/48/-	8million pounds/month	3:00PM-11:00PM	-	-Vernal UT - Roosevelt UT - SLC UT
H	Special freight carrier (Tanker)	Petroleum and general goods	3/9/25	250million gallons/year	8:00AM-5:00PM	70%	- Salt Lake County - Western, WY - Washington County, UT
I	Special freight carrier	Powder cement, fly ash	-/-/73	10million Tons/year	2:00AM-6:00PM	90%	- Salt Lake County - Utah County - Davis & Weber County
J	Over-the-road-carrier	General commodities	1/106/0	3,000,000lbs/ week	6-9AM 2-6PM	50% 50%	- SLC→Los Angeles (I-15) - SLC→East (I-80) - SLC→Northwest (I-80 and I-84)
K	Private carrier	Used goods	85/-/-	-	8:00AM-5:00PM	70%	- SLC - Provo - Ogden –Layton
L	Special freight carrier (Flatbed)	Fuel	40/40/50	4-5 million/month	8:00AM-5:00PM	75%	- Utah (I-15) - Nevada (I-80) - Idaho (I-84and I-15)

* SLC: Salt Lake City

4.2 Commodity Flow Pattern Analysis Using GIS Tools

Challenges attributable to increasing truck traffic include, but are not limited to, traffic congestion, transportation system deficiencies, safety, infrastructure deterioration, inter-modal connections, environmental impacts, quality of life, economic development, and losses in productivity.

Identifying main routes for intrastate truck traffic in Utah will be helpful for UDOT to set directions for highway investment planning and programming. Therefore, main routes of intrastate truck traffic in Utah were identified using the shortest path analysis feature of the ArcGIS Network Analysis Tool (ESRI, 2007).

4.2.1 Introduction

The frequency of heavy load applications by commercial truck traffic plays a major role in the structural design of pavement. The damages caused by truck traffic are estimated based on the results of analysis of historical traffic weight data collected by the WIM program. The WIM data can be combined with other data, such as highway location, highway type, number of lanes, highway direction, truck traffic, and lane factor, to determine equivalent truck damage factors. Identification of potential truck routes is one of the important tasks for effective capital investment in and management of highways.

4.2.2 Methodology

The scope of the analysis is limited to the identification of potential truck routes in Utah because a full-scale analysis requires detailed freight data including the industrial structure of the entire Utah, freight terminals, truck traffic volumes, and so on. Such a comprehensive freight analysis was beyond the scope of the current study.

In order to achieve the purpose of the analysis, the shortest path analysis available in ArcGIS was used. The analysis procedure using ArcGIS included the following tasks:

- Collect data about the ATR stations in Utah,
- Map the ATR stations using ArcGIS,
- Select ATR stations that are located on or near the state boundary to the neighboring states, that is, Nevada, Idaho, Wyoming, Colorado, and Arizona, and
- Perform a shortest path analysis using the ArcGIS Network Analysis Tool to identify potential truck routes.

This shortest path analysis was done with an assumption that all truck drivers would objectively choose the shortest path to cross the state of Utah to save time and fuel.

4.2.3 Importance of Identifying Truck Routes

4.2.3.1 The Meaning of the Truck Route

The term "truck route" has two aspects for a transportation system: operational and productivity-related. First, a wide range of potential strategies can be considered for effectively managing increasing truck traffic if truck routes are known including improved highway design, special roadway facilities for trucks, operational improvements, use of intelligent transportation systems, improved signing, regulatory changes in vehicle size or configuration, and enhanced enforcement and compliance. Second, physical management strategies for dealing with truck traffic can be considered including pavement improvement or rehabilitation, climbing lanes, lane restrictions, and WIM station installations. Expected benefits of these projects primarily include improvement in safety, reduction in congestion, improvement in investment priority setting compared with other competitive alternative infrastructures, and increase in productivity (Craig et. al., 2002).

4.2.3.2 Major Factors for Planning Truck Routes

Truck route planning forces truck drivers to use designated truck routes first for long haul, and then to divert from the designated truck routes to make their deliveries or pick-ups. These diversions could result in longer distances, and could have adverse effects on the efficiency of truck operations, eventually impacting the trucking business.

The Florida DOT (2003) listed the following considerations for evaluating existing truck routes and considering new ones in their truck route planning:

- Land use sensitivity: Because land use sensitivity was a factor in the original truck route study done in 1994, changes in land use were examined. Land uses such as residential areas, schools, parks, hospitals, and historical sites and museums were considered.
- Engineering considerations with safety as the major factor: Physical and geometric data were collected and compiled for the original truck route study. For the most part, the engineering data have not changed. Factors considered in the original study were curve severity, outside lane width, minimum intersection radius, bridge sufficiency, railroad crossing safety, pavement structure, roadway functional classification, and truck accident rate.
- Alternate route availability: In the original truck route study, the choice of the alternate route was targeted to those road segments that had marginal engineering, safety, and factors sensitive to land use. This sometimes resulted in a very long alternate route that might place a significant financial burden on trucking companies. A measure of alternate route intolerance was established by obtaining the opinions and route selection sensitivity of truck drivers. The approach assumes that drivers, when faced with the dilemma of an uncertain fine for a violation and a certain economic impact of the longer designated route, a predictable number of drivers will chose to risk the fine.

4.2.3.3 Present Truck Route Identification Methods

Many states have identified strategic corridors within their respective state. Most states have not identified these corridors based on the movement of freight but, instead, on the movement of people. A number of different methods were used by these states to select freight corridors. Craig and Walton (2002) identified the following four factors for determining freight corridors:

- Truck volume,
- Preferred route by trucking company,
- National Highway System (NHS), and
- Freight volume (Tonnage).

4.2.4 Shortest Path Analysis in the GIS Network Analysis Tool

The ArcGIS Network Analysis Tool is an extension that provides network-based spatial analysis including routing, travel directions, closest facility, and service area analysis (ESRI, 2007). The ArcGIS Network Analysis Tool enables users to dynamically model realistic network conditions, including turn restrictions, speed limits, height restrictions, and traffic conditions, different time of day.

With the ArcGIS Network Analysis Tool, the user can conduct drive-time analysis, point-to-point routing, route directions, service area definition, shortest path, optimum route, closest facility, and origin-destination analysis. Also, the ArcGIS Network Analysis Tool provides a rich environment with easy-to-use menus and tools as well as the robust functionality available in the geoprocessing environment for modeling.

4.2.4.1 Basic Theory

Shortest path analysis finds the path with the minimum cumulative impedance between nodes on a network. The path may connect just two nodes – an origin and a destination – or have specific stops between the nodes. Shortest path analysis can help a driver plan routine trips between home and workplace, a van driver set up a schedule for dozens of deliveries, and an emergency service connect a dispatch station, accident location, and hospital. It can also be used to connect a potential user with a park-and-ride facility.

Shortest path analysis typically begins with impedance matrix, in which a value represents the impedance of a direct link between two nodes on a network and an ∞ (infinity) means no direct connection. The analysis then follows Dijkstra's algorithm to find the shortest distance from node 1 to all other nodes in an iterative process. Although Dijkstra's algorithm is the common algorithm for solving the shortest path problem, different computational methods have been proposed (ESRI, 2007).

Figure 4-1 illustrates a road network with six cities to explain how the shortest path works (Chang, 2006). The impedance matrix of travel time measured in minutes is shown in Table 4-2. The value of ∞ above and below the principal diagonal in the impedance matrix means no direct path between two nodes. Suppose someone wants to find the shortest path from node 1 to all other roads in Figure 4-1. User can solve the problem by using an iterative procedure. At each step, the user chooses the shortest path from a list of candidate paths and places the node of the shortest in the solution list. The first step is to choose the minimum among the three paths from node 1 to nodes 2, 3, and 4, respectively.

$$\min (p_{12}, p_{13}, p_{14}) = \min (20, 53, 58) \qquad \text{(Equation 4-1)}$$

The user, then, chooses p_{12} because it has the minimum impedance value among the three candidate paths. He then places node 2 in the solution list with node 1.

The second step is to prepare a new candidate list of paths that are directly or indirectly connected to nodes in the solution list (nodes 1 and 2):

$$\min (p_{13}, p_{14}, p_{12}+p_{23}) = \min (53, 58, 59) \qquad \text{(Equation 4-2)}$$

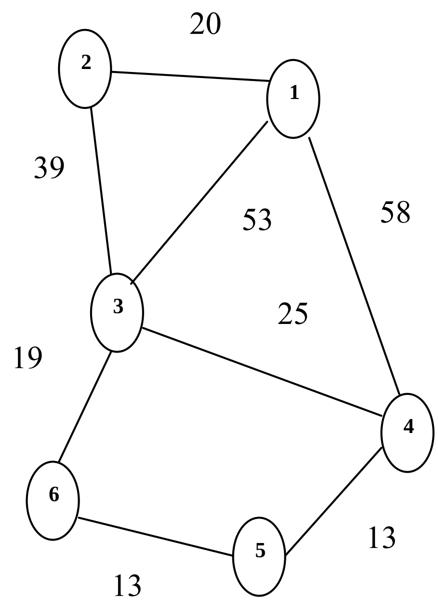

Figure 4-1 Link Impedance Values between Cities and Road Network

Table 4-2 Impedance Matrix among Six Nodes in Figure 1

	(1)	(2)	(3)	(4)	(5)	(6)
(1)	∞	20	53	58	∞	∞
(2)	20	∞	39	∞	∞	∞
(3)	53	39	∞	25	∞	19
(4)	58	∞	25	∞	13	∞
(5)	∞	∞	∞	13	∞	13
(6)	∞	∞	19	∞	13	∞

The user chooses p_{13} and add node 3 to the solution list. To complete the solution list with other nodes on the network he needs to go through the following steps:

$$\min (p_{14}, p_{13}+p_{34}, p_{13}+p_{36}) = \min (58, 78, 72) \quad \textbf{(Equation 4-3)}$$

$$\min (p_{13}+p_{36}, p_{14}+p_{45}) = \min (72, 71) \quad \textbf{(Equation 4-4)}$$

$$\min (p_{13}+p_{36}, p_{14}+p_{45}+p_{56}) = \min (72, 84) \quad \textbf{(Equation 4-5)}$$

Table 4-3 summarizes the solution to the shortest path problem from node 1 to all other nodes. The difference between shortest path analysis and path analysis is that the two analyses differ in the data model and data analysis environment (Chang, 2006).

Table 4-3 Shortest paths from Node 1 to All Other Nodes in Figure 4-1

From-node	To-node	Shortest Path	Minimum Cumulative Impedance
1	2	p_{12}	20
1	3	p_{13}	53
1	4	p_{14}	78
1	5	$p_{14}+p_{45}$	71
1	6	$p_{13}+p_{36}$	72

4.2.4.2 Application in ArcGIS

Network analysis involves tracing. The term tracing is used here to describe building a set of network elements. Tracing can be considered as placing a transparency on top of a map of the network and tracing all the network elements onto the transparency that are desired to be included (ESRI, 2007).

When working with networks, tracing involves connectivity. A network element can only be included in a trace result if it is in some way connected to other elements in the trace result. The trace result is the set of network features that is found by the trace operation.

For example, suppose all of the features upstream of a particular point in a river network are desired to be found. Using a transparency placed over the map of the river network, one could trace over all of the branches of the river that were upstream of that point. What is drawn on the transparency after this task will be his desired result.

Similarly, when the user performs a trace operation in ArcMap, the results are a set of network elements including rout traces. In ArcMap, the route tracing results can either be drawings on top of the user’s map or a selection of a network.

4.2.5 Application to Utah Highway Systems

4.2.5.1 Data Collection and Mapping of Truck Counting Station

UDOT provided the BYU research team with the locations of ATR stations. The total number of ATR stations is 95 as of this writing. The existing ATR stations spread over 50 highways. Three types of traffic counting methods are used: i.e., total volume-only, volume-by-length, and volume-by-class. The characteristics of the three counting methods are as follows:

- Volume-only: only one loop per lane, collecting only axle count information;
- Volume-by-length: two loops per lane collecting vehicle length data; and
- Volume-by-class: Piezo cable per lane collecting WIM data and length data between axles to give class information.

Figure 4-2 maps the locations of ATR stations in Utah using ArcGIS, and Table 4-4 shows the grouping of ATR stations in Utah, as received from UDOT.

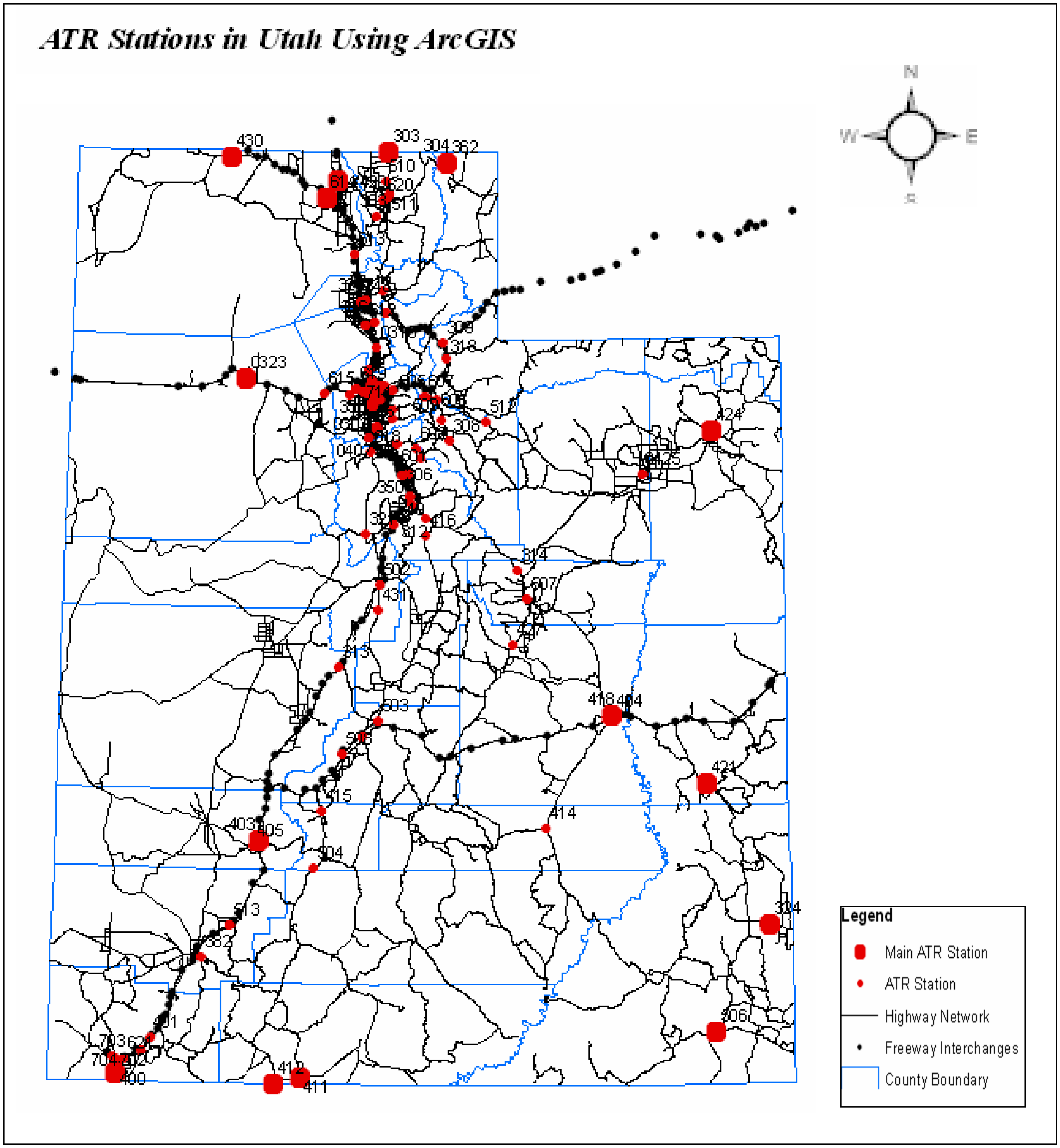

Figure 4-2 Mapping of ATR Stations in Utah Using ArcGIS

Table 4-4 Grouping of ATR Stations in Utah

Type	TN*	RN** (#)	Station Number (Mile Post)
Class	3	10 (1)	427(49.51)
		15 (1)	502(206.53)
		35 (1)	512(10.4)
Length	70	6 (5)	321(141.44), 312(182.22), 314(226.97), 507(239.23), 418(266.96)
		9 (1)	402(1.8)
		11 (1)	412(0.0)
		14 (1)	482(1.6)
		15 (15)	400(1.8), 621(1.8), 401(22.39), 513(76.38), 403(111.98), 313(183.75), 349(244.92), 611(262.3), 306(270.79), 616(314.6), 315(321.87), 612(331.8), 348(340.54), 613(360.8), 310(385.73)
		21 (1)	405(96.12)
		24 (1)	305(7.9)
		28 (1)	431(16.0)
		30 (1)	430(81.02)
		39 (1)	320(8.73)
		40 (3)	509(12.8), 308(20.51), 425(111.39)
		68 (1)	407(38.15)
		70 (2)	508(37.29), 404(149.52)
		73 (1)	618(36.1)
		80 (6)	323(69.54), 615(99.5), 340(119.5), 301(126.59), 318(161.46), 309(165.94)
		84 (2)	614(36.6), 307(92.53)
		89 (8)	411(8.87), 504(156.98), 415(181.38), 503(193.32), 416(265.38), 329(402), 362(410.2), 304(415.84)
		91 (2)	363(19.55), 303(43.89)
		92 (1)	601(8.0)
		95 (1)	414(0.0)
		173 (1)	335(7.92)
		189 (1)	350(0.0)
		191 (4)	506(24.5), 420(72.14), 421(128.62), 424(202.8)
		201 (1)	619(10.6)
		210 (1)	317(3.86)
		215 (3)	617(5.1), 351(11.55), 353(18.5)
		218 (1)	510(5.7)
		237 (1)	511(1.39)
		248 (1)	606(2.5)
		491 (1)	324(1.7)
		3196 (1)	704(7.54)
Volume	22	6 (1)	327(174.75)
		8 (1)	703(0.64)
		18 (1)	702(2.61)
		30 (1)	620(109.1)
		68 (1)	408(57.55)
		71 (2)	406(16.93), 333(21.2)
		80 (1)	341(123.54)
		89 (2)	325(324.29), 329(324.29)
		154 (1)	711(20.25)
		167 (1)	609(1.25)
		171 (2)	355(0.9), 354(8.8)
		186 (2)	409(2.92), 332(9.25)
		189 (1)	319(13.38)
		190 (1)	322(2.46)
		215 (1)	501(26.61)
		224 (2)	605(-), 607(-)
Total	95	50	

*: Total number of stations

**: Route Number

4.2.5.2 Selection of Main ATR Stations for Truck Traffic Counting

Main ATR stations which are located near the boundary to the neighboring states including Nevada, Idaho, Wyoming, Colorado, and Arizona were chosen in order to identify potential interstate truck traffic routes in Utah. Table 4-5 shows the station numbers of the main ATR stations for truck counting in Utah. These ATR stations were used as the origin and destination nodes in the shortest path analysis by ArcGIS Network Analysis Tool.

Table 4-5 Main Truck Counting Stations in Utah

	Main Truck Counting Stations for Interstate Freight Movement
East	324, 418, 421, 424, 506
West	323, 403, 430
North	303, 310, 362, 614
South	400, 411, 412

4.2.5.3 Analyzing Main Truck Routes Using the Shortest Path Analysis

Using the ATR stations for truck counting, and intermediate nodes, the shortest path from/to the main ATR stations by direction can be determined using the ArcGIS Network Analysis Tool. Figure 4-3, Figure 4-4, Figure 4-5, and Figure 4-6 show the main truck routes by direction: “North-South”, “East-West”, “East-South/North”, and “West-South/North”, respectively.

Main Truck Routes for North-South Direction

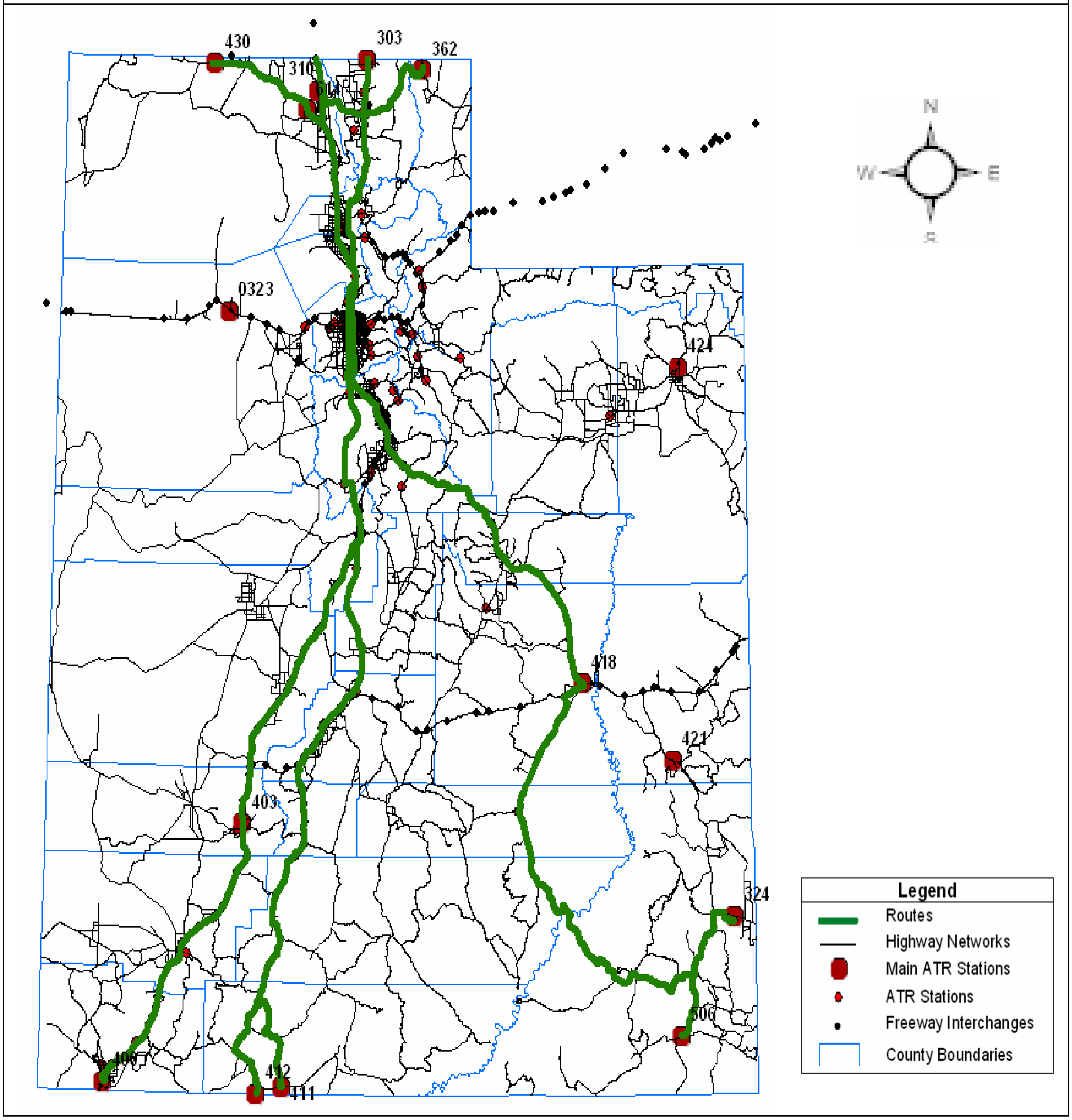

Figure 4-3 Main Truck Routes for North-South direction

Main Truck Routes for East-West Direction

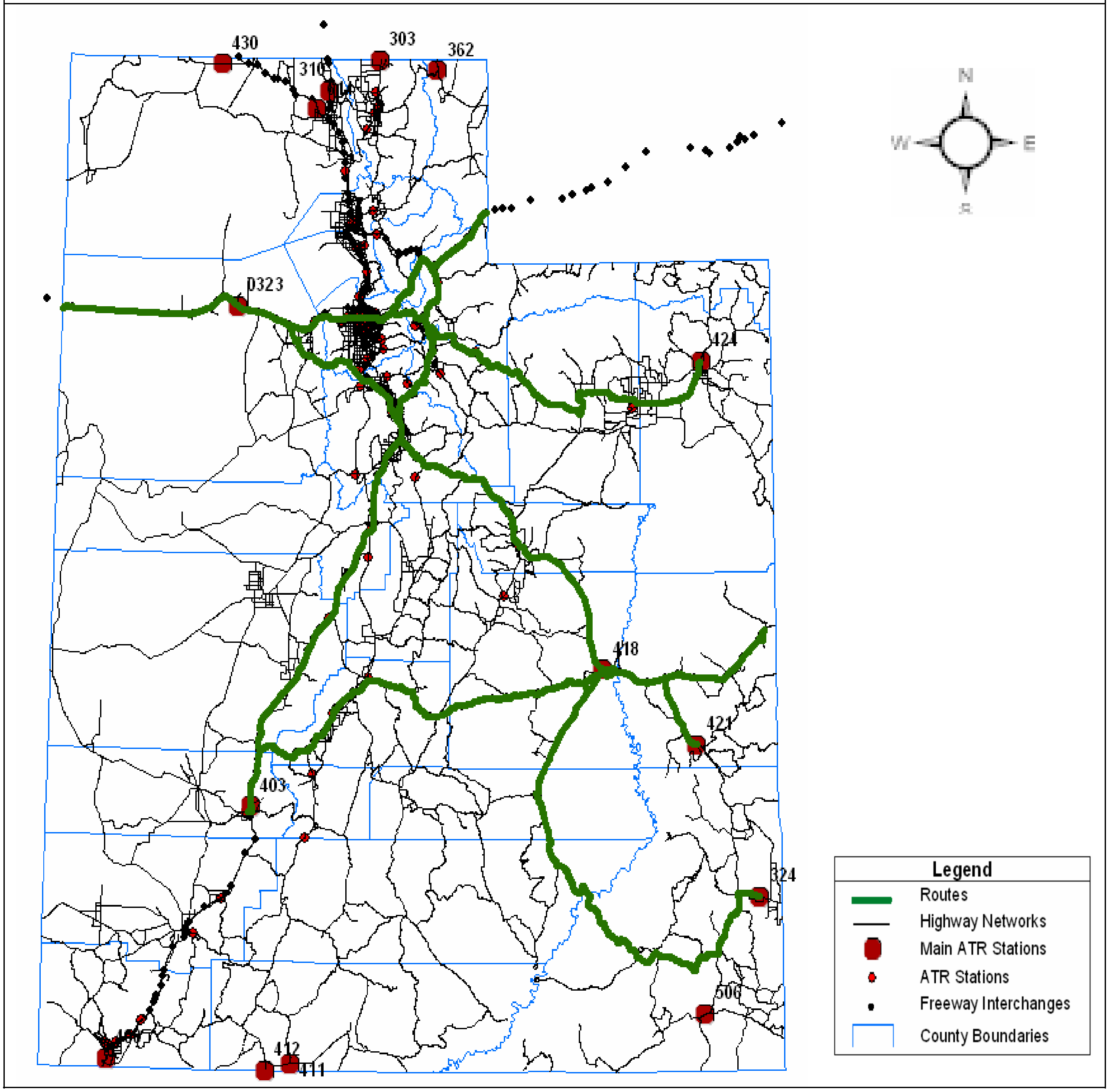

Figure 4-4 Main Truck Routes for East-West direction

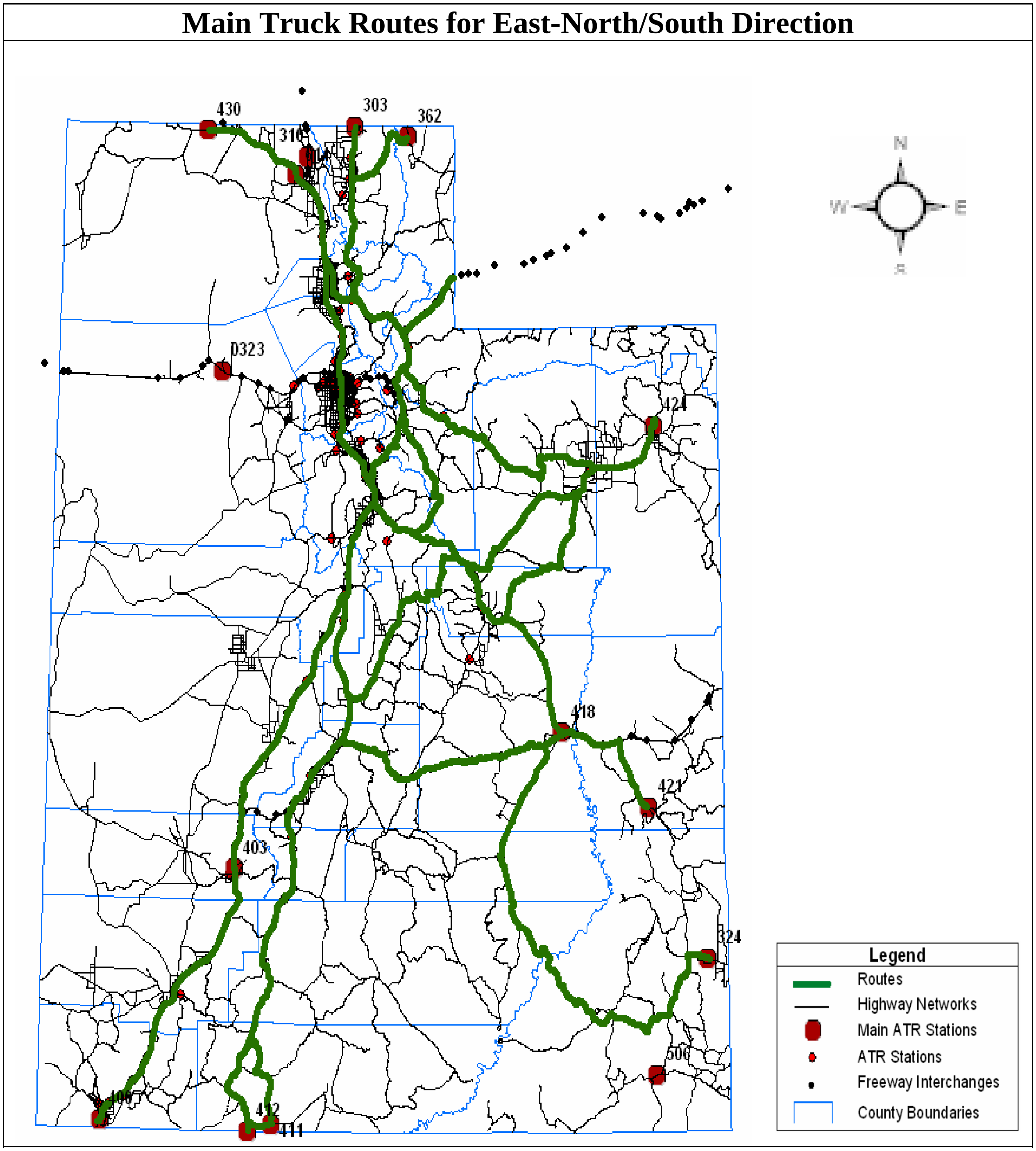

Figure 4-5 Main Truck Routes for East - North/South Direction

Main Truck Routes for West-North/South Direction

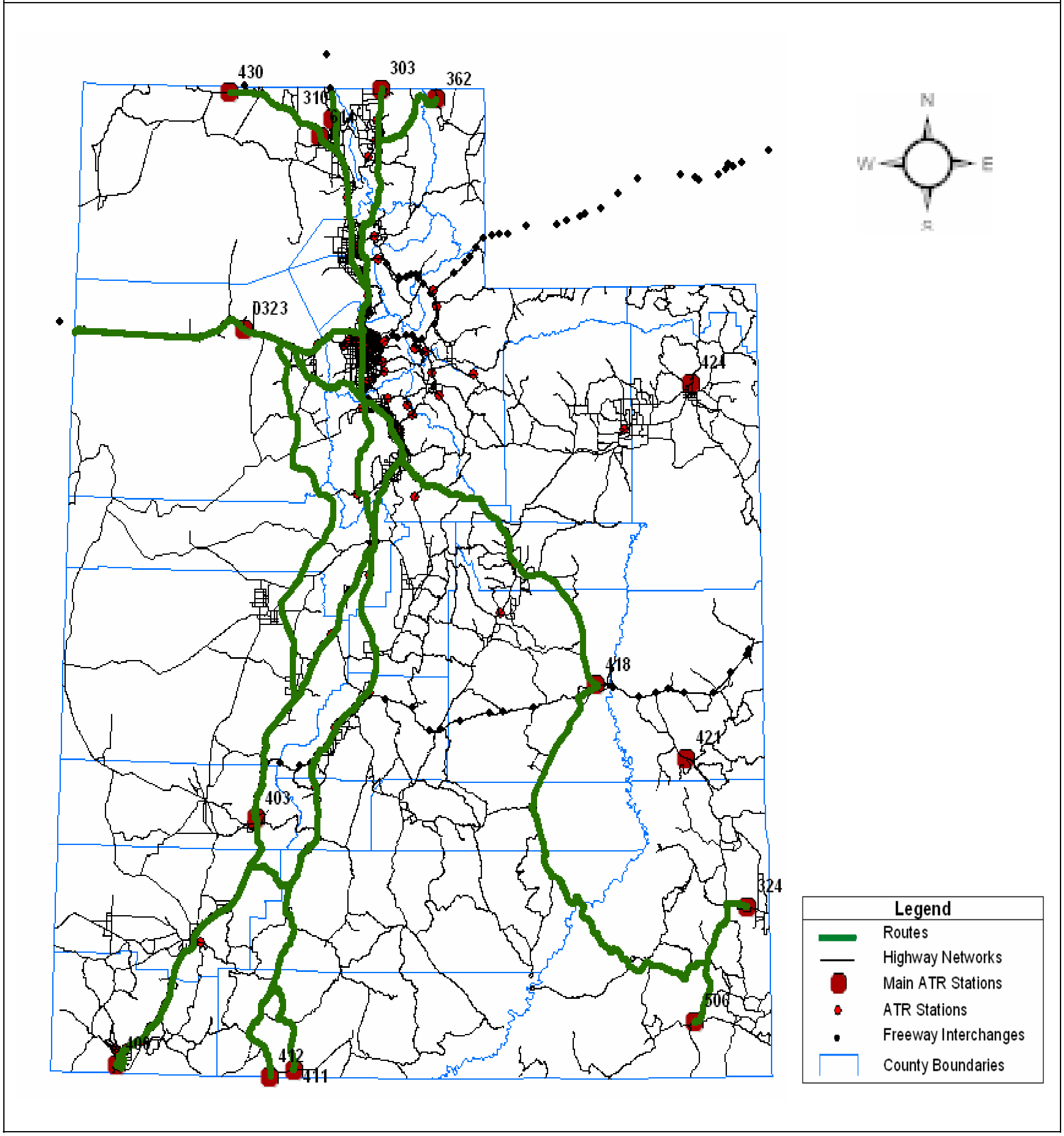

Figure 4-6 Main Truck Routes for West-North/South Direction

4.3 Chapter Summary

Identifying main truck routes in Utah is a beginning step for dealing with increasing truck traffic on Utah's highway system. Knowing the major intrastate truck routes will help UDOT improve design and operation of highway facilities for trucks, utilize intelligent transportation systems, improve signing system, help regulatory changes in allowed vehicle size or configuration, enhance enforcement and compliance, and identify truck-related highway investment needs. Also, the information on main truck routes helps UDOT develop guidelines or strategies for highway management to deal with increasing truck traffic in the area of pavement maintenance and rehabilitation, designing climbing lanes, setting up lane use restrictions, and the performance evaluation of WIM program. Expected benefits of these projects include an improvement in safety, a reduction in congestion, and an increase in highway performance.

As for the commodity flow pattern survey, the number of responses was too small to make any in-depth analysis in commodity flow pattern. These responses are only a handful of all the trucking companies in Utah. Nevertheless, the findings from these responses will benefit UDOT in conducting a freight flow study in the future.

Using the main ATR stations for truck counting and intermediate nodes, the truck route to and from of each main truck counting station by direction was identified by using the ArcGIS Network Analysis Tool. Even though the truck routes identified in the pilot study may not be exact, the result from this analysis should help UDOT designate certain highways as truck routes.

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5 Ground Truth Data Collection Process

5.1 Design of Ground Truth Data Collection

5.1.1 ATR Stations in Utah

Truck traffic data are collected with other traffic data including motorcycles passenger cars and buses at ATR stations. UDOT has three different traffic types of ATR stations: volume only, volume by length, and volume by vehicle class. They are called “volume”, “length”, and “class” counters by UDOT personnel. Volume counters are typically inductive loops embedded in pavement and count the number of axles which is converted to the number of vehicles. Length counters are typically inductive loops (some are microwave sensors) and count the number of vehicles by length group. Class counters are Piezo cable sensors and part of the WIM system. They count the number of vehicles by FHWA’s vehicle classification.

Table 5-1 shows a summary of UDOT’s ATR stations. At the time of the study, 90 stations of the 95 ATR stations were operating. Five stations were not functioning for various reasons such as under construction or simply stopped functioning. Table 5-2 shows ATR number, location, type, and data collection method of the 90 ATR stations.

Table 5-1 UDOT’s ATR Stations

Number of Operating Stations		
Type of Data	Collection Method	Number of Station
Class	Loops	2
Length	Loops	70
	Microwave	3
Volume	Loops	15
Total		90

Table 5-2 Information of Current Operating Permanent Traffic Station

ATR	Description	Type of Data	Collecting Method
427	SR-10, 1 mile North of SR-155, Huntington	Class	Loops
512	SR-35, 0.7 mile East of Summit County Line, Woodland	Class	Loops
301	I-80, 1 mile East of I-215, Parleys Canyon	Length	Loops
303	US-91, 1.5 miles North of SR 61, Webster Jct.	Length	Loops
304	US-89, 0.6 mile North of SR 30, Garden City	Length	Loops
305	SR-24, 0.1 mile North of SR 118, Sigurd	Length	Loops
306	I-15, 2 miles North of Center Street Int., Provo	Length	Loops
307	I-84, 0.5 mile East of West Mr. Green Int., Mt. Green	Length	Loops
308	US-40, 1 mile East of POE, Daniels Canyon	Length	Loops
309	I-80, 1 mile East of Echo Jct., Echo	Length	Loops
310	I-15, 3 miles South of Plymouth Int., Plymouth	Length	Loops
313	I-15, 1 mile South of Scipio Int., Scipio	Length	Loops
314	US-6, 2 miles West of US-191, Helper	Length	Loops
315	I-15, 1.8 miles South of Lagoon Drive Int., Farmington	Length	Loops
316	US-89, 2 miles South of SR 193, Hillfield Road, Layton	Length	Loops
317	SR-210, Mouth of Little Cottonwood Canyon, SLC	Length	Loops
318	I-80, 1 mile West of Coalville Int., Coalville	Length	Loops
320	SR-39, 0.5 mile West of SR 158, Ogden Canyon	Length	Loops
321	US-6, 0.25 mile West of SR 68, Elberta Jct.	Length	Loops
322	SR-190, Mouth of Big Cottonwood Canyon, SLC	Length	Loops
323	I-80, 1 mile West of Delle Interchange, Delle	Length	Loops
324	US-491 9 miles East of US-191, Monticello	Length	Loops
335	SR-173, 950 West 5400 South	Length	Loops
340	I-80, 1325 West, SLC	Length	Loops
349	I-15, 2 miles North of Santaquin Int., Santaquin	Length	Loops
350	US-189, 3710 North University Avenue, Provo	Length	Loops
351	I-215, 700 West, SLC	Length	Loops
353	I-215, 2800 South, SLC	Length	Loops
362	US-89, 0.2 mile West of SR 30, Garden City	Length	Loops
363	US-91, 0.8 mile North of SR 101, Wellsville	Length	Loops
382	SR-14, 1.7 miles East of SR-130, Cedar City	Length	Loops
400	I-15, 1 mile South of Bloomington Int., Bloomington	Length	Loops
401	I-15, 1 mile South of Leeds Int., Leeds	Length	Loops
402	SR-9, 1.3 miles West of SR 318, Hurricane	Length	Loops
403	I-15, 0.5 mile North of North Beaver Int., Beaver	Length	Loops
404	I-70, 1 mile West of US-6 Int., Green River	Length	Loops
405	SR-21, 3 miles West of Main Street, Beaver	Length	Loops
407	SR-68, 2 miles North of Utah County Line, Bluffdale	Length	Loops
408	SR-68, 1200 South Redwood Road, SLC	Length	Loops
411	US-89, 10 miles East of Kanab, Kanab	Length	Loops
412	SR-11, 2 miles South of Kanab, Kanab	Length	Loops
414	SR-95, 0.2 mile South of SR 24, Hanksville	Length	Loops
415	US-89, 1 mile North of Marysvale, Marysvale	Length	Loops
416	US-89, 5.5 miles South of US-6, Birdseye	Length	Loops
418	US-6, 0.7 mile North of I-70, Green River	Length	Loops

Table 5-2 Continued

ATR	Description	Type of Data	Collecting Method
420	US-191, 6 miles North of US-491, Monticello	Length	Loops
421	US-191, 0.2 mile North of SR-279, Moab	Length	Loops
424	US-191, 3.5 miles North of US-40, Vernal	Length	Loops
425	US-40, 3 miles West of SR-121, Roosevelt	Length	Loops
430	SR-30, 6.01 miles East of SR-42, Curlew Jct.	Length	Loops
431	SR-28, 1.5 miles South of SR-78, Levan	Length	Loops
502	I-15, 0.5 mile South of South Nephi Int., Nephi	Length	Loops
503	US-89, 0.5 mile South of US-50, Salina	Length	Loops
504	US-89, 1 mile South of Circleville, Circleville	Length	Loops
506	US-191, 1.2 miles West of US-163, Bluff	Length	Loops
507	US-6, 1 mile North of SR-55 Int., Price	Length	Loops
508	I-70, 1.5 miles Northeast of West Richfield Int., Richfield	Length	Loops
509	US-40, 0.5 mile West of SR-32, Heber/Midway	Length	Loops
510	SR-218, 100 North 319 West, Smithfield	Length	Loops
511	SR-237, 800 East 2416 North, North Logan	Length	Loops
513	I-15, 1 mile North of South Parowan Int., Parowan	Length	Loops
601	SR-92, American Fork Canyon West Toll Booth	Length	Loops
606	SR-248, 0.5 mile West of US-40, Park City	Length	Loops
609	SR-167, 1.2 miles East of Mountain Greet Int.	Length	Loops
612	I-15, North of SR-126., Layton	Length	Loops
613	I-15, 2 miles South of South Brigham Int.	Length	Loops
616	I-15, 0.7 mile North of I-215 on-ramp, Woods Cross	Length	Loops
617	I-215, 5800 South Knudsen's Corner	Length	Loops
618	SR-73, West of SR-68 Redwood Road, Lehi	Length	Loops
619	SR-201, 6174 West, SLC	Length	Loops
621	I-15, 0.43 mile South of Washington City Int., St. George	Length	Loops
704	Federal Route 3196, 2250 East Redcliff Drive, St. George	Length	Loops
611	I-15, 1 mile South of SR-77 Springville Int., Springville	Length	Microwave
614	I-84, 3.2 miles West of Bothwell Int., Bothwell	Length	Microwave
615	I-80, 0.5 mile East of SR-36 Mills Jct., Tooele	Length	Microwave
319	US-189, 1 mile West of SR 92, Provo Canyon	Volume	Loops
325	US-89, 1087 South State Street, SLC	Volume	Loops
327	US-6, 0.2 mile West of Center Street, Spanish Fork	Volume	Loops
329	US-89, 3450 South Washington Blvd., So Ogden	Volume	Loops
332	SR-186, 950 South Foothill Blvd., SLC	Volume	Loops
333	SR-71, 1190 South 700 East, SLC	Volume	Loops
354	SR-171, 3300 South 1176 West, SLC	Volume	Loops
355	SR-171, 3500 South 7658 West, Magna	Volume	Loops
406	SR-71, 4550 South 700 East, SLC	Volume	Loops
409	SR-186, 1200 West North Temple	Volume	Loops
602	SR-92, American Fork Canyon East Toll Booth	Volume	Loops
605	SR-224, 0.1 mile North of Canyons Resort Drive, Park City	Volume	Loops
620	SR-30 West of 600 West, Logan	Volume	Loops
703	SR-8, 1313 West Sunset Blvd., St. George	Volume	Loops
711	SR-154, 2500 South Bangerter Hwy, SLC	Volume	Loops

5.1.2 Design of Ground Truth Data Collection

Ground truth data are essential for determining the accuracy level of truck traffic data. Ground truth data collected at the sampled ATR stations should represent the characteristics of truck traffic moving through the state of Utah and the remaining ATR stations. To obtain reliable information to determine truck traffic accuracy level, a systematic sampling of ATRs was necessary. BYU's Center for Statistical Consultation and Collaborative Research (CSCCR) was consulted for designing ground truth data collection.

The factors used in this study for sampling ATR stations to collect ground truth truck traffic data included hardware, location, time, and other miscellaneous conditions. Table 5-3 shows the factors considered in this study. Hardware factors consisted of data type, data collection method, and the number of stations. Location factors included highway functional class, regional distribution, regional characteristics, data collection direction, and space availabilities. Time factors included time of day and day of the week of data collection. The other factors included traffic volume range, traffic condition, and environment surrounding the ATRs during data collection. Volume type ATR stations were excluded because they could not classify vehicles; hence, 15 volume type stations were excluded in this project.

Table 5-3 Factors of Designing Ground Truth Data Collection

Main Factors		Elements in Each Factor
Hardware Factor	Type of data	Class, length, and volume
	Data collection method	Inductive loops and microwave
	Number of stations	Number of stations for each of the above two categories
Location Factor	Highway functional class	Interstate highway and non-interstate highway
	Regional distribution	Covered area, e.g. east, west, north, and south, center of Utah
	Regional characteristics	Urban and rural area
	Data collection direction	East, west, north, and south
	Space availability	Check on enough space for collecting data
Time Factor	Time of day	AM and PM
	Day of the week	Monday through Friday
Other Factors	Traffic volume range	Less than 100, 100-300, 300-500, 500-1000, and over 1000
	Traffic condition (Congested)	Yes and No
	Under construction around station	Yes and No

5.1.3 Coordination between Field Data Collection and Data Collection by ATRs

Ground truth data obtained from the field data collection and traffic data obtained from ATRs were compared for determining the accuracy level of truck traffic data. In order to match the time for traffic count data from the selected ATR stations and the time for the ground truth data collection, the clock-time available from the mobile phone was used as the reference time. It was assumed that the clock time by the mobile phone was the clock time of the server that processes traffic data from ATR stations.

5.2 Pilot Ground Truth Data Collection

5.2.1 Outline of the Pilot Ground Truth Data Collection

With the opinion of a statistician from BYU's CSCCR, a small scale pilot field data collection was carried out before the full-scale field data collection, primarily to obtain the information on traffic count variability, improve the efficiency of the full-scale data collection, and estimate the time needed to travel to the ATR stations from BYU, videotape the traffic, and return to BYU.

Based on the opinions expressed in the second TAC meeting, which was held on December 19 in 2007, five stations were chosen as the pilot data collection sites. Table 5-4 shows the information of these five stations including data collection type, route number, mile post, data collection date, and time of day.

Table 5-4 Five Stations Chosen for the Pilot Survey

Station Number	Data Collection Type	Route Number	Mile Post	Day, Date and Time
615	Length	80	99.5mile	April 2, Wed., 3:00-4:00PM
611	Length	15	262.3mile	April 2, Wed., 10:00-11:00APM
312	Length	6	182.22mile	April 4, Fri., 2:00-3:00PM
427	Class	10	49.51mile	April 4, Fri., 11:00-12:00AM
349	Length	15	244.92mile	April 10, Thu., 10:00-11:00AM

Table 5-5 shows the sample size of the pilot survey. The total number of samples of the pilot survey was five stations, which consisted of one class data type and four length data types.

Table 5-5 Population and Sample Size of ATR Stations

Data Type	Number of Stations in Each Type	Number of Routes In Each Type	Number of Stations in the Pilot Data Collection
Class	2	2	1
Length	73	31	4
Volume	15	16	-
Total	90	50	5

5.2.2 Ground Truth Data Collection Method

In order to collect ground truth traffic data at the five stations, two visual collection methods, a video camera and a traffic data collection trailer, were initially selected for use. Figure 5-1 shows these two visual data collection methods.

Figure 5-1 Visual Data Collection Methods: Video Camera (Left) and Traffic Data Collection Trailer (Right)

It was found that there was not enough space in the roadside to safely park the trailer; hence, the use of video camera on the tripod was selected for the pilot survey. Figure 5-2 shows the photos of the five stations used for the pilot data collection.

1. Pilot Survey Station 1: #615
(Route I-80, Milepost: 99.5 mile)

2. Pilot Survey Station 2: #349
(Route I-15, Milepost: 247 mile)

3. Pilot Survey Station 3: #611
(Route I-15, Milepost: 262.3 mile)

4. Pilot Survey Station 4: #312
(Route US-6, Milepost: 188.22 mile)

5. Pilot Survey Station 5: #427
(Route SR-10, Milepost: 49.51 mile)

Figure 5-2 Five Pilot Survey Stations

5.2.3 Data Reduction Process

The ground truth data collected at the five ATR stations were reduced by the following four steps.

1) Change video files to AVI files with the help from the IT Center at BYU,
2) Analyze AVI files frame by frame using the DelayAnnotator software (Saito, 2008),
3) Count vehicles and summarize at a five minute interval and categorize them into FHWA's 13 vehicle classes, and
4) Enter traffic counts into Excel spreadsheets for statistical analyses.

Figure 5-3 shows the user interface of the DelayAnnotator. The one second of video recording consists of 30 frames. The DelayAnnotator software allows the analyst advance the video one frame at a time, allowing data reduction done at the analyst's pace.

Figure 5-3 Data Reduction Using the DelayAnnotator Software

5.2.4 Results of the Pilot Ground Truth Data Analysis

With the help of UDOT, the traffic data from the ATR stations for the same data collection date and time as those for the ground truth data collection were obtained. After data reduction, the vehicles in the ground truth data were categorized into FHWA's thirteen vehicle classes. The traffic count data from the ATR stations are categorized into length groups. Length-type detectors categorize vehicles into five length groups consisting of 16 feet, 30feet, 50feet, 79 feet, and >79 feet length groups. In order to compare the two vehicle counts, these two different categories were matched using the standard criteria of vehicle length, described in the AASHTO's *A Policy on Geometric Design of Highways and Streets, 5th Edition* (AASHTO, 2004). Table 5-6 shows the results of the regrouping of FHWA's thirteen vehicle classes to match UDOT's five length groups.

Table 5-6 Regrouping of FHWA's 13 Vehicle Classes

Length Group by UDOT	Regrouped Ground Truth Data
16 Feet (up to 16-ft)	Class 1 and Class 2
30 Feet (16.1ft to 30-ft)	Class 3
50 Feet (30.1 ft to 50-ft)	Class 4 to Class 8
79 Feet (50.1 ft to 79-ft)	Class 9 to Class 12
> 79 Feet	Class 13

The regrouped ground truth data were compared with the traffic volume data by the ATR stations and the difference between the two volume groups was computed. The difference was divided by the ground truth data to determine the error rate. Figure 5-4 shows the results of the pilot data collection.

As it turned out the ATR station #312 on US-6 was not working because the three mile section that contains the station was under construction, consisting of lane addition and widening work. Hence, station #312 was excluded from the analysis. Data for station #611 were collected at the wrong spot in the pilot study; later the right spot was identified and traffic data were retaken. These new data are shown in Figure 5-4.

As shown in Figure 5-4, three stations, station #611, station #615 and station #349, were length-type ATR stations and the remaining station, station #427 was class-type ATR station. The accuracy level of the traffic data from the three length-type stations were determined using the regrouped ground truth data while the data from the class-type ATR station were compared as is with the thirteen FHWA classes.

No apparent trends were found among the four stations. The truck volume at stations #611 and station #349 had the lower error rate (less than 10%), which meant that the accuracy level was higher. The total traffic volumes were more accurate at the other two stations, station #615 and station #427. For the length-type ATR stations, the error rate of the over '79 feet' group was the highest. The error rates of the other vehicle length groups did not manifest any special trends. At the class-type station, station #427, the error rates of class 1 and class 4 were the highest. Because the traffic volume in these classes was very low, one misclassification significantly altered the error rate.

Accuracy Level of 4 Pilot Study Traffic Count Stations

Route	Station	Class	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Truck	Total
I-15	#611	TOC Counter	1223	1200	134	103	68	2728	2359
		Ground Truth	2372	21	212	119	19	2743	3000
		Error Rate	**-0.4844**	**56.1429**	**-0.3679**	**-0.1345**	**2.5789**	**-0.0055**	**-0.2137**
		Percentage	**-48%**	**5614%**	**-37%**	**-13%**	**258%**	**-1%**	**-21%**
I-80	#615	TOC Counter	439	409	47	31	61	139	987
		Ground Truth	570	239	73	80	23	176	985
		Error Rate	**-0.2298**	**0.7113**	**-0.3562**	**-0.6125**	**1.6522**	**-0.2102**	**0.0020**
		Percentage	-23%	71%	-36%	-61%	165%	-21%	0%
US-6	#312	TOC Counter							
		Ground Truth	221	77	50	25	8	83	381
		Error Rate							
		Percentage							
I-15	#349	TOC Counter	503	143	49	147	31	227	873
		Ground Truth	408	140	55	139	24	218	766
		Error Rate	**0.2328**	**0.0214**	**-0.1091**	**0.0576**	**0.2917**	**0.0413**	**0.1397**
		Percentage	23%	2%	-11%	6%	29%	4%	14%

Reference	
16 Feet:	Class 1 and Class2
30 Feet:	Class 3
50 Feet:	Class 4 to Class 8
79 Feet:	Class 9 to Class 12
> 79 Feet:	Class 13

Route	Station	Class	1	2	3	4	5	6	7	8	9	10	11	12	13	Truck	Total
SR-10	#427	TOC Counter	0	90	27	0	13	1	0	6	2	0	0	0	24	73	163
		Ground Truth	1	83	41	1	4	1	0	5	4	0	0	0	34	90	174
		Error Rate	**-1.0000**	**0.0843**	**-0.3415**	**-1.0000**	**2.2500**	**0.0000**		**0.2000**	**-0.5000**				**-0.2941**	**-0.1889**	**-0.0632**
		Percentage	-100%	8%	-34%	-100%	225%	0%		20%	-50%				-29%	-19%	-6%

Figure 5-4 Result of Pilot Ground Truth Data Collection

Even though any special trend was not found in the error rate (accuracy level) among the four ATR stations, the pilot ground truth data collection provided the BYU team with a wealth of information on data collection scheduling and sample size evaluation.

5.3 Designing a Stratified Sampling of ATR Stations

5.3.1 Strategy for Designing a Stratified Sampling

In subsection 5.1.2 Design of Ground Truth Data Collection, factors for determining ground truth data collection locations were discussed for designing a stratified sampling of ATRs. Figure 5-5 shows the sampling relationship among the design factors.

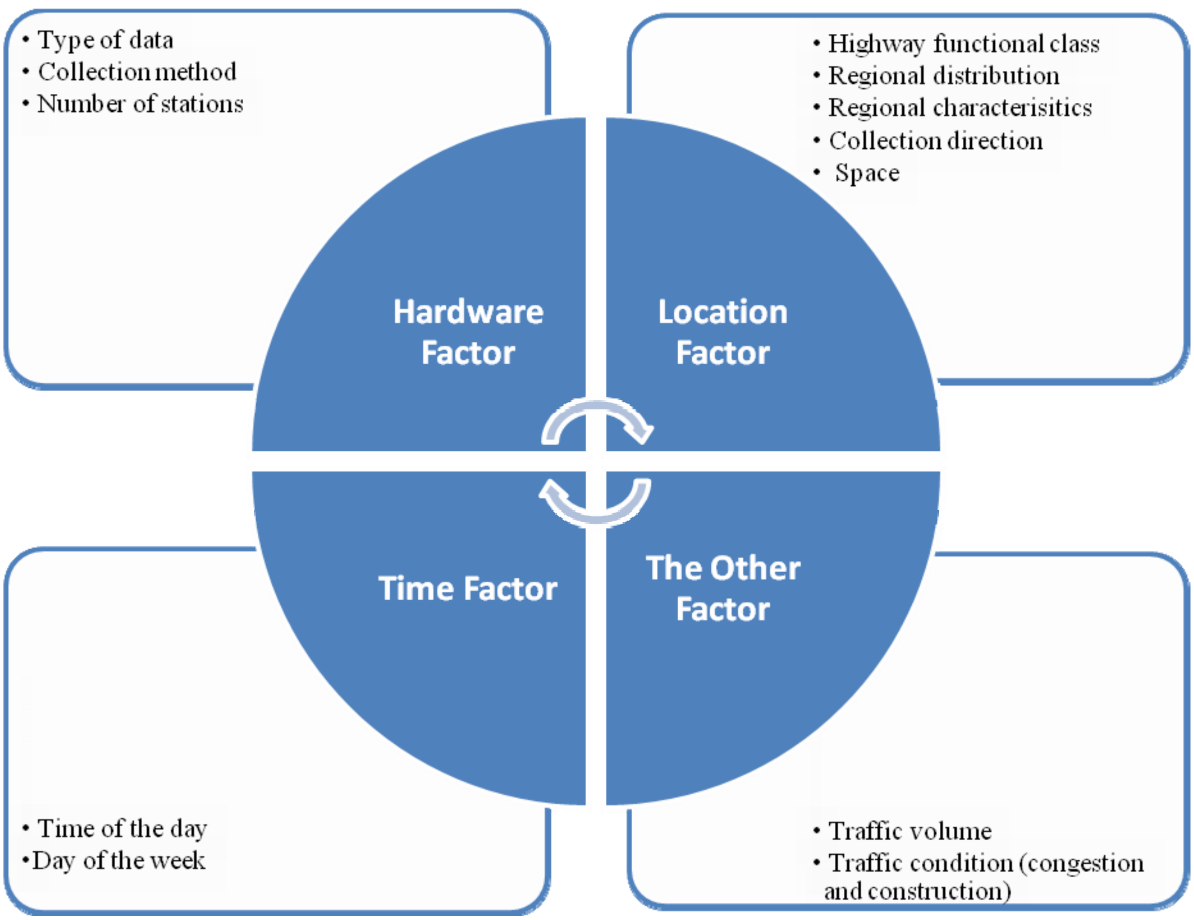


Figure 5-5 Relationship among Data Collection Design Factors

The following principles were used for carrying out a stratified sampling:

- Estimate the number of stations by data type, and by collection method;
- Establish, if possible, the tolerance (standard error) and accuracy level (error rate) based on the findings from the pilot ground truth data collection, the literature review, and the state-of-the-practice survey;
- Estimate the necessary number of stations by data type and collection method;
- Distribute appropriately the number of samples needed for each data type and each collection method by highway functional class, regional distribution, regional characteristic, and collection direction;
- Determine or distribute appropriately the number of samples of each data type and each data collection method by time of day and day of the week;
- Consider traffic conditions such as traffic volume; and
- Avoid, if possible, the ATR stations located within traffic congestion and construction zone and without enough space to set up the data collection equipments.

5.3.2 Design of a Stratified Sampling

The results of the pilot analysis were discussed with a statistical consultant of BYU's CSCCR. Based on the error rate (accuracy level) of the four stations used for the pilot study, sampling 30 stations for the full-scale data collection was recommended at the 95% confidence level.

Also, considering the statistical reliability and repeatability, two data collections at each station were conducted. Main factors for designing a full-scale field data collection included:

- Randomness,
- Reasonableness,
- Variability,
- Accuracy level,

- Reliability,
- Consistency,
- Adjustability, and
- Repeatability.

In the end, the following are the summary of a full-scale ground truth data collection:

- Number of ATR stations: 30 stations (class type - 2 stations, length type - 28 stations (loop detector – 25 stations, microwave – 3 stations)), including four stations of the pilot study,
- Split between interstate highway and non-interstate highway: 14 stations on interstate highway and 16 stations on non-interstate highways,
- Duration of the field survey: May 5th through July 18th, 2008,
- Replications: two data collections at each station (same time of day and same day of the week a few weeks apart), and
- Data collection method: visual data collection using a video recorder.

5.4 Full-Scale Ground Truth Data Collection

5.4.1 Outline of the Full-Scale Ground Truth Data Collection

The full-scale ground truth data collection was carried out from May 5th to July 18th, 2008. Thirty ATR stations were chosen using the sampling method discussed in the previous section. Data collection was done twice at each ATR station at the same time of day, and on the same day of the week one to seven weeks apart.

Table 5-7 shows a summary of the full-scale ground truth data collection. Interstate highways had 14 ATR stations and non-interstate highways had 16 ATR stations. Because two class-type ATR stations were located only on non-interstate highways, the remaining 28 length-type ATR stations were evenly allocated in interstate and non-interstate highways. Three length-type ATR stations equipped with a microwave sensor were included in the analysis, although there were only three stations of this type.

Table 5-7 Summary of Full-Scale Ground Truth Data Collection (Hardware Factors)

Highway Class	#	Station by Routes	Data Collection Method
Interstate Highway	14	I-15 (8): #306, #310, #349, #401, #403, #502, **#611**,#613 I-70 (1): #404 I-80 (3): #318, #323, **#615** I-84 (2): #307, **#614**	Class (0) Length (14): Loop (11), **Microwave (3) (#611, #614, #615)**
Non-Interstate Highway	16	US-6 (2): #321, #507 US-89 (2): #316, #411 One Station in a Route: SR-10 (**#427**), SR-11 (#412), SR-21 (#405), SR-28 (#431), SR-35 (**#512**), SR-39 (#320), US-40 (#509), SR-73 (#618), US-91 (#363), US-189 (#350), US-191 (#421), SR-218 (#510)	**Class (2): #427, #512** Length: Loop (14)
Total	30	Interstae:14 Non-Interstate: 16	Class: 2 Length: 28
Plan	30	Interstate: 15 Non-Interstate: 15	Class: 2 Length: 28

To reflect the regional factor in the design of a full-scale ground truth data collection, the 30 ATR stations were distributed to different areas in Utah. Table 5-8 shows the regional factors used for the field data collection.

Table 5-8 Regional Distribution of Selected ATR Locations

Covered Area		#	Stations
North		5	310, 363, 510, 613, 614
Central	East	5	318, 427, 507, 509, 512,
	Middle	7	306, 307, 316, 320, 350, 611, 618
	West	7	321, 323, 403, 431, 405, 502, 615
South	East	2	404, 421
	Middle	2	411, 412
	West	2	401, 621

5.4.2 Data Collection

Just as for the pilot ground truth data collection, a video recorder was used for visual data collection. The data collection trailer was not used for the full-scale data collection because a few operational problems were identified in the early stage of the data collection, including a lack of safe space to set up the trailer around the selected ATR stations and a large amount of time required to set up the equipment for data collection.

Table 5-9 shows the thirty ATR stations selected for the full-scale ground truth data collection, together with station number, route number, mile post, data collection method, and collection date and time of the first and the second field data collection. The coordination time in the first and the second field data collection was the difference between the correct clock time (mobile phone time) and the clock time of the video recorder used for data collection.

Table 5-9 ATR Stations Selected for a Full-Scale Ground Truth Data Collection

#	Station	Route	MP	Type	First Field Survey		Second Field Survey	
					Film Date and Time	Coordination Time	Film Date and Time	Coordination Time
1	615	I-80	99.5	Length	4/2, 3:00-4:00PM	31 sec Behind	5/7, 3:00-4:00PM	17 sec Behind
2	349	I-15	246-247	Length	4/10,10:00-11:00AM	15 sec Behind	5/8, 10:00-11:00AM	17 sec Behind
3	316	89	403-404	Length	5/13, 11:00-12:00PM	25 sec Faster	5/20, 11:00-2:00PM	6 sec Behind
4	307	I-84	92.53	Length	5/13, 1:00-2:00PM	24 sec Faster	5/20, 1:00-2:00PM	9 sec Behind
5	320	39	13-14	Length	5/13, 3:00-4:00PM	24 sec Faster	5/20, 3:00-4:00PM	8 sec Behind
6	427	10	57.1	Class	4/4, 11:00-12:00PM	31 sec Behind	6/13, 11:00-2:00PM	39 sec Behind
7	431	28	28-29	Length	5/5, 11:00-12:00PM	15 sec Behind	6/9, 11:00-12:00PM	6 sec Faster
8	502	I-15	222-223	Length	5/5, 1:00-2:00PM	15 sec Behind	6/9, 1:00-2:00PM	6 sec Faster
9	321	6	149-150	Length	5/5, 3:00-4:00PM	15 sec Behind	6/9, 3:00-4:00PM	6 sec Faster
10	512	35	10.4	Class	5/6, 10:00-11:00AM	16 sec Behind	6/10, 10:00-1:00AM	6 sec Faster
11	509	40	12.8	Length	5/6, 12:00-1:00PM	16 sec Behind	6/10, 12:00-1:00PM	5 sec Faster
12	318	I-80	161.46	Length	5/6, 3:00-4:00PM	16 sec Behind	6/10, 3:00-4:00PM	5 sec Faster
13	507	6	239.23	Length	5/9, 1:00-2:00PM	17 sec Behind	6/13, 1:00-2:00PM	38 sec Behind
14	614	I-84	36.6	Length	5/14, 6:00-7:00AM	25 sec Faster	6/11, 06:00-7:00AM	4 sec Faster
15	310	I-15	389-390	Length	5/14, 8:00-9:00Am	26 sec Faster	6/11, 8:00-9:00AM	5 sec Faster
16	510	218	5.7	Length	5/14, 10:00-1:00AM	25 sec Faster	7/2, 10:00-11:00AM	13 sec Faster
17	363	91	19.55	Length	5/14, 12:00-1:00PM	25 sec Faster	6/11, 12:00-1:00PM	5 sec Faster
18	613	I-15	358-359	Length	5/14, 2:00-3:00PM	24 sec Faster	6/11, 2:00-3:00PM	4 sec Faster
19	350	189	5-6	Length	5/30, 9:00-10:00AM	1sec Behind	6/20, 9:00-10:00AM	11 sec Faster
20	618	73	36.1	Length	5/30, 11:00-12:00PM	1sec Behind	6/20, 11:00-2:00PM	12 sec Faster
21	611	I-15	259-260	Length	5/30, 1:00-2:00PM	1sec Behind	6/20, 1:00-2:00PM	10 sec Faster
22	306	I-15	269-270	Length	5/30, 3:00-4:00PM	1sec Behind	6/20, 3:00-4:00PM	12 sec Faster
23	403	I-15	112-113	Length	6/16, 11:00-12:00PM	34 sec Behind	6/23, 11:00-2:00PM	13 sec Faster
24	405	21	104-105	Length	6/16, 1:00-2:00PM	35 sec Behind	6/23, 1:00-2:00PM	13 sec Faster
25	401	I-15	22-23	Length	6/16, 6:00-7:00PM	37 sec Behind	6/23, 6:00-7:00PM	11 sec Faster
26	412	11	0-1	Length	6/17, 7:00-8:00APM	36 sec Behind	6/24, 7:00-8:00AM	12 sec Faster
27	411	89	54-55	Length	6/17, 9:00-10:00AM	37 sec Behind	6/24, 9:00-10:00AM	12 sec Faster
28	421	191	130-131	Length	6/17, 4:00-5:00PM	38 sec Behind	6/24, 4:00-5:00PM	10 sec Faster
29	404	I-70	156-157	Length	6/18, 7:00-8:00AM	38 sec Behind	6/25, 7:00-8:00AM	11 sec Faster
30	323	I-80	68-69	Length	7/11, 10:00-1:00AM	21 sec Faster	7/18, 10:00-1:00AM	24 sec Faster

5.4.3 Data Reduction

Using the same method employed in the reduction of pilot ground truth data, ground truth data of the full-scale field data collection were analyzed. One change was, however, made in the data reduction process. The EZ MPEG (a type of video format) to AVI converter was purchased in order to allow better and faster data reduction process. The field data reduction was performed in the following steps. Also, the comparison between ground truth data and the data from the ATR stations were done in the same manner as done in the pilot study:

1. Convert video to AVI file using the EZ MPEG to AVI converter program.
2. Analyze frame by frame using the DelayAnnotator.
3. Count vehicles by station, by hour, and by vehicle class.
4. Enter traffic counts in Excel spreadsheet for statistical analyses.

5.5 Chapter Summary

Ground truth traffic data were collected in the field in two stages: a pilot study and a full-scale study. For conducting a stratified sampling, a statistician from BYU's CSCCR was consulted and the opinions of TAC members were taken into account. To achieve a systematic stratified data collection, several sampling design factors such as hardware type, station location, time of day, day of the week, etc were used. Visual data were reduced using the DelayAnnotator software and vehicles were classified into the thirteen classes as defined by FHWA.

6 Results of Statistical Analysis

Ground truth traffic data collected in the field were analyzed and compared with the traffic data collected at the selected ATR stations using statistical analysis tools. Factors that can affect the performance of traffic counters, identified by the literature review and the state-of-the-practice survey, were used in the statistical analysis. BYU's CSCCR was consulted for proper statistical analyses to evaluate the level of accuracy of the current truck traffic data.

6.1 Goals of Statistical Analysis

Statistical analysis was carried out in order to meet the following goals.

- Compare ground truth traffic data with the traffic data obtained by ATR stations,
- Evaluate the level of accuracy of the current truck traffic data,
- Evaluate and suggest an optimal spatial spread of ATR stations that will help UDOT to elevate truck traffic count to the level of accuracy targeted by UDOT, and
- Recommend future directions for data collection, reduction, and determination for improving the accuracy level of truck traffic data.

6.2 Analysis Procedure

The statistical analysis consisted of various procedures starting with simply sorting and comparing the two traffic count data sets (ground truth data and ATR count data), and ending with determining and evaluating the effect of main factors on the level of accuracy of truck traffic data. Main factors that affected the accuracy level of traffic counts were identified.

6.2.1 Data Entry and Sorting

The ground truth traffic data obtained by the reduction process presented in Chapter 5 were entered into a Microsoft Excel® spreadsheet in order to make necessary sorting tasks simple. One hour traffic data taken at each station was entered in unit time intervals (5 minutes) by FHWA's thirteen vehicle classes. Figure 6-1 shows an example of reduced traffic data.

Satation #:	618
Route #:	73
Milepost:	36.1
Collection Type:	Length (Loops)
Direction:	East (North)

First Data Collection

Date:	2008-05-30
Time:	11:00-12:00PM

Time	1	2	3	4	5	6	7	Class8: 4- axle CT	Class9: 5 axle CT	Class10: 6+ axle CT	Class11: 5 axle MTT	Class12: 6 axle MTT	Class13Class13: 7+ axle MTT	Total
00:01-05:00	0	44	0	1	0	0	0	2	0	0	0	0	0	47
05:01-10:00	0	72	0	0	0	3	0	2	0	0	0	0	0	77
10:01-15:00	0	60	1	3	0	2	1	0	0	0	0	0	0	67
15:01-20:00	1	60	0	1	1	0	0	3	1	1	0	0	0	68
20:01-25:00	0	50	1	0	1	0	0	3	1	0	0	0	0	56
25:01-30:00	0	63	0	2	0	1	0	0	0	0	0	0	0	66
30:01-35:00	0	48	0	0	0	2	0	1	1	0	0	0	0	52
35:01-40:00	0	62	0	0	2	0	1	1	0	1	0	0	0	67
40:01-45:00	0	73	0	0	0	0	0	4	0	0	1	0	0	78
45:01-50:00	2	56	1	0	2	1	0	1	1	1	0	0	0	65
50:01-55:00	1	45	0	0	0	2	0	0	0	1	0	0	0	49
55:01-60:00	1	67	2	0	0	0	1	0	0	0	0	0	0	71
Tot	5	700	5	7	6	11	3	17	4	4	1	0	0	763

Time	1	2	3	4	5	6	7	Class8: 4- axle CT	Class9: 5 axle CT	Class10: 6+ axle CT	Class11: 5 axle MTT	Class12: 6 axle MTT	Class13: 7+ axle MTT	Total
Tot	5	700	5	7	6	11	3	17	4	4	1	0	0	763

Truck

16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
705	5	44	9	0	763

Reference

16 Feet:	Class 1 and Class2
30 Feet:	Class 3
50 Feet:	Class 4 to Class 8
79 Feet:	Class 9 to Class 12
> 79 Feet:	Class 13

Second Data Collection

Date:	2008-06-20
Time:	11:00-12:00PM

Time	1	2	3	4	5	6	7	Class8: 4- axle CT	Class9: 5 axle CT	Class10: 6+ axle CT	Class11: 5 axle MTT	Class12: 6 axle MTT	Class13: 7+ axle MTT	Total
00:01-05:00	0	49	0	0	1	0	0	4	1	0	1	0	1	57
05:01-10:00	0	50	2	0	2	0	1	0	0	1	0	0	0	56

Figure 6-1 Example of Ground Truth Traffic Data Summarized by Vehicle Class for 5-minute Intervals (Station # 618)

Traffic data from UDOT's ATR stations were also entered into an Excel spreadsheet to compare with the ground truth data. Traffic data obtained at the ATR stations were summarized for each direction by lane and by length group. Table 6-1 shows an example of traffic data from an ATR station summarized by UDOT by direction, by lane, and by vehicle length.

Table 6-1 Example Traffic Data Summary Provided by UDOT (Station 306)

Friday, May 30, 2008, 3:00-4:00 p.m.						
	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	All Lengths
Lane 1 (North)	924	143	60	54	11	1192
Lane 2 (North)	1079	139	70	82	17	1387
Lane 3 (North)	941	497	17	6	3	1464
Lane 4 (South)	1182	495	11	2	0	1690
Lane 5 (South)	904	604	81	95	21	1705
Lane 6 (South)	529	521	76	114	17	1257
All Lanes	5559	2399	315	353	69	8695
Friday, June 20, 2008, 3:00-4:00 p.m.						
	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	All Lengths
Lane 1 (North)	804	132	70	62	14	1082
Lane 2 (North)	993	99	57	97	21	1267
Lane 3 (North)	785	351	16	4	3	1159
Lane 4 (South)	881	399	12	1	1	1294
Lane 5 (South)	811	530	71	98	22	1532
Lane 6 (South)	422	459	104	110	37	1132
All Lanes	4696	1970	330	372	98	7466

Because ground truth traffic counts were categorized by FHWA's thirteen classes (AASHTO, 1992) and the count data from ATRs were grouped by vehicle length, thirteen vehicle class data were regrouped into UDOT's five length groups using the vehicle length criteria found in *A Policy on Geometric Design of Highways and Streets, 5th Edition* published by AASHTO (2004). Table 6-2 shows the relation between UDOT's vehicle length groups and FHWA's thirteen vehicle classes.

Table 6-2 Reference of Difference of Vehicle Classification

Length Group by UDOT	Regrouped Ground Truth Data
16 Feet (up to 16-ft)	Class 1 and Class 2
30 Feet (16.1ft to 30-ft)	Class 3
50 Feet (30.1 ft to 50-ft)	Class 4 to Class 8
79 Feet (50.1 ft to 79-ft)	Class 9 to Class 12
> 79 Feet	Class 13

During the ground truth data collection, pick-ups were considered as Class 3 vehicles and shorter than 30 feet. Including Class 5 (two-axle six-tire single unit truck) vehicles in the 50-ft group (ranging from 30.1-ft to 50-ft long) might skew the error rate of this group or the 30-ft group (16.1-ft to 30-ft long). However, the research team decided to include Class 5 vehicles in the 50-ft length group to match the length groups by UDOT because Class 5 vehicles are obviously trucks; they are not pickups which are obviously part of the "passenger car" group. On the other hand, it is possible that the 30-ft length group may include trucks as well as long passenger cars. The existence of different classes in the same 30-ft length group is a problem for correctly matching vehicle class and length group from video-taped traffic data. Class 5 vehicles accounted for only 2.3% of all the vehicles analyzed during the ground truth data collection and the impact of these vehicles on the conclusion of the study is considered to be minimal even if they are included in the 50-ft length group. As discussed later, due to the large variations in error rates in the individual length classes, vehicles were grouped into only two groups: shorter-length vehicle group, named "passenger car" group (shorter than or equal to 30 feet) and longer-vehicle group, name "truck" group (longer than 30 feet).

As an example of data comparison, Table 6-3 shows the combined ground truth traffic data together with the traffic data from the ATR station #306. The regrouped ground truth traffic data and the traffic data from the ATR station were sorted by station, route, milepost data, collection type, direction of traffic, collection time, collection date, collection day of the week, and vehicle length. Refer to Appendix 4-1 for the sorted and combined ground truth data and the data from ATR stations with computed error rate for the entire list of sampled ATR stations.

Table 6-3 Regrouped Ground Truth Traffic Data and Traffic Data from ATR Station #306

Satation	Data Order	Route	M.P.	Collection Type	Direction	Time	Date	Day		Traffic Volume by Length					
										16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
306	1	I-15	269.xx	Length (Loops)	North	3:00-4:00PM	2008-05-30	F	Ground Truth	3497	41	256	134	19	3947
									ATR Count	2944	779	147	142	31	4043
									Difference	-553	738	-109	8	12	96
306	2	I-15	269.xx	Length (Loops)	North	3:00-4:00PM	2008-06-20	F	Ground Truth	3467	29	289	147	21	3953
									ATR Count	2582	582	143	163	38	3508
									Difference	-885	553	-146	16	17	-445

6.2.2 Analysis of Main Factors

Two main factors, the error rate and the difference between ground truth traffic volume and the traffic volume from ATR stations were first analyzed. These main two factors reflect the performance of traffic counters and were identified as such in the literature review.

The difference between the ground truth traffic volume and the traffic volume from ATR station, (ATR traffic volume – Ground truth traffic volume), was determined and the error rate was computed as follows:

$$ErrorRate = \frac{ATRTrafficVolume - GroundTruthTrafficVolume}{GroundTruthTrafficVolume} \qquad \textbf{(Equation 6-1)}$$

The error rate is an indicator of accuracy level. A larger error rate means a lower accuracy level while a smaller error rate means a higher accuracy level. The error rate 5% and 10% were used as the target tolerance values, which were identified by the state DOT survey.

6.2.3 Statistical Analysis

The SAS program (2003) and the Microsoft Excel (2008) were used to analyze the two main factors: the volume difference and the error rate (accuracy level). Descriptive statistics such as average, variance, standard deviation, and confidence interval were determined. Statistical analyses were conducted using the following factors and their elements:

- Total volume;
- Highway class: Interstate highway (I) and Non-interstate (NI) highway;
- Data collection time period: AM and PM;
- Data collection order: first data collection and second data collection;
- Data collection elapsed period: one week elapsed, three weeks elapsed, four weeks elapsed, five weeks elapsed, and seven weeks elapsed;
- Data collection day of the week: Monday through Friday;
- Data collection type: loop and microwave;
- Data collection direction: east, west, south, and north, and
- Traffic volume per hour based on ground truth (GT) volume range: GT<100, 100<GT<300, 300<GT<500, 500<GT<1000, and 1000<GT.

Evaluation and inference of the results of the analysis were made in consultation with BYU's CSCCR. Four meetings were held to ensure the appropriateness of the analysis.

6.3 Analysis Parameters and Key Points of the Analysis

In order to achieve the goals of the statistical analysis, four statistical parameters were computed and used to determine the accuracy level of truck traffic data. As these statistics were computed, the existence of outliers became apparent. Inclusion or exclusion of the outliers was consulted with BYU's CSCCR.

6.3.1 Statistics Selected for the Study

Four parameters were considered in the statistical analysis including:

- Mean (or Average): a measure of accuracy level,
- Variance or Standard Deviation: a measure of repeatability,
- Confidence Interval: an index for indicating the reliability of an estimate,
- Number of samples: a parameter for evaluating if there were an adequate number of samples collected to infer the accuracy level of truck traffic at the 95% confidence level. The number of samples, N, is determined by the following formula:

$$E = \pm \frac{z \cdot \sigma}{\sqrt{N}} \qquad \textbf{(Equation 6-2)}$$

Where E = standard error of the mean
z = z-score, 1.96 for the 95% confidence level
σ = standard deviation
N = Number of samples

6.3.2 Finding Extreme Outliers

During the review process of statistical analysis results, it was found that outliers might skew the analysis. The SAS program (2003) was helpful to determine that ATR station #411 near milepost 54 on US-89 near Kanab was an extreme outlier. Hence, ATR station #411 was excluded from further analysis after consultation with BYU's CSCCR.

Table 6-4 shows a summary of information on ATR station #411 including data collection type, direction of data collection, data collection type, data collection date, traffic volumes by length from the ground truth and ATR data sets, and the difference and the error rate of traffic data. At this station, the total volume count was less than 100 vehicles per hour. The error rate of the total volume on the first data collection is 0.0000 while that of the second data set is 0.3167, 31.67% off the ground truth volume count. The error rates of the two sample sets had a large difference indicating potential problems for further analyses. The error rates of each length group were also widely different indicating problems associated with data reduction by the ATR, especially the count for the 30ft length group was completely wrong.

Table 6-4 Summary of Information on ATR Station # 411

Station (Route)	M.P.	Collection Type	Direction	Time	Date	Information	Traffic Volume by Length					
							16 Feet	30 Feet	50 Feet	79 Feet	>79 Feet	Total
411 (US89)	54	Length (Loops)	West	9:00-10:00 AM	6/17 /2008	Ground Truth	51	4	14	5	1	75
						ATR Count	41	14	2	11	7	75
						Difference	-10	10	-12	6	6	0
						Error Rate	**-0.1961**	**2.5000**	**-0.8571**	**1.2000**	**6.0000**	**0.0000**
					6/24 /2008	Ground Truth	36	0	11	8	5	60
						ATR Count	53	10	7	4	5	79
						Difference	17	10	-4	-4	0	19
						Error Rate	**0.4722**	**-**	**-0.3636**	**-0.5000**	**0.0000**	**0.3167**

- : Not computable

The data quality of ATR station #411 might have been affected by nearby construction work also. Three to four mile downstream of station ATR #411 a shoulder reconstruction was underway. One direction was closed during construction. This might have affected the data quality of ATR station #411.

Therefore, the subsequent statistical analyses were carried out with and without ATR station #411. The evaluation of the results of the analysis was focused on the cases without ATR station #411 (See Appendix 4-2 for detailed analysis results). If the reader would like to check the results of the analysis with ATR station #411, refer to Appendix 4-3 Accuracy Level with ATR Station #411.

6.3.3 Exclusion of the Analysis Results of Vehicle-by-Class ATR Stations

Among the thirty ATR stations sampled, two ATR stations, station #427 on SR-10 and station #512 on SR-35, had volume by class counters. Table 6-5 shows the analysis result of the two volume-by-class ATR stations. All traffic volume by class from these two ATR stations were very different from the ground truth counts except vehicle class 2, and large difference in the error rate existed between the first and the second data collection at the these stations (ATR station #427: 0.2643/0.0000, ATR station #512: -0.5000/1.1250). Hence, the two volume-by-class ATR stations were excluded from further analysis after consultation with BYU’s CSCCR.

Table 6-5 Summary of Volume by Class ATR Stations

	Satation	Route	M.P.	Collection Type	Direction	Time	First Date	Second Date		1	2	3	4	5	6	7	8	9	10	11	12	13	All Classes
1	427	10	49.xx	Class	North	11:00-12:00PM	First	2008-04-04	Ground Truth	1	83	41	1	4	1	0	5	4	0	0	0	0	140
									ATR Count	0	87	25	0	20	1	0	6	3	1	0	0	34	177
									Difference	-1	4	-16	-1	16	0	0	1	-1	1	0	0	34	37
									Error Rate	**-1.0000**	**0.0482**	**-0.3902**	**-1.0000**	**4.0000**	**0.0000**	*	**0.2000**	**-0.2500**	*	*	*	*	**0.2643**
							Second	2008-06-13	Ground Truth	3	110	1	0	3	2	1	13	2	1	0	0	12	148
									ATR Count	0	78	27	1	12	2	0	13	2	1	0	0	12	148
									Difference	-3	-32	26	1	9	0	-1	0	0	0	0	0	0	0
									Error Rate	**-1.0000**	**-0.2909**	**26.0000**	*	**3.0000**	**0.0000**	**-1.0000**	**0.0000**	**0.0000**	**0.0000**	*	*	**0.0000**	**0.0000**
2	512	35	10.4	Class	South	10:00-11:00AM	First	2008-05-06	Ground Truth	1	4	0	0	0	1	0	0	0	0	0	0	0	6
									ATR Count	0	2	0	0	0	1	0	0	0	0	0	0	0	3
									Difference	-1	-2	0	0	0	0	0	0	0	0	0	0	0	-3
									Error Rate	**-1.0000**	**-0.5000**	*	*	*	**0.0000**	*	*	*	*	*	*	*	**-0.5000**
							Second	2008-06-10	Ground Truth	0	7	0	0	0	0	0	1	0	0	0	0	0	8
									ATR Count	0	7	4	1	3	1	0	0	0	0	1	0	0	17
									Difference	0	0	4	1	3	1	0	-1	0	0	1	0	0	9
									Error Rate	*	**0.0000**	*	*	*	*	*	**-1.0000**	*	*	*	*	*	**1.1250**
	Average							**Error Rate**	First	-1	-0.2259	*	*	*	0.0000	*	*	*	*	*	*	*	-0.1179
									Second	*	-0.1455	*	*	*	*	*	-0.5000	*	*	*	*	*	0.5625
*: Not Computable																							

6.3.4 Exclusion of the Difference Factor between Ground Truth Data and ATR Station Data

After consulting with BYU’s CSCCR, it was decided to drop the difference between ground truth data and ATR station data from subsequent analyses. Even though the difference was chosen as one of the main factors for evaluation at the beginning of the analysis, the difference in the two data sets was not as descriptive as the error rate for determining the accuracy level.

If the reader would like to check the analysis results about the difference between ATR Station Data and Ground Truth Data, refer to Appendix 4-4.

6.3.5 Regrouping of Vehicle Classes by Vehicle Length

Regrouping of vehicle classes into vehicle length groups became necessary to continue statistical analyses because error rates by original five vehicle length group did not show a clear picture of accuracy level of truck traffic data. The 16-ft and 30-ft length groups were combined into one group, called as a “passenger car group” and the remaining longer vehicles were combined into a “truck” group. This reclassification helped clearly understand the issue of truck traffic data accuracy level as presented in the subsequent sections.

6.4 Results of the Statistical Analysis

This section discusses the results of the statistical analysis without ATR station #411. Results of the comprehensive analysis of accuracy level of the total traffic volume and the effect of data collection factors without and with ATR station #411 can be found in Appendix 4-2 and Appendix 4-3.

6.4.1 Accuracy Level of the Traffic Data Collected by ATRs

In this section, the analysis results of the accuracy level of the total traffic volume as indicated by error rate are first presented, followed by the analysis results of vehicle length groups together with the regrouped length groups.

6.4.1.1 Accuracy Level of Total Volume

Table 6-6 shows error rates of the length groups and the entire data (Total). The average error rate of the entire data without the outlier ATR station #411 was 0.0012 (only 0.12% off the ground truth data) and the standard deviation was 0.0717. The standard deviation of error rate without the outlier (0.0717) was slightly less than that with the outlier (0.0821)

On the other hand, the error rate of each length group significantly varied as shown in Table 6-6, ranging from 20.1244 of the 30-ft length group to -0.0304 of the 79-ft length group, while the standard deviation of each length group varied from 20.4194 of the 30-ft length group to 0.2173 of the 16-ft length group. Positive error rates are overestimation while negative error rates are underestimation.

Confidence intervals of each vehicle group and the total were computed at the 95% confidence level. As shown in Table 6-6, the confidence interval of the total data ranged from -0.0176 to 0.0200 containing zero, meaning the difference was statistically zero. Using the same logic, all length groups but the 79-ft length group had the statistically significant difference.

In terms of reliability of the average value, the confidence interval can be used. The interval length of the total data is the narrowest (0.0376 = 0.0200-(-0.0176)) and that of the 30-ft length group was the widest (10.6963 = 25.4726-14.7763), meaning the average value of total traffic data is most reliable and the 30-ft length group was least reliable.

Table 6-6 Error Rates without the Outlier (Total)

Total	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.2004	20.1244	-0.4332	-0.0304	1.8509	0.0012
Variance	0.0472	416.9507	0.0251	0.0889	22.4007	0.0051
S D*	0.2173	20.4194	0.1583	0.2982	4.7329	0.0717
Upper Bound of CI	-0.1434	25.4726	-0.3917	0.0477	3.0905	0.0200
Lower Bound of CI**	-0.2573	14.7763	-0.4747	-0.1085	0.6113	-0.0176

* SD: Standard deviation
** CI: Confidence interval

Figure 6-2 shows a bar chart of error rate of the total traffic count by station. The error rates of ATR station #510 (SR-218, Smithfield), ATR station #502 (I-15, Nephi), ATR station #349 (I-15, Santaquin), ATR station #507 (US-6, Price), and ATR station #306 (I-15, Provo) significantly affected the average error rate of the total traffic count.

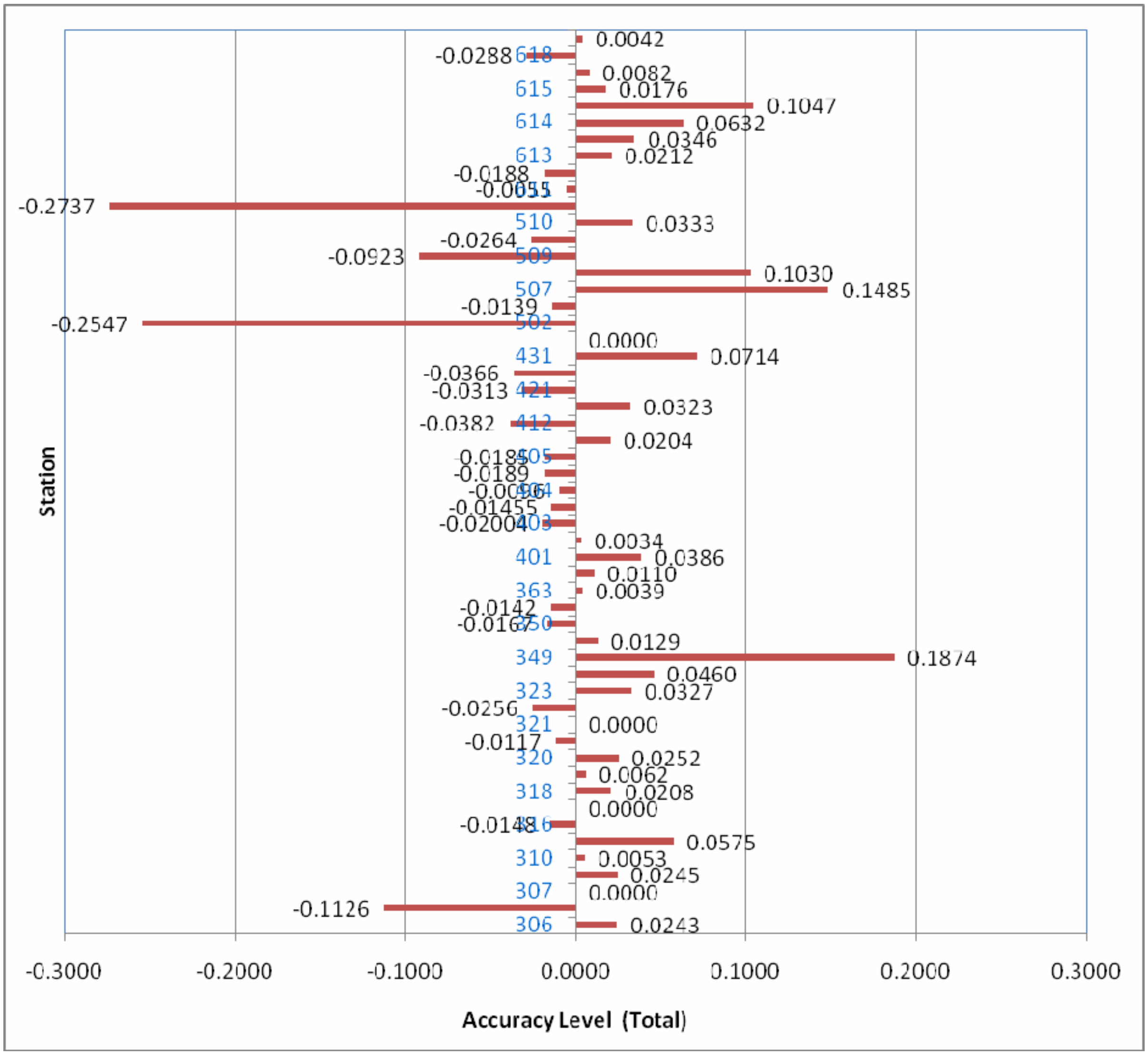


Figure 6-2 Error Rates of the Total Data by Station

6.4.1.2 Error Rates of Reclassified Length Groups

A major objective of the study was to evaluate the data accuracy of truck counts; hence, error rates were computed for the reclassified length groups. Table 6-7 shows the error rates for the reclassified length groups and the total traffic count. The error rate of passenger car group (shorter than or equal to 30 feet) was 0.0573 and that of the truck group (longer than 30 feet) was -0.2113. This means the passenger car group was over counted by 5.73%

and the truck group was under counted by 21.13%. Since neither group contains zero in the confidence interval, these differences were statistically significant at the 95% confidence level.

As shown in Table 6-7, the confidence interval of the passenger car group was 0.0515 = 0.0831-0.0316, while that of the truck group (over 30-ft) was 0.0876 = (-0.1675)-(-0.2551). Hence, the average error rate of the passenger car group was slightly more reliable than that of the truck group, meaning that the confidence interval of the passenger car group (0.0515) was smaller than that of the truck group (0.0876).

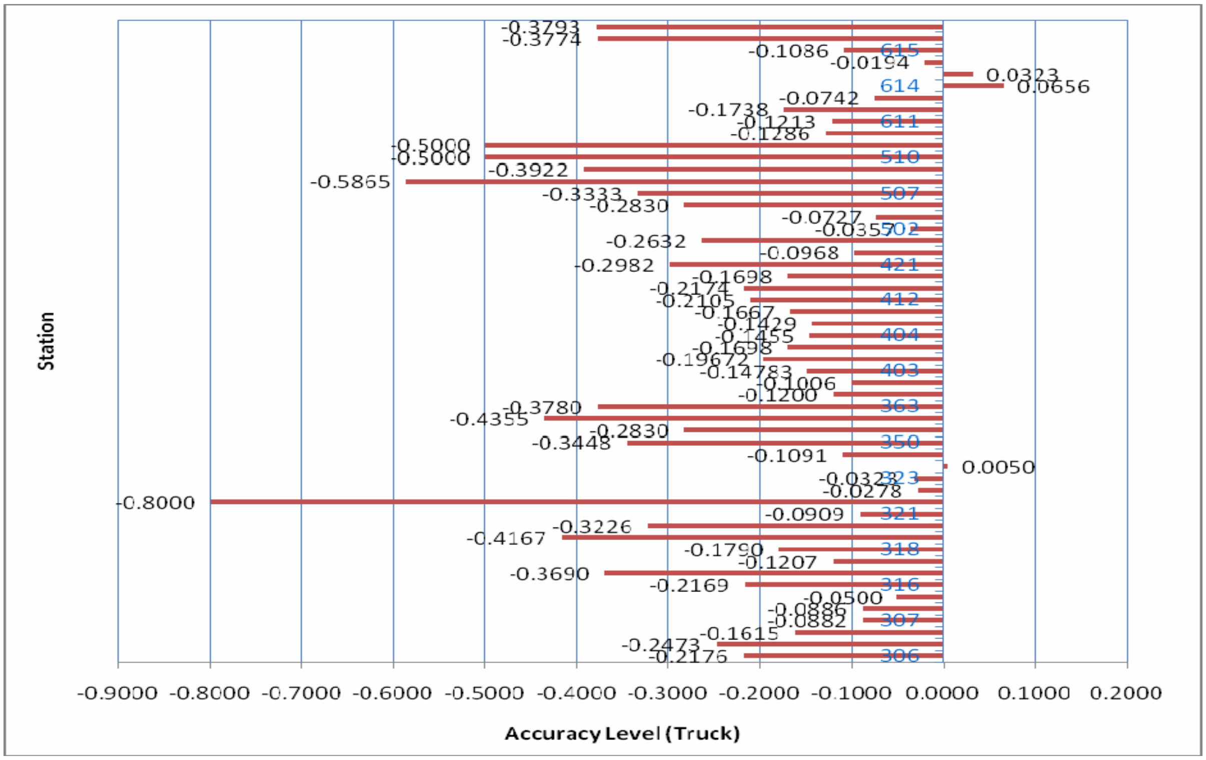
Table 6-7 Error Rates of Reclassified Vehicle Length Group

	Passenger Car Group (Shorter than or equal to 30 feet)	Truck Group (Longer than 30 feet)	Total
Average	0.0573	-0.2113	0.0012
Variance	0.0097	0.0279	0.0051
S D*	0.0983	0.1672	0.0717
Upper Bound of CI**	0.0831	-0.1675	0.0200
Lower Bound of CI	0.0316	-0.2551	-0.0176

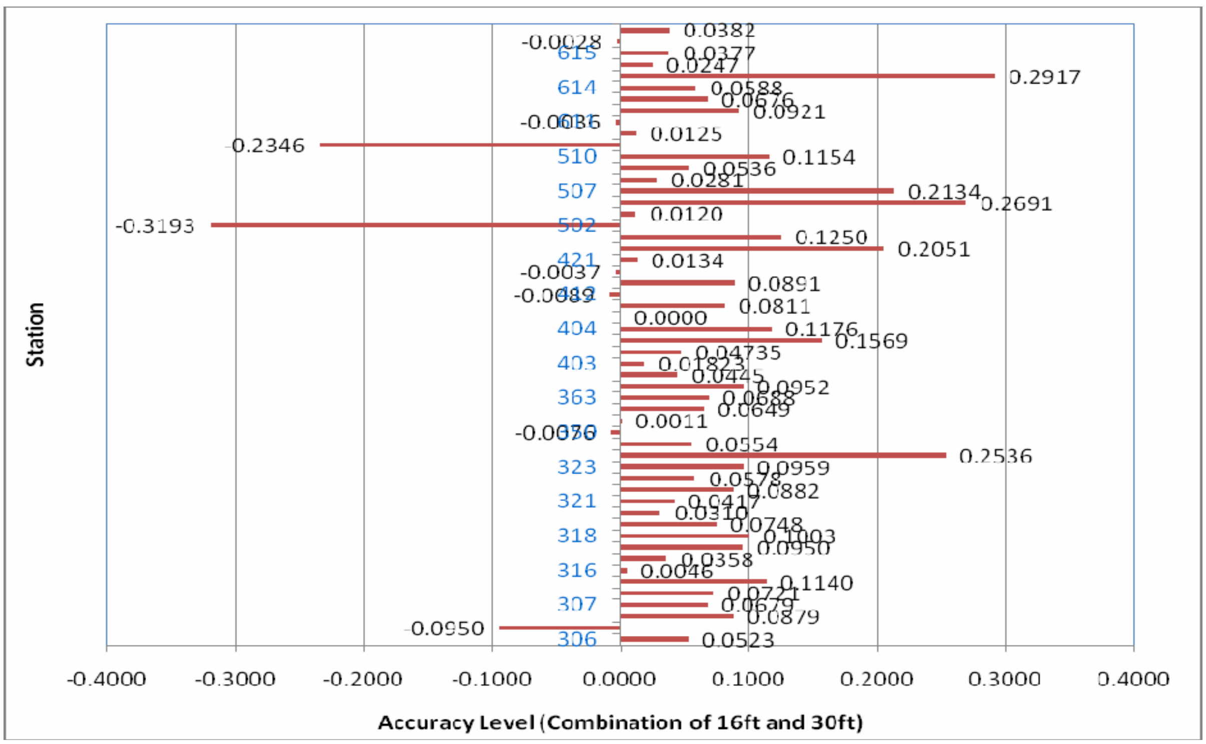
* SD: Standard deviation
** CI: Confidence interval

Figure 6-3 shows a bar chart of error rate of the reclassified length group by station. As shown in the figure, the error rate of station #321 (US-6, Jericho) was quite high compared to the other few stations that had relatively high error rates and significantly affected the average error rate of the passenger car group. Similarly the error rate of station ATR #502 (I-15, Nephi) was the highest among the sampled stations and affected the average error rate of the truck group, as shown in (a) of Figure 6-3.

Figure 6-3 (a) and (b) show a distinct trend. The error rates of the truck group were mostly negative while the error rates of the passenger car group were mostly positive. As shown in Table 6-5, the ATR had difficulty in classifying vehicles in the 30-ft vehicle length group (16.1-ft to 30-ft vehicle length).



(a) Distribution of Error Rates of the Truck Group



(b) Distribution of Error Rates of the Passenger Car Group

Figure 6-3 Error Rates of the Reclassified Length Groups by Station

6.4.1.3 Required Number of Samples

Using equation 6-2, the required number of samples given the standard deviation of the sample data set was determined for the 95% confidence level for 5% and 10% tolerance level. Table 6-8 shows the required number of samples. The total number of samples available for the analysis was 54 without ATR station #411 (extreme outliers) and two class-type ATR stations (ATR station #427 and ATR station #512). For each length group, the number of samples available for the analysis was larger than the required number of samples except for the 30-ft and greater than 79-ft length group for the tolerance (E) level of 10%.

For the 5% tolerance level, the available number of samples (54) was enough for the regrouped passenger car and truck groups but, not adequate for original vehicle groups except for the 50-ft and total count groups.

Table 6-8 Number of Samples with 95% confidence Interval

Total-Without 3 stations	16-ft	30-ft	50-ft	79-ft	> 79-ft	Total	Passenger Car (Shorter than or equal to 30 feet)	Truck (Longer than 30 feet)
E=5%	73	640,703	39	137	34,422	8	15	43
E=10%	18	160,176	10	34	8,605	2	4	11

6.4.2 Statistical Analyses of Data Collection Conditions

Other analyses by data collection conditions mentioned in the previous section were subsequently performed. The statistical analyses without the largest outlier (ATR station #411) and two class-type ATR stations (ATR station #427 and ATR station #512) were carried out for highway class, data collection time zone, data collection order, data collection elapsed period, data collection day of the week, data collection loop type, data collection direction, and traffic volume based on ground truth. These analyses were done for the total count and the counts of the reclassified vehicle length groups.

6.4.2.1 Total Count

Table 6-9 shows the results of the statistical analysis for the total count. The values on the table are error rates. The smaller the error rate is, the higher the accuracy level becomes. “Interstate” highway in the highway class, “PM” in the data collection time period, “Second” data collection in the data collection order, and “Inductive loop” equipment in the data collection type were more accurate than the rest in the same factor. Also, “Wednesday” among the data collection day of the week, “One week” among data collection weeks elapsed between first data collection and second data collection, “West” direction of the four data collection directions, and “GT<100” per hour of the five traffic volume ranges showed more accurate results than the rest in the same factor.

Also, standard deviation shows the measure of repeatability in the analysis results. The smaller the standard deviation is, the better the repeatability is. This is reflected in the size of confidence interval.

The confidence interval implies two things. First, if the confidence interval contains zero, the error rate is statistically zero at the selected confidence level. Second, the narrower the confidence interval is, the more reliable the average error rate is. “Interstate” highway in the highway class, “PM” in the data collection time period, “Second” data collection in the data collection order, and “Inductive loop” in the data collection type were more reliable than the rest in the same factor. Also, “Tuesday” data collection days of the week, “One week” among the data collection weeks elapsed between first and second data collection, “West” direction among the four data collection directions, and “100<GT<300” vehicles per hour among the five traffic vehicle ranges were more reliable than the rest in the same factor.

In statistical analyses, outliers affect the analysis results. The last column in Table 6-9 shows the stations that had error rate larger than 0.1 (10% tolerance level). Out of the 27 stations included in this analysis, the stations shown in this column affected the outcomes of the analysis.

Table 6-9 Results of Statistical Analysis of Total Count by Data Collection Condition

Main Factor		Average	S D*	Upper Bound of CI**	Lower Bound of CI	Stations with Relative Large Accuracy Rates (Over 0.1)
Highway Class	**NI**	-0.0068	0.0722	0.0200	-0.0335	#510, #507, # 509
	I	0.0086	0.0718	0.0352	0.0182	#502, #349, #306, #614
Data Collection Time Zone	**AM**	0.0127	0.0944	0.0563	-0.0309	#510, #349, #614
	PM	-0.0037	0.0606	0.0156	-0.0229	#502, #507, #306,
Data Collection Order	First	0.0060	0.0758	0.0341	-0.0220	#502, #349
	Second	-0.0036	0.0685	0.0217	-0.0290	#509, #306, #614, #502
Data Collection Time Elapsed Period	**One Week**	0.0004	0.0261	0.0113	-0.0104	-
	Three Weeks	-0.0293	0.0423	0.0001	-0.0586	#306
	Four Weeks	0.0502	0.0579	0.0861	0.0143	#349, #614
	Five Weeks	-0.0027	0.0934	0.0463	-0.0516	#502, #507
	Seven Weeks	-0.1202	0.2171	0.1807	-0.4211	#510
Data Collection Day of the Week	Monday	-0.0178	0.0797	0.0273	-0.0629	#502
	Tuesday	-0.0102	0.0336	0.0063	-0.0266	-
	Wednesday	0.0042	0.0862	0.0493	-0.0410	#510, #614
	Thursday	0.1002	0.1234	0.2712	-0.0709	#349
	Friday	0.0135	0.0665	0.0511	-0.0241	#306, #507
Data Collection Loop Type	**Loops**	-0.0022	0.0739	0.0183	-0.0227	#510, #502, #349, #507, #306
	Microwave	0.0282	0.0467	0.0656	-0.0092	#614
Data Collection Direction	East	0.0112	0.0979	0.0624	-0.0401	#510, #507, #614
	West	-0.0003	0.0365	0.0189	-0.0194	#502, #306
	South	0.0228	0.0524	0.0485	-0.0029	#349
	North	-0.0377	0.0770	0.0059	-0.0813	-
Ground Truth Traffic Volume (GT)	**GT <100**	-0.0025	0.1040	0.0620	-0.0670	#510, #614
	100< GT< 300	0.0121	0.0312	0.0314	-0.0073	-
	300< GT< 500	-0.0156	0.0941	0.0400	-0.0711	#502, #507
	500< GT<1000	0.0137	0.0630	0.0456	-0.0182	#349, #507
	1000> GT	-0.0082	0.0464	0.0240	-0.0403	#306

*: Standard Deviation
**: Confidence Interval

Using equation 6-2, the required number of samples was obtained for the total count at the 95% confidence level (z score = 1.96) with the tolerance level 5%. Standard deviations (σ) in Table 6-7 were used for this analysis. Results of this computation are shown in Figure 6-4. A total of 54 samples were available for the analysis because one outlier (ATR station #411) and two class-type stations (ATR station #427 and ATR station #512) were excluded from the analysis. Out of these multiple factor elements, “Seven week”, “Thursday”, “East”, “GT<100” and “300<GT<500” groups required more samples than the available number of samples. Hence, most of the factor elements had enough number of samples to make the results reliable.

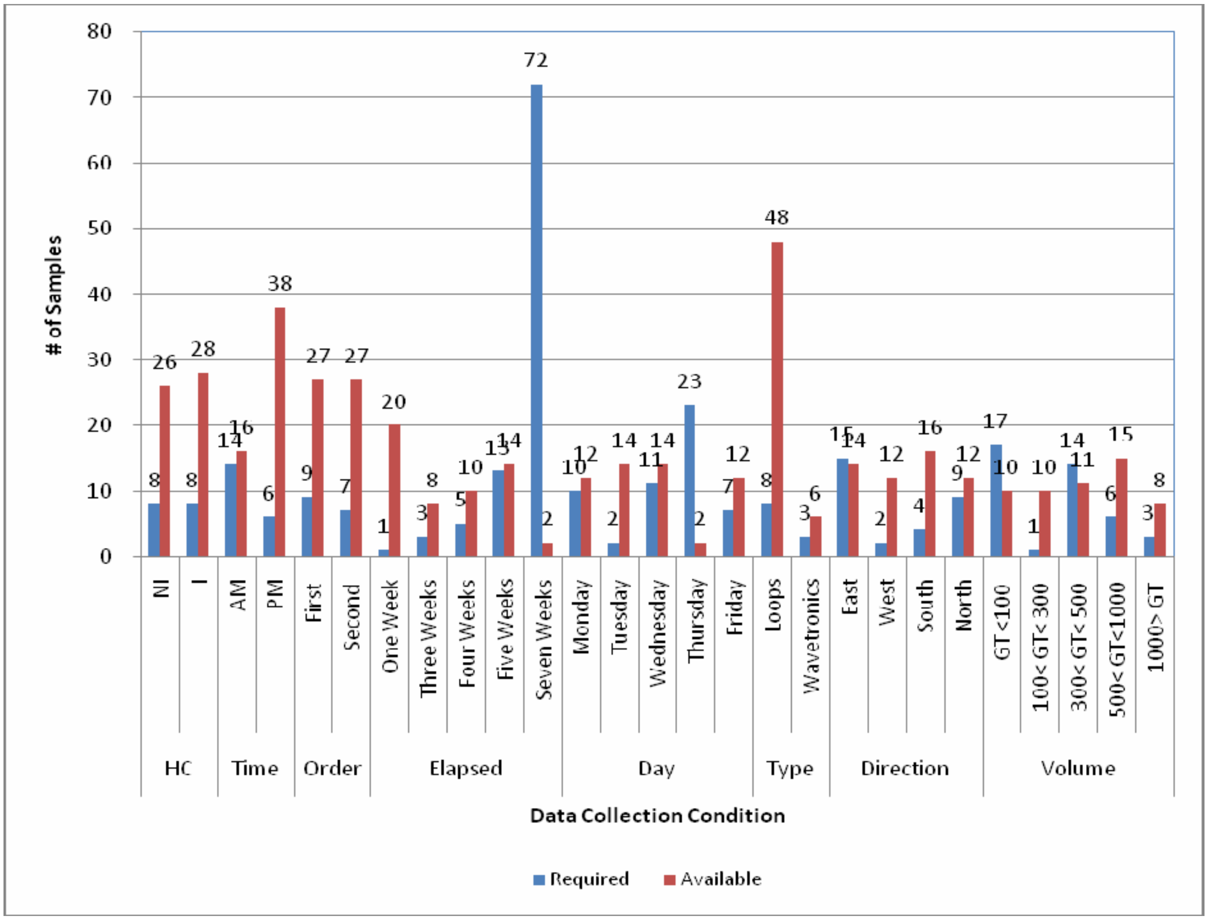


Figure 6-4 Number of Required and Available Samples for the Analysis on Total Count at 95% Confidence Level (Tolerance 5%)

6.4.2.2 Passenger Car Group (Shorter Than or Equal To 30 Feet)

Table 6-10 shows the results of statistical analysis of the passenger car group (the combined group of 16-ft and 30-ft vehicle groups). As shown in the table, “Non-interstate” highway in the highway class, “PM” in the data collection time period, “First” data collection in the data collection order, and “Inductive loop” in the data collection type were more accurate than the rest in the same factor. Also, “Tuesday” among the data collection days of the week, “Three weeks” among the data collection weeks elapsed between first data collection and second data collection, “North” direction among the four data collection directions, and “GT>1,000” volumes per hour among the five traffic vehicle ranges were more accurate than the rest in the same factor.

As for the size of confidence interval, “Interstate” highway in the highway class, “PM” in the data collection time zone, “Second” data collection in the data collection order, and “Inductive loop” in the data collection type had narrower confidence intervals than the rest in the same factor. Also, “Tuesday” among the data collection days of the week, “One week” among the data collection weeks elapsed between first data collection and second data collection, “West” direction among the four data collection directions, and “100<GT<300” vehicles per hour among the five traffic vehicle ranges had narrower confidence intervals than the rest in the same factor. The narrower the confidence interval is, the more reliable the error rate becomes in this analysis.

The required number of samples at the 95% confidence level with the tolerance level 5% was computed for each data collection condition groups is shown in Figure 6-5 together with the available number of samples for all factor elements. As shown in Figure 6-5, about one-half of the factor elements had required number of samples larger than the available number of samples. Hence, to improve the reliability of analysis, more samples are needed.

Table 6-10 Results of Statistical Analysis of the Combined of 16-ft and 30-ft Vehicle Group by Data Collection Condition

Main Factor		Average	S D	Upper Bound of CI	Lower Bound of CI	Stations with Relative Large Accuracy Rates (Over 0.1)
Highway Class	**NI**	0.0533	0.0931	0.0877	0.0188	13
	I	0.0611	0.1045	0.0998	0.0479	17
Data Collection Time Zone	**AM**	0.0768	0.1175	0.1311	0.0225	21
	PM	0.0492	0.0895	0.0776	0.0207	12
Data Collection Order	**First**	0.0570	0.1063	0.0963	0.0176	17
	Second	0.0577	0.0916	0.0916	0.0237	13
Data Collection Time Elapsed Period	**One Week**	0.0553	0.0449	0.0741	0.0365	3
	Three Weeks	-0.0083	0.0453	0.0231	-0.0396	3
	Four Weeks	0.1139	0.0859	0.1671	0.0607	11
	Five Weeks	0.0696	0.1371	0.1414	-0.0022	29
	Seven Weeks	-0.0596	0.2475	0.2834	-0.4025	94
Data Collection Day of the Week	Monday	0.0000	0.0000	0.0000	0.0000	24
	Tuesday	0.0478	0.0384	0.0666	0.0289	2
	Wednesday	0.0748	0.1106	0.1328	0.0169	19
	Thursday	0.1545	0.1402	0.3488	-0.0398	30
	Friday	0.0526	0.1003	0.1094	-0.0042	15
Data Collection Loop Type	**Loops**	0.0557	0.0978	0.0828	0.0286	15
	Microwave	0.0703	0.1105	0.1587	-0.0181	19
Data Collection Direction	East	0.0730	0.1300	0.1411	0.0049	26
	West	0.0806	0.0366	0.0997	0.0614	2
	South	0.0818	0.0687	0.1155	0.0481	7
	North	-0.0168	0.1050	0.0426	-0.0762	17
Traffic Volume - GT	**GT <100**	0.0772	0.1378	0.1627	-0.0082	29
	100< GT< 300	0.0800	0.0468	0.1090	0.0510	3
	300< GT< 500	0.0353	0.1397	0.1178	-0.0472	30
	500< GT<1000	0.0653	0.0737	0.1026	0.0280	8
	1000> GT	0.0195	0.0578	0.0596	-0.0206	5

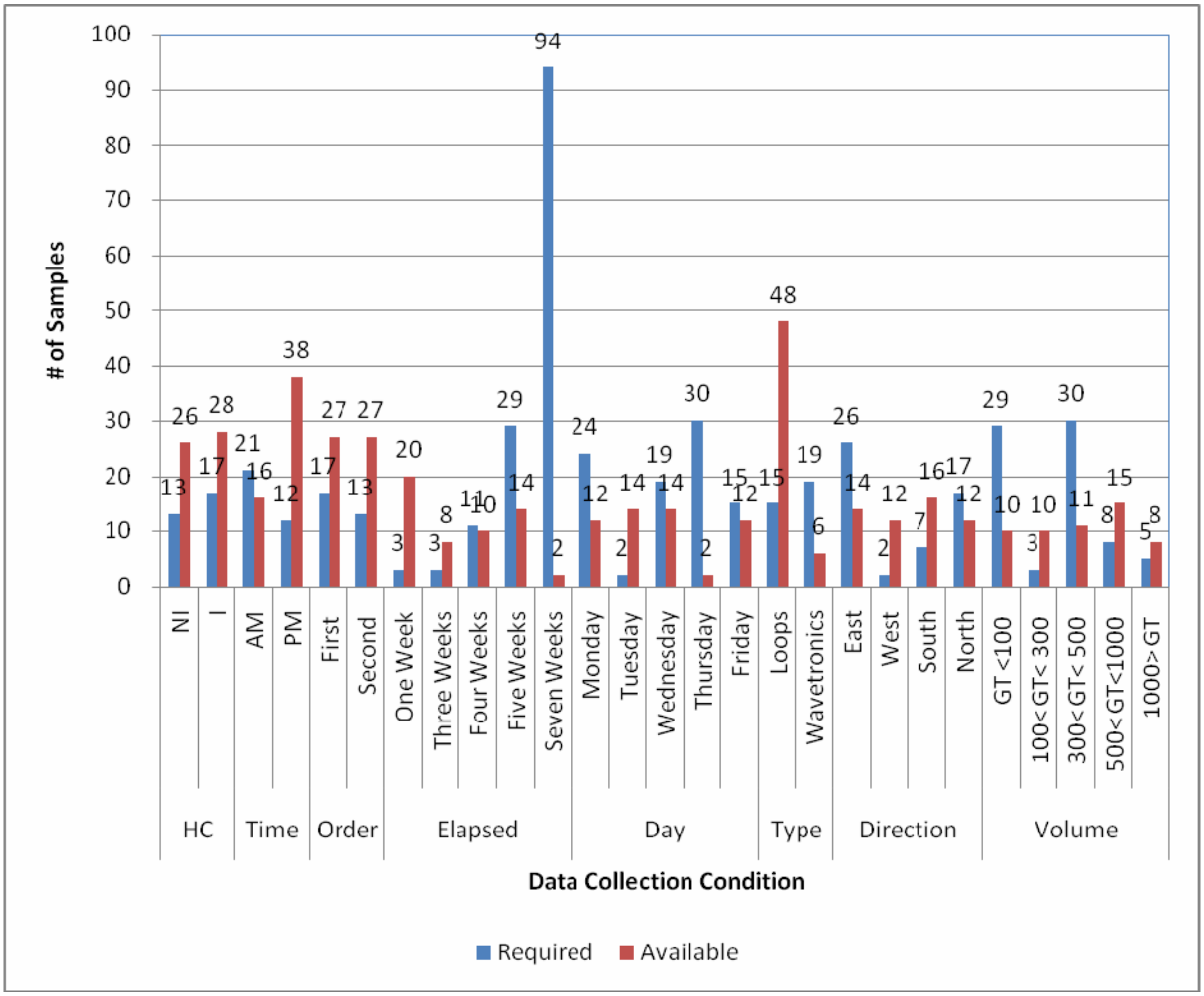


Figure 6-5 Number of Required and Available Samples for the Analysis on Passenger Car Group at 95% Confidence Level (Tolerance 5%)

6.4.2.3 Truck Group (Longer Than 30 feet)

Table 6-11 shows the results of statistical analysis of the truck (over 30-ft) group by data collection condition. As shown in the table, "Interstate" highway in highway class, "AM" in the data collection time period, "First" data collection in the data collection order, and "Microwave" sensor in the data collection group were more accurate than the rest in the same factor. Also "Thursday" among the data collection days of the week, "Four weeks" among the data collection weeks elapsed between first data collection and "Second" data collection, "South" direction among the four data collection directions, and "100<GT<300" vehicles per hour among the five traffic vehicle ranges were more accurate than the rest group in the same factor.

As for the size of confidence interval, "Interstate" highway in the highway class, "PM" in the data collection time period, "First" data collection in the data collection order, and "Inductive loop" in the data collection type were more accurate than the rest in the same factor. Also, "Tuesday" among the data collection days of the week, "One week" among the data collection weeks elapsed between first data collection and second data collection, "North" direction among the four data collection directions, and "GT>1000" vehicles per hour among the five traffic vehicle ranges were more accurate than the rest in the same factor.

The required number of samples at the 95% confidence level with the tolerance 5% was computed for each factor group and shows in Figure 6-6 together with the available number of samples for all factor elements. As shown in Figure 6-6, most of the factor elements had required number of samples larger than the available number of samples. Hence, to improve the reliability of analysis, more number of data samples are needed.

Table 6-11 Results of Statistical Analysis of Truck Group by Data Collection Condition

Main Factor		Average	S D	Upper Bound of CI	Lower Bound of CI	Stations with Relative Large Accuracy Rates (Over 0.1)
Highway Class	**NI**	-0.3298	0.1580	-0.2713	-0.3883	38
	I	-0.1012	0.0751	-0.0734	-0.0215	9
Data Collection Time Zone	**AM**	-0.1610	0.1742	-0.0805	-0.2415	47
	PM	-0.2324	0.1618	-0.1810	-0.2839	40
Data Collection Order	**First**	-0.1930	0.1599	-0.1338	-0.2523	39
	Second	-0.2295	0.1752	-0.1646	-0.2944	47
Data Collection Time Elapsed Period	**One Week**	-0.1860	0.1018	-0.1435	-0.2286	16
	Three Weeks	-0.2561	0.1141	-0.1771	-0.3352	20
	Four Weeks	-0.1206	0.1668	-0.0173	-0.2240	43
	Five Weeks	-0.2416	0.2260	-0.1232	-0.3600	79
	Seven Weeks	-0.5000	0.0000	-0.5000	-0.5000	-
Data Collection Day of the Week	Monday	-0.1862	0.2024	-0.0716	-0.3007	63
	Tuesday	-0.2678	0.1371	-0.2006	-0.3350	29
	Wednesday	-0.1818	0.1928	-0.0808	-0.2828	57
	Thursday	-0.0520	0.0807	0.0598	-0.1639	10
	Friday	-0.2313	0.1265	-0.1597	-0.3029	25
Data Collection Loop Type	**Loops**	-0.2318	0.1639	-0.1864	-0.2773	41
	Microwave	-0.0467	0.0845	0.0209	-0.1143	11
Data Collection Direction	East	-0.2574	0.2424	-0.1304	-0.3844	90
	West	-0.2202	0.1721	-0.1301	-0.3104	46
	South	-0.1837	0.1304	-0.1198	-0.2476	26
	North	-0.1853	0.0881	-0.1354	-0.2352	12
Traffic Volume - GT	**GT <100**	-0.2463	0.2737	-0.0766	-0.4159	115
	100< GT< 300	-0.1681	0.1286	-0.0884	-0.2478	25
	300< GT< 500	-0.1594	0.0812	-0.1114	-0.2074	10
	500< GT<1000	-0.2730	0.1711	-0.1864	-0.3596	45
	1000> GT	-0.1770	0.0890	-0.1153	-0.2387	12

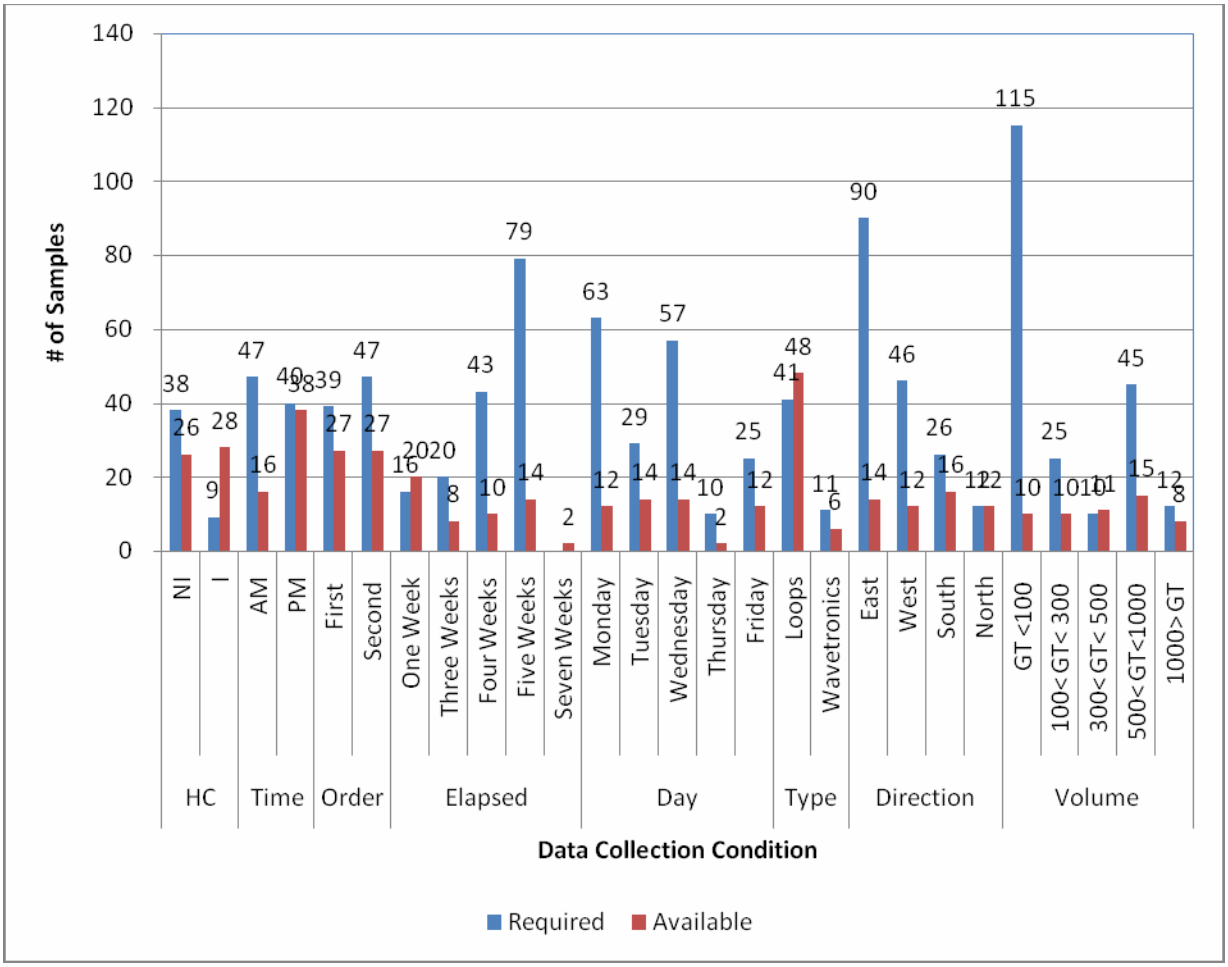


Figure 6-6 Number of Required and Available Samples for the Analysis on the Truck Group at 95% Confidence Level (Tolerance 5%)

6.5 Chapter Summary

In order to evaluate and suggest optimal spatial spread of ATR stations to achieve the level of accuracy in truck traffic count desired by UDOT, statistical analyses were done on error rates. Error rate is the criterion used to evaluate the accuracy level of the current traffic count. The larger the error rate is, the lower the accuracy level becomes. Multiple analyses were done on error rates for vehicle length groups and data condition factors at the 95% confidence level and tolerance level of 5% and 10%.

Mean or average error rate (a measure of accuracy level), variance or standard deviation of error rate (a measure of repeatability), confidence interval (a measure of determined reliability of an estimate), the number of samples (a measure of adequate same data) were used to meet the goals of the analysis. For these analyses, ATR station #411 and two class type ATR stations (#427 and #512) were excluded because their error rates abnormally affected the rest of the samples and determined as outliers.

It was found that total vehicle counts had a very low average error rate (0.0012 or 0.12%), meaning total ATR counts were statistically equivalent to the ground truth traffic counts. However, the same was not true for the passenger car and truck groups. The trucks longer than 30 feet (truck group) were underestimated by 21.13 % (95% confidence interval: -25.51% to -16.75%), while the vehicles shorter than or equal to 30 feet (passenger car group) were overestimated by 5.73% (95% confidence interval: 3.16% to 8.31%). It was also found that identifying vehicles in the 30-ft length group (16.1-ft to 30-ft) was the most problematic with the currently used vehicle length groups because passenger cars and some single unit trucks may be included in the same length group.

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7 Conclusion and Recommendations

This study was carried out to evaluate the level of accuracy of current truck traffic counts obtained at ATR stations in Utah. The objective was met by conducting a literature review on the state-of-the-art and state-of-the-practice of obtaining truck traffic counts, a best practice survey of other state DOTs, and by comparing ground truth vehicle classification data obtained by field data collection using a video recorder and the data from ATR stations. This chapter presents a conclusion of the analysis and recommendations for system improvement, research implementation, and future studies.

7.1 Conclusion

Major findings from the literature review and the best practice survey of the state DOT's on truck traffic count are the following:

- Typical desired tolerance (standard error): 5% to 10%
- Targeted accuracy level (error rate): 90% ~ 95% (10% ~ 5%)
- Traffic data collection method: inductive loop detectors and microwave sensors
- Classification type: volume only, volume by length, and volume by class
- Method of collecting ground truth count data: visual counts by lane and by direction (freeway and main arterial),
- Collection time: every 3 months to 3 years.

In the best practice survey, state DOT employees in charge of traffic counts in other state DOTs cited sensor problems (sensor configuration, calibration, location, and limitation), vehicle classification algorithms, and environmental problem (weather) as their major reasons that would lower the accuracy level of truck traffic counts.

Main factors for designing a stratified sampling of permanent traffic count stations (ATR stations) were identified as follows:

- Hardware factor: type of data, collection method, tolerance, and targeted accuracy level (error rate);
- Location factor: highway functional class, regional characteristics, and availability of space for placing traffic count equipment;
- Time factor: time period to collect, and day of the week; and
- Other factors: traffic volume and traffic condition (congestion and construction).

Through various statistical analyses of error rates, the research team found the relationship between error rate (accuracy level) and vehicle class at sampled ATR stations for this study as follows:

- Passenger car group (vehicles shorter than or equal to 30 feet): over-counted by 5.73% (95% confidence interval: 3.16 to 8.31%);
- Truck group (vehicles longer than 30 feet): under-counted by 21.13% (95% confidence interval: -25.51% to -16.75%), far greater than targeted 5% to 10% error rates;
- Total count: ATR counts were statistically equivalent to the ground truth counts. The error rate was 0.12% (95% confidence interval: -1.76% to 2.00%).

It appears that the over-counts of the passenger car group and the under-counts of the truck group cancel each other to make total counts accurate. It was also found that identifying vehicles in the 30-ft length group (16.1 feet to 30 feet) was the most problematic with the currently used vehicle counting methods.

The large undercount of trucks will significantly affect design, operation, management, and maintenance of UDOT's highways, and UDOT needs to develop procedures to reduce such a large under-count caused by the existing traffic count equipment.

The sample size available for this study was adequate for the tolerance level of 10% and for the two vehicle group analysis (the passenger car group and the truck group). To evaluate the accuracy level of truck traffic for each of the current vehicle length groups, it is necessary to have a larger sample size.

7.2 Recommendations

In order to improve truck traffic counts, the following recommendations are made:

- Check regularly the accuracy level (error rate) with a well-designed stratified sampling of ATR stations,
- Establish an efficient and economical ground truth data collection and analysis method,
- Explore the possibility of synthesizing truck and freight related data obtained by the WIM program and at the Ports of Entry with the truck counts obtained at the ATR stations to improve the overall accuracy level (lowering error rate) of truck traffic counts, and
- Explore the possibility of using truck traffic count data obtained at ATR stations that produce high accuracy truck counts to adjust the traffic count data obtained at other ATR stations that produce truck counts at a lower accuracy level.

Besides the recommendations given above, the following recommendations related to hardware and vehicle classification algorithms are made:

- Change the boundaries for vehicle length groups and make them commensurate with the FHWA's vehicle classes or reflect the vehicle lengths specified in the AASHTO's Green Book (AASHTO, 2004),
- Use the inductive loop length detector until microwave detectors can classify vehicles with higher accuracy level (Note that UDOT at present uses only 3 microwave-based ATRs and further testing of microwave detectors is recommended), and
- Install more class-type ATR stations at locations with higher traffic volume (currently there are only three class-type ATR stations installed only at remote locations with

very low traffic volume) to evaluate how correctly they can classify vehicles into FHWA's thirteen classes.

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Appendices

Appendix 1: Survey Form for Best Practice of State DOT's on Truck Traffic Estimation

STATE OF PRACTICE: EVALUATION OF ACCURACY LEVEL OF TRUCK TRAFFIC DATA

INTRODUCTION

Brigham Young University (BYU) is conducting a study on the accuracy level of truck traffic data on state highways on behalf of the Utah Department of Transportation (UDOT). In conjunction with an extensive literature search, UDOT is hoping to gather the most update information on methods for evaluating the accuracy of truck traffic counts.

INSTRUCTIONS

If the state has any of the following:

1. Manual or guidelines for evaluating the accuracy level of truck traffic counts, or
2. Documentation of research studies on evaluating the accuracy level of truck traffic counts,

Please send a copy of the document and a payment invoice to be reimbursed for document copies to:

Dr. Mitsuru Saito, Ph.D., P.E., F. ASCE
Brigham Young University
Department of Civil and Environmental Engineering
368 Clyde Building
Provo, Utah, 84602

Or send an Internet URL (address) of the document(s) to: tgjin2004@hotmail.com

The survey is sent to you electronically as a MS Word file. However, your response can be sent back either electronically or as a hard copy. Please choose the method you feel most convenient.

If you choose to fill out and return the survey electronically, please save the survey file under an appropriate name in an appropriate folder first. After the survey was filled out, please attach the file to your response e-mail and mail it to tgjin2004@hotmail.com. If you choose to fill out the hardcopy, please print and fill out the survey and mail it to Dr. Saito's address shown above. Some questions ask you to fill in appropriate cells in a table, circle the correct answer, or enter specific values while other questions require a freestyle type of response. Hopefully, adequate space has been allotted. If you need more space, please use the reverse side of the survey sheet with appropriate question number attached to your response.

If appropriate data are not available for any of the questions in the survey, please answer only Question 1 and return the survey by leaving the response to the remaining questions empty. Please be as complete as possible!

If you have any questions, please contact Thomas Jin by email at: tgjin2004@hotmail.com

Thank you for taking the time to complete this questionnaire!

QUESTIONAIRE

1. Contact Information

a. What state is response from?
b. contact person's information:

c. Survey completion date.: (Month / Day / 2008)

2. Truck Traffic Counting Method (Extent and Data Collection Equipment Type)

How many permanent traffic counting stations does the state have for the traffic counting methods listed below per highway functional class? Write in the number of count stations the state has in the appropriate blank cells. Please list the number of stations according to the type of data they can collect. When multiple data types are collected at one station, please include them in all the applicable cells. (If the state has special traffic counting methods other than the listed, please write them down in the blank cells below the video surveillance.)

Main Type	Data Types Collected	Highway Functional Class			
		Freeway	Major Arterial	Minor Arterial	Collectors
Inductive loop detectors	Volume				
	Vehicle Class				
	Vehicle Length				
	Occupancy				
	Density				
Acoustic sensors	Volume				
	Vehicle Class				
	Vehicle Length				
	Occupancy				
	Density				
Infrared sensors	Volume				
	Vehicle Class				
	Vehicle Length				
	Occupancy				
	Density				

Main Type	Data Types Collected	Highway Functional Class			
		Freeway	Major Arterial	Minor Arterial	Collectors
Radar/Microwave sensors	Volume				
	Vehicle Class				
	Vehicle Length				
	Occupancy				
	Density				
Video surveillance	Volume				
	Vehicle Class				
	Vehicle Length				
	Occupancy				
	Density				
Special Method 1 (please describe):	Volume				
	Vehicle Class				
	Vehicle Length				
	Occupancy				
	Density				
Special Method 2:	Volume				
	Vehicle Class				
	Vehicle Length				
	Occupancy				
	Density				
Special Method 3:	Volume				
	Vehicle Class				
	Vehicle Length				
	Occupancy				
	Density				
Special Method 4:	Volume				
	Vehicle Class				
	Vehicle Length				
	Occupancy				
	Density				

3. Evaluation Methodology of the Accuracy Level of Truck Traffic Data

a. Does the state have its own special evaluation method, which will help the engineer estimate the accuracy level of truck traffic counts?

Yes **No**

♣ If you answered “Yes” to question ‘a’, please describe the method in the box below, attach a copy of the method (a hard copy or an electronic copy), or direct us to its website. If you answered "No" to question 'a', please go to Question 4: Mechanistic-Empirical Pavement Design Guide and Comments. (If the state has special truck traffic accuracy evaluation methods other than the listed, please write them down in the blank cells below the electronic counting boards.)

Main Type	Data Types Collected	Highway Functional Class			
		Freeway	Major Arterial	Minor Arterial	Collectors
Tally sheets	Volume				
	Vehicle Class				
	Vehicle Length				
	Occupancy				
	Density				
Mechanical counting boards	Volume				
	Vehicle Class				
	Vehicle Length				
	Occupancy				
	Density				
Electronic counting boards	Volume				
	Vehicle Class				
	Vehicle Length				
	Occupancy				
	Density				
Special Method 1:	Volume				
	Vehicle Class				
	Vehicle Length				
	Occupancy				
	Density				
Special Method 2:	Volume				
	Vehicle Class				
	Vehicle Length				
	Occupancy				
	Density				
Special Method 3:	Volume				
	Vehicle Class				
	Vehicle Length				
	Occupancy				
	Density				

b. What's the state's targeted accuracy level of the truck traffic data? Please circle or highlight the one that is most close to the state's targeted accuracy level. (For example, the targeted accuracy level '95 %' means that the count is within the tolerance of the true value ninety five times out of one hundred truck traffic counts.)

Tolerance criterion: What is the state's tolerance criterion to call the truck traffic count "accurate"? Please circle one or add the exact value in the parentheses of answer 4).

1) ±5%of the true value, 2) ±7.5%of the true value, 3) ±10.0%of the true value,

4) ±( )%of the true value

Targeted Accuracy level: Please circle the closest one.

1) Over 97.5% 2) 95%-97.5% 3) 90%-95% 4) 85%-90% 5) Less 85%

c. Please describe how this target value is achieved.

d. How does the state collect ground truth truck traffic counts for evaluating the accuracy level of truck traffic counts? (Ground truth data are often measured by visual observation in the field or by videotaped traffic, which is analyzed in the laboratory or office.)

<table>
<tr><td>1) Ground truth data collection method</td><td colspan="4"></td></tr>
<tr><td>2) Data collection: level of aggregation (circle all that apply)</td><td colspan="4">a) By lane b) By direction
c) By link (both directions together)
d) Others ( )</td></tr>
<tr><td>3) Duration of ground truth data collection</td><td colspan="4">minutes</td></tr>
<tr><td rowspan="2"></td><td colspan="4">Highway Functional Class</td></tr>
<tr><td>Freeway</td><td>Major Arterial</td><td>Minor Arterial</td><td>Collectors</td></tr>
<tr><td>4) How many ground truth data collection stations does the state have?</td><td></td><td></td><td></td><td></td></tr>
<tr><td>5) The number of ground truth data collections by this method per year. (times/year/station)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>6) What's the actual accuracy level of truck traffic data if the state did an analysis of the accuracy level of truck traffic data?
(Please state in the parentheses the average variation from the true mean that you found)</td><td></td><td></td><td></td><td></td></tr>
</table>

e. What are the major contributing reasons that you found for resulting in the accuracy level lower than the state's targeted accuracy level?

4. Mechanistic-Empirical Pavement Design Guide and Comments

a. Has the state approved the use of the Mechanistic-Empirical Pavement Design Guide? Please circle your answer below. If you answered "Yes" to question 'a', please enter month and year when it was approved.

Yes **No** **Not now, but may be later**

If yes, in what year was it approved (Month /Year):

b. **Comments on Improving Data Quality and Traffic Operation Related to Truck Traffic.** Please write down three most serious problems encountered in the state related to maintaining truck traffic data accuracy at the targeted level that must be solved in order to improve the quality of truck traffic data and truck traffic operation.

Thank you for completing the survey!
Please return the completed survey by mail or e-mail to the address at the beginning of the survey.

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Appendix 2: Responses to the Best Practice Survey on Truck Traffic Count

Appendix 2-1 Contact Information

State or Province	Contact Person			Survey Date
	Name	Telephone	E-mail Address	
Virginia	Tom Schinkel	804-225-3123	Tom.schinkel@VDOT.Virginia.Gov	3/21/2008
South Dakota	Kenneth E. Marks	605-733-3336	Ken.Marks@state.sd.us	3/24/2008
Alberta Canada	Peter Kilburn	(780) 415-1359	peter.kilburn@gov.ab.ca	3/25/2008
Washington	John Rosen	360-570-2373	RosenJ@wsdot.wa.gov	4/4/2008
New Jersey	Louis C. Whiteley		Louis.Whiteley@dot.state.nj.us	4/8/2008
Georgia	Tim Christian	770-986-1434	tchristian@dot.ga.gov	4/9/2008
Tennessee	Mickey Phelps	615-532-3387	mickey.phelps@state.tn.us	4/10/2008
Pennsylvania	Andrea Bahoric	717-705-2382	abahoric@state.pa.us	3/26/2008
Iowa	Brian Carlson	515)239-1526	brian.carlson@dot.iowa.gov	4/7/2008
Michigan	Mike Walimaki	517-335-2914	walimakim@michigan.gov	4/5/2008
Maryland	Karl Hess	410-545-5523	khess@sha.state.md.us	4/15/2008
	Barry Balzanna	410-545-5509	bbalzanna@sha.state.md.us	
	Abhay Nigma	410-545-5506	anigam@sha.state.md.us	
Missouri	Mary Beth Anthony	573-751-3702	MaryBeth.Anthony@modot.mo.gov	4/15/2008
Texas	Catherine L. Wolff	512-486-5124	cwolff@dot.state.tx.us	4/15/2008
British Columbia	Gina Zak	1-250-356-9326	gina.zak@gov.bc.ca	4/18/2008
Maine	Deborah Morgan	207-624-3606	Deborah.Morgan@maine.gov	4/29/2008
Utah	Todd Hadden	801-865-4527	thadden@utah.gov	3/31/2009

Appendix 2-2 Truck Traffic Counting Method (Extent and Data Collection Equipment Type)

2.1 Virginia

Main Type	Data Types Collected	Highway Functional Class				Total	Special Comments
		F	MA	MI	C		
Inductive Loop Detectors (With Piezoelectric Sensor)	Volume	166	109	32	15	322	With Piezoelectric Sensor
	Vehicle Class	144	109	32	15	300	
	Vehicle length	160	109	32	15	316	
	Occupancy					0	
	Density	160	109	32	15	316	
	Total	630	436	128	60	1254	
Radar/Microwave Sensors	Volume	8				8	These sensors will produce volume by length; however, we are not satisfied with their performance and do not use it for that purpose.
	Vehicle Class					0	
	Vehicle length					0	
	Occupancy	8				8	
	Density	8				8	
	Total	24	0	0	0	24	
Total	Volume	174	109	32	15	330	
	Vehicle Class	144	109	32	15	300	
	Vehicle length	160	109	32	15	316	
	Occupancy	8	0	0	0	8	
	Density	168	109	32	15	324	
	Total	654	436	128	60	1278	

Note: F: Freeway, MA: Major Arterial, MI: Minor Arterial, C: collectors

2.2 South Dakota

Main Type	Data Types Collected	Highway Functional Class				Total
		F	MA	MI	C	
Inductive Loop Detectors	Volume	16	28	9	3	56
	Vehicle Class	8	13	3	0	24
	Vehicle length					0
	Occupancy					0
	Density					0
	Total	24	41	12	3	80
Total	Volume	16	28	9	3	56
	Vehicle Class	8	13	3	0	24
	Vehicle length	0	0	0	0	0
	Occupancy	0	0	0	0	0
	Density	0	0	0	0	0
	Total	24	41	12	3	80

2.3 Alberta, Canada

Main Type	Data Types Collected	Highway Functional Class				Total	Special Comments
		F	MA	MI	C		
Inductive Loop Detectors	Volume					369	We do not have ATRs identified by the highway functional class
	Vehicle Class						
	Vehicle length						
	Occupancy						
	Density						
	Total					369	
Special Method 1 (Manual Observation Intersection Turning Movement Studies)	Volume	2400				2400	2400+ Intersection
	Vehicle Class	2400				2400	2400+ we do not have vehicle counts identified by the functional class of highway
	Vehicle length						
	Occupancy						
	Density						
	Total						
Special Method 2 (Weigh In Motion)	Volume	6				6	
	Vehicle Class	6				6	
	Vehicle length	6				6	
	Occupancy					0	
	Density					0	
	Total	18				18	
Total	Volume	2406	0	2406	0	2775	
	Vehicle Class	2406	0	2406	0	2406	
	Vehicle length	6	0	6	0	6	
	Occupancy	0	0	0	0	0	
	Density	0	0	0	0	0	
	Total	4818	0	4818	0	18	

2.4 Washington

Main Type	Data Types Collected	Highway Functional Class				Total
		F	MA	MI	C	
Inductive Loop Detectors	Volume	4	3	0	7	14
	Vehicle Class	43	80	13	136	272
	Vehicle length	23	13	1	37	74
	Occupancy					0
	Density					0
	Total	70	96	14	180	360
Radar/Microwave Sensors	Volume		1		1	2
	Vehicle Class					0
	Vehicle length					0
	Occupancy					0
	Density					0
	Total	0	1	0	1	2
Total	Volume	4	4	0	8	16
	Vehicle Class	43	80	13	136	272
	Vehicle length	23	13	1	37	74
	Occupancy	0	0	0	0	0
	Density	0	0	0	0	0
	Total	70	97	14	181	362

2.5 New Jersey

Main Type	Data Types Collected	Highway Functional Class				Total
		F	MA	MI	C	
Inductive Loop Detectors	Volume	23	31	13	5	72
	Vehicle Class					0
	Vehicle length					0
	Occupancy					0
	Density					0
	Total	23	31	13	5	72
Special Method 1 (Weigh-In-Motion)	Volume	32	30	11	1	74
	Vehicle Class	32	30	11	1	74
	Vehicle length					0
	Occupancy					0
	Density					0
	Total	64	60	22	2	148
Total	Volume	55	61	24	6	146
	Vehicle Class	32	30	11	1	74
	Vehicle length	0	0	0	0	0
	Occupancy	0	0	0	0	0
	Density	0	0	0	0	0
	Total	87	91	35	7	220

2.6 Georgia

Main Type	Data Types Collected	Highway Functional Class				Total
		Freeway	Major Arterial	Minor Arterial	Collectors	
Inductive Loop Detectors	Volume	81	60	51		192
	Vehicle Class	54	44	36	42	176
	Vehicle length				30	30
	Occupancy					0
	Density					0
	Total	135	104	87	72	398
Special Method 1 (Short Term Traffic Counts)	Volume	604	5322	3760	878	10564
	Vehicle Class	150	1436	1015	183	2784
	Vehicle length					0
	Occupancy					0
	Density					0
	Total	754	6758	4775	1061	13348
Total	Volume	685	5382	3811	878	10756
	Vehicle Class	204	1480	1051	225	2960
	Vehicle length	0	0	0	30	30
	Occupancy	0	0	0	0	0
	Density	0	0	0	0	0
	Total	889	6862	4862	1133	13746

2.7 Tennessee

Main Type	Data Types Collected	Highway Functional Class				Total
		F	MA	MI	C	
Inductive Loop Detectors (Automatic Traffic Recorder)	Volume	10	8	10	5	33
	Vehicle Class					0
	Vehicle length					0
	Occupancy					0
	Density					0
	Total	10	8	10	5	33
Inductive Loop Detectors (Embedded Detector Loops)	Volume	17				17
	Vehicle Class	17				17
	Vehicle length	17				17
	Occupancy					0
	Density					0
	Total	51	0	0	0	51
Radar/Microwave Sensors	Volume	206				206
	Vehicle Class					0
	Vehicle length					0
	Occupancy	206				206
	Density					0
	Total	412	0	0	0	412
Total	Volume	233	8	10	5	256
	Vehicle Class	17	0	0	0	17
	Vehicle length	17	0	0	0	17
	Occupancy	206	0	0	0	206
	Density	0	0	0	0	0
	Total	473	8	10	5	496

2.8 Pennsylvania

Main Type	Data Types Collected	Highway Functional Class				Total
		F	MA	MI	C	
Inductive Loop Detectors	Volume	178	93	25	14	310
	Vehicle Class	11	7	2	0	20
	Vehicle length					0
	Occupancy					0
	Density					0
	Total	189	100	27	14	330
Total	Volume	178	93	25	14	310
	Vehicle Class	11	7	2	0	20
	Vehicle length	0	0	0	0	0
	Occupancy	0	0	0	0	0
	Density	0	0	0	0	0
	Total	189	100	27	14	330

2.9 Iowa

Main Type	Data Types Collected	Highway Functional Class				Total
		F	MA	MI	C	
Inductive Loop Detectors	Volume	2	3	3	3	11
	Vehicle Class	8	33	7	2	50
	Vehicle length	9	11	10	10	40
	Occupancy					0
	Density					0
	Total	19	47	20	15	101
Radar/Microwave Sensors	Volume	3	2			5
	Vehicle Class					0
	Vehicle length					0
	Occupancy					0
	Density					0
	Total	3	2	0	0	5
Total	Volume	5	5	3	3	16
	Vehicle Class	8	33	7	2	50
	Vehicle length	9	11	10	10	40
	Occupancy	0	0	0	0	0
	Density	0	0	0	0	0
	Total	22	49	20	15	106

2.10 Michigan

Main Type	Data Types Collected	Highway Functional Class				Total
		F	MA	MI	C	
Inductive Loop Detectors	Volume	64	56	7	1	128
	Vehicle Class	25	20	2		47
	Vehicle length					0
	Occupancy					0
	Density					0
	Total	89	76	9	1	175
Total	Volume	64	56	7	1	128
	Vehicle Class	25	20	2	0	47
	Vehicle length	0	0	0	0	0
	Occupancy	0	0	0	0	0
	Density	0	0	0	0	0
	Total	89	76	9	1	175

2.11 Maryland

Main Type	Data Types Collected	Highway Functional Class				Total
		F	MA	MI	C	
Inductive Loop Detectors	Volume	7	3	3	0	13
	Vehicle Class	9	8	1	0	18
	Vehicle length	22	12	1	2	37
	Occupancy					0
	Density					0
	Total	38	23	5	2	68
Total	Volume	7	3	3	0	13
	Vehicle Class	9	8	1	0	18
	Vehicle length	22	12	1	2	37
	Occupancy	0	0	0	0	0
	Density	0	0	0	0	0
	Total	38	23	5	2	68

2.12 Missouri

Main Type	Data Types Collected	Highway Functional Class				Total
		F	MA	MI	C	
Inductive Loop Detectors	Volume	6	27	11	3	47
	Vehicle Class	4	18	8	2	32
	Vehicle length	4	18	8	2	32
	Occupancy					0
	Density					0
	Total	14	63	27	7	111
Radar/Microwave Sensors	Volume	2	3			5
	Vehicle Class	2	1			3
	Vehicle length	2	1			3
	Occupancy					0
	Density					0
	Total	6	5	0	0	11
Total	Volume	8	30	11	3	52
	Vehicle Class	6	19	8	2	35
	Vehicle length	6	19	8	2	35
	Occupancy	0	0	0	0	0
	Density	0	0	0	0	0
	Total	20	68	27	7	122

2.13 Texas

Main Type	Data Types Collected	Highway Functional Class				Total
		F	MA	MI	C	
Inductive Loop Detectors	Volume	98	42	30	35	205
	Vehicle Class					0
	Vehicle length					0
	Occupancy					0
	Density					0
	Total	98	42	30	35	205
Total	Volume	98	42	30	35	205
	Vehicle Class	0	0	0	0	0
	Vehicle length	0	0	0	0	0
	Occupancy	0	0	0	0	0
	Density	0	0	0	0	0
	Total	98	42	30	35	205

2.14 British Columbia, Canada

Main Type	Data Types Collected	Highway Functional Class				Total
		F	MA	MI	C	
Inductive Loop Detectors	Volume	80		16		96
	Vehicle Class					0
	Vehicle length	59		4		63
	Occupancy					0
	Density					0
	Total	139	0	20	0	159
Special Method 1: Piezoelectric sensors in conjunction with loops (loop-piezo-loop-piezo) at weigh-in-motion station	Volume	5				5
	Vehicle Class	5				5
	Vehicle length	5				5
	Occupancy					0
	Density					0
	Total	15	0	0	0	15
Total	Volume	85	0	16	0	101
	Vehicle Class	5	0	0	0	5
	Vehicle length	64	0	4	0	68
	Occupancy	0	0	0	0	0
	Density	0	0	0	0	0
	Total	154	0	20	0	174

2.15 Maine

Main Type	Data Types Collected	Highway Functional Class				Total
		F	MA	MI	C	
Inductive Loop Detectors	Volume	11	21	16	16	64
	Vehicle Class					0
	Vehicle length					0
	Occupancy					0
	Density					0
	Total	11	21	16	16	64
Special Method 1: Piezo electric sensors	Volume					0
	Vehicle Class	2	4	7	2	15
	Vehicle length					0
	Occupancy					0
	Density					0
	Total	2	4	7	2	15
Total	Volume	11	21	16	16	64
	Vehicle Class	2	4	7	2	15
	Vehicle length	0	0	0	0	0
	Occupancy	0	0	0	0	0
	Density	0	0	0	0	0
	Total	13	25	23	18	79

2.16 Utah

Main Type	Data Types Collected	Highway Functional Class				Total
		F	MA	MI	C	
Inductive Loop Detectors	Volume	1	12	3	0	16
	Vehicle Class	0	1	1	0	2
	Vehicle length	29	29	18	0	76
	Occupancy	0	0	0	0	0
	Density	0	0	0	0	0
	Total	30	42	22	0	94
Radar/Microwave Sensors	Volume	0	0	0	0	0
	Vehicle Class	0	0	0	0	0
	Vehicle length	1	0	0	0	1
	Occupancy	0	0	0	0	0
	Density	0	0	0	0	0
	Total	1	0	0	0	1
Total	Volume	1	12	3	0	16
	Vehicle Class	0	1	1	0	2
	Vehicle length	30	29	18	0	77
	Occupancy	0	0	0	0	0
	Density	0	0	0	0	0
	Total	31	42	22	0	95

Appendix 2-3 Methodology Used for Evaluating Accuracy Level of Truck Data

3.1 Existence of Special Evaluation Method

3.1.1 Virginia:	No
3.1.2 South Dakota:	Not Response
3.1.3 Alberta, Canada:	No
3.1.4 Washington	Yes

Main Type	Data Types Collected	Highway Functional Class				Total
		Fr	MA	MI	C	
Electronic Counting Boards	Volume					0
	Vehicle Class	1				1
	Vehicle length					0
	Occupancy					0
	Density					0
	Total	1	0	0	0	1
Total	Volume	0	0	0	0	0
	Vehicle Class	1	0	0	0	1
	Vehicle length	0	0	0	0	0
	Occupancy	0	0	0	0	0
	Density	0	0	0	0	0
	Total	1	0	0	0	1

3.1.5 New Jersey:	No
3.1.6 Georgia:	Yes, but not answer special answer
3.1.7 Tennessee:	No
3.1.8 Pennsylvania:	No
3.1.9 Iowa:	No
3.1.10 Michigan:	No
3.1.11 Maryland:	Yes, but not answer special answer
3.1.12 Missouri:	No
3.1.13 Texas:	Yes

Main Type	Data Types Collected	Highway Functional Class				Total
		F	MA	MI	C	
Mechanical Counting Boards	Volume					0
	Vehicle Class	*	*	*	*	0
	Vehicle length					0
	Occupancy					0
	Density					0
	Total	0	0	0	0	0

3.1.14 British Columbia, Canada:	No
3.1.15 Maine	No
3.1.16 Utah	No

3.2 Targeted accuracy level of the truck counts

3.2.1. Tolerance Criterion

3.2.1.1 Virginia:	4) ± (5)% of the true value
3.2.1.2 South Dakota:	No Answer
3.2.1.3 Alberta, Canada:	No Answer
3.2.1.4 Washington	1) ± 5% of the true value
3.2.1.5 New Jersey:	1) ± 5% of the true value
3.2.1.6 Georgia:	3) ± 10.0% of the true value
3.2.1.7 Tennessee:	No Answer
3.2.1.8 Pennsylvania:	No Answer
3.2.1.9 Iowa:	3) ± 10.0% of the true value
3.2.1.10 Michigan:	No Answer
3.2.1.11 Maryland:	1) ± 5% of the true value
3.2.1.12 Missouri:	No Answer
3.2.1.13 Texas:	3) ± 10.0% of the true value
3.2.1.14 British Columbia, Canada:	No Answer
3.2.1.15 Maine	No Answer
3.2.1.16 Utah	1) ± 5% of the true value

3.2.2. Targeted Accuracy Level

3.2.2.1 Virginia:	No Answer
3.2.2.2 South Dakota:	No Answer
3.2.2.3 Alberta, Canada:	No Answer
3.2.2.4 Washington	1) Over 97.5%
3.2.2.5 New Jersey:	3) 90%-95%
3.2.2.6 Georgia:	3) 90%-95%
3.2.2.7 Tennessee:	No Answer
3.2.2.8 Pennsylvania:	No Answer
3.2.2.9 Iowa:	4) 85%-90%
3.2.2.10 Michigan:	No Answer
3.2.2.11 Maryland:	4) 85%-90%
3.2.1.12 Missouri:	No Answer
3.2.1.13 Texas:	3) 90%-95%
3.2.1.14 British Columbia, Canada:	No Answer
3.2.1.15 Maine	2) 95%-97.5%
3.2.1.16 Utah	2) 95%

3.3 Description of the Method to Achieve the Target Value

3.3.1 Virginia:	Through a quality traffic data collection program.
3.3.2 South Dakota:	No Answer
3.3.3 Alberta, Canada:	N/A
3.3.4 Washington	- Physical site evaluation - Manual count compared to collector count
3.3.5 New Jersey:	It is a target – it may not always be achieved. All continuous classification data is from weigh-in-motion systems. Tolerances and accuracy are applied to truck weights.
3.3.6 Georgia:	In the case of portable truck data collected with road tubes, it's difficult to assess the accuracy of the truck data. We are still in the "assessment phase" right now and we feel that it's fair to say that accuracy varies widely depending on the type of facility being sampled. Where possible, we do compare our portable truck traffic with "known" ATR truck data. We probably have not done enough sampling on enough facility types to accurately state the accuracy (at this point). In the future, we will perform more sampling and analysis so we will be able to more accurately determine the level of accuracy of our truck data.
3.3.7 Tennessee:	No Answer
3.3.8 Pennsylvania:	No Answer
3.3.9 Iowa:	Adjust sensor calibration and spacing lengths in program of count units
3.3.10 Michigan:	No Answer
3.3.11 Maryland:	- To collect classification data, the ATRs in the state of Maryland uses loop piezo loop sensor - MDSHA performs speed verification on all our ATRs on a periodic basis using a Laser radar gun. The technicians, if required, adjust the sensitivity of the sensors and the distance between them within the ATR controller. This helps improve the quality of the data from the ATR. - On a bi-annual basis, we perform portable counts at all the ATR locations, comparing the data on a lane by lane basis. Using this data, we are able to identify any discrepancy in lanes or any other sensor issues.
3.3.12 Missouri:	No Answer
3.3.13 Texas:	Classification data is regularly screened and compared with previous years' counts.
3.3.14 British Columbia, Canada:	No Answer
3.3.15 Maine	Currently not able to meet this level – now achieving 90%-95%.
3.3.16 Utah	No Answer

3.4 Ground Truth Data Collection Method

3.4.1 Method

3.4.1.1 Virginia:	No Answer
3.4.1.2 South Dakota:	No Answer
3.4.1.3 Alberta, Canada:	No Answer
3.4.1.4 Washington	Manual count by visual observation
3.4.1.5 New Jersey:	Weights during annual or biennial calibration, class by observation during calibration.
3.4.1.6 Georgia:	On a limited basis, we use video tapes to measure and QC traffic data
3.4.1.7 Tennessee:	No Answer
3.4.1.8 Pennsylvania:	No Answer
3.4.1.9 Iowa:	Visual observation
3.4.1.10 Michigan:	No Answer
3.4.1.11 Maryland:	Manual verification & portable counts
3.4.1.12 Missouri:	No Answer
3.4.1.13 Texas:	No Answer
3.4.1.14 British Columbia, Canada:	No Answer
3.4.1.15 Maine	For permanent site only: by visual observation
3.4.1.16 Utah	Visual counts

3.4.2 Data Collection: Level of Aggregation

3.4.2.1 Virginia:	a) By Lane
3.4.2.2 South Dakota:	No Answer
3.4.2.3 Alberta, Canada:	No Answer
3.4.2.4 Washington	a) By Lane and b) By Direction
3.4.2.5 New Jersey:	a) By Lane
3.4.2.6 Georgia:	b) By Direction and c) By Link (Both directions together)
3.4.2.7 Tennessee:	No Answer
3.4.2.8 Pennsylvania:	No Answer
3.4.2.9 Iowa:	a) By Lane
3.4.2.10 Michigan:	No Answer
3.4.2.11 Maryland:	a) By Lane
3.4.2.12 Missouri:	No Answer
3.4.2.13 Texas:	b) By Direction
3.4.2.14 British Columbia, Canada:	No Answer
3.4.2.15 Maine	b) By Direction
3.4.2.16 Utah	a) By Lane

3.4.3 Duration of Ground Truth Data Collection

3.4.3.1 Virginia:	No Answer
3.4.3.2 South Dakota:	No Answer
3.4.3.3 Alberta, Canada:	N/A
3.4.3.4 Washington	180 minutes
3.4.3.5 New Jersey:	Several Hours
3.4.3.6 Georgia:	No Answer
3.4.3.7 Tennessee:	No Answer
3.4.3.8 Pennsylvania:	No Answer
3.4.3.9 Iowa:	240 minutes
3.4.3.10 Michigan:	No Answer
3.4.3.11 Maryland:	48 hours portable count
3.4.3.12 Missouri:	No Answer
3.4.3.13 Texas:	1440 minutes
3.4.3.14 British Columbia, Canada:	No Answer
3.4.3.15 Maine	240-360 minutes
3.4.3.16 Utah	60 minutes

3.4.4 The Number of Ground Truth Data Collection Stations

3.4.4.1 Virginia: No Answer
3.4.4.2 South Dakota: No Answer
3.4.4.3 Alberta, Canada: No Answer
3.4.4.4 Washington No Answer
3.4.4.5 New Jersey: No Answer
3.4.4.6 Georgia:

F	MA	MI	C
less than 10	less than 5	n/a	n/a

3.4.4.7 Tennessee: No Answer
3.4.4.8 Pennsylvania: No Answer
3.4.4.9 Iowa:

F	MA	MI	C
17	44	17	12

3.4.4.10 Michigan: No Answer
3.4.4.11 Maryland: We do portable verification counts at each of the ATR location
3.4.4.12 Missouri: No Answer
3.4.4.13 Texas:

F	MA	MI	C	Total
*	*	*	*	640

3.4.4.14 British Columbia, Canada: No Answer
3.4.4.15 Maine

F	MA	MI	C
2	4	7	2

3.4.4.16 Utah No Answer

3.4.5 The Number of Ground Truth Data Collection Stations by the method per year (times/year/station)

3.4.5.1 Virginia: No Answer

3.4.5.2 South Dakota: No Answer

3.4.5.3 Alberta, Canada: No Answer

3.4.5.4 Washington No Answer

3.4.5.5 New Jersey: No Answer

3.4.5.6 Georgia:

F	MA	MI	C
Less than 10	Less than 5	n/a	n/a

3.4.5.7 Tennessee: No Answer

3.4.5.8 Pennsylvania: No Answer

3.4.5.9 Iowa:

F	MA	MI	C
Once every 3 years	Once every 3 years	Once every 3 years	Once every 3 years

3.4.5.10 Michigan: No Answer

3.4.5.11 Maryland: No Answer

3.4.5.12 Missouri: No Answer

3.4.5.13 Texas:

F	MA	MI	C
1	1	1	1

3.4.5.14 British Columbia, Canada: No Answer

3.4.5.15 Maine

F	MA	MI	C
3	3	3	3

3.4.5.16 Utah No Answer

3.4.6 The Actual Accuracy Level of Truck Traffic Data

3.4.6.1 Virginia: No Answer

3.4.6.2 South Dakota: No Answer

3.4.6.3 Alberta, Canada: No Answer

3.4.6.4 Washington No Answer

3.4.6.5 New Jersey: No Answer

3.4.6.6 Georgia:

F	MA	MI	C
90-95%	90-95%	n/a	n/a

3.4.6.7 Tennessee: No Answer

3.4.6.8 Pennsylvania: No Answer

3.4.6.9 Iowa: N/A

3.4.6.10 Michigan: No Answer

3.4.6.11 Maryland: We have not performed an accuracy level of truck traffic data analysis, but we strive for $\pm$5% of true value.

3.4.6.12 Missouri: No Answer

3.4.6.13 Texas: No Answer

3.4.6.14 British Columbia, Canada: No Answer

3.4.6.15 Maine Have not completed an analysis at this time

3.4.6.16 Utah 95%, we strive for non biased data, and how that the error rate decreased with large sample size.

3.5 Major Contributing Reasons for Lessening the Accuracy Level

3.5.1 Virginia:	No Answer
3.5.2 South Dakota:	No Answer
3.5.3 Alberta, Canada:	N/A
3.5.4 Washington	Manual count by visual observation
3.5.5 New Jersey:	Partial failure of sensor array; failed temperature sensor; incorrect algorithm.
3.5.6 Georgia:	In the case of video tapes, human error reviewing video tapes will always be an issue. With respect to the level of accuracy, we set our accuracy levels to be more like goals so they will be difficult to achieve.
3.5.7 Tennessee:	No Answer
3.5.8 Pennsylvania:	No Answer
3.5.9 Iowa:	Sensor calibration off or distance between sensors not accurate to the programmed distance
3.5.10 Michigan:	No Answer
3.5.11 Maryland:	The major contributing reasons are the pavement conditions, sensor instillation, ATR counter
3.5.12 Missouri:	No Answer
3.5.13 Texas:	No Answer
3.5.14 British Columbia, Canada:	No Answer
3.5.15 Maine	- The limitations of the existing data collection equipment. - The cost of new technologies is a problem considering the state financial situation. - The state workforce continues to shrink as government spending in cut.
3.5.16 Utah	- Wrong loop distance, faulty and failed wires - The greatest problem we have is congestion and we go through the data collection and take out data that shows signs of congestion and faulty wires.

Appendix 2-4 Mechanistic-Empirical Pavement Design Guide and Comments

4.1 The Use of M-E PDG

4.1.1 Virginia:	No
4.1.2 South Dakota:	No
4.1.3 Alberta, Canada:	Not now, but may be later
4.1.4 Washington	No Answer
4.1.5 New Jersey:	Not now, but may be later
4.1.6 Georgia:	Not now, but may be later
4.1.7 Tennessee:	No
4.1.8 Pennsylvania:	Not now, but may be later
4.1.9 Iowa:	Yes (Aug/2005)
4.1.10 Michigan:	No Answer
4.1.11 Maryland:	No
4.1.12 Missouri:	Yes (Sep/2006)
4.1.13 Texas:	Not now, but may be later
4.1.14 British Columbia, Canada:	No
4.1.15 Maine	Not now, but may be later
4.1.16 Utah	Yes (2007)

4.2 Comments on Improving Data Quality and Traffic Operation Related to Truck Traffic

4.2.1 Virginia:	We need a quality piezoelectric sensor that will last when installed in the pavement. Our inductance loops are installed at a depth of 4 inches, which allows them to survive most routine milling and paving operations. However the piezoelectric sensors are installed near the surface and do not survive the same operations.
4.2.2 South Dakota:	No Answer
4.2.3 Alberta, Canada:	For the M-E PDG, we intend to expand our weigh in Motion program. Weigh in motion is the only cost effective way to capture the load spectra required for the M-EPDG. Currently, we are having a university student review the calibration verification data we have for our 6 WIM sites. If the accuracy of the WIMs is good enough for the M-E PDG, then we will expand the number of WIM sites
4.2.4 Washington	- Good site Installation is a key factor to having quality WIM Data –Site installed in poor location –We are in process to correcting this issue - Annual Calibration is another key task to good WIM Data –Not having annual Calibration –We are now doing this. - Preventive maintenance is key to the amount of available data –Not having a preventive
4.2.5 New Jersey:	1) Equipment issues (hardware and software) 2) Inconsistent traffic flow 3) 3. Sensor failure and pavement deterioration

4.2.6 Georgia:	- Classifying trucks in high volume/congested areas is a big challenge at Georgia DOT. We find that the equipment classifies vehicles with a lot more accuracy in rural areas than in congested areas such as Atlanta's urban freeways and arterials. - - With respect to collecting WIM data, The condition of the pavement has to be taken into consideration when installing Class I WIM sensors. Rigid concrete pavement is preferred as opposed to flexible asphalt pavement which is subject to rutting. Any rutting in the pavement preceding the installed sensor(s) can result in excessive vibration and consequent degradation of the integrity of collected vehicle weight data. The installation of quartz piezoelectric WIM sensors can further improve the accuracy of collected weight data, but the higher costs of adding these sensors can make their usage cost prohibitive
4.2.7 Tennessee:	1) Our Automatic Traffic Recorders (ATRs) only count classification by length and not by axle. 2) Road Weather Information System (RWIS): Equipment will only collect and report 3 classes – Passenger Cars, Single-unit Trucks & Multi-unit Trucks 3) 3) Obtaining software that will properly work with our traffic counters to accurately record traffic data
4.2.8 Pennsylvania:	1) Maintaining permanent classification traffic sites 2) Insufficient resources to ensure the accuracy level of truck data collection 3) 3. Limited funding for the installation/maintenance of additional classification/weight sites
4.2.9 Iowa:	No Answer
4.2.10 Michigan:	There should be efforts by the industry to create improved life and consistency of sensors.
4.2.11 Maryland:	No Answer
4.2.12 Missouri:	- Construction - Length based classification – data integrity - Maintaining consistent data as technology advances
4.2.13 Texas:	1) Pavement type or condition for permanent sites. 2) Free-flowing versus congestion conditions. 3) Adequate number of class sites across all functional roadway categories (for example, limited availability of utilities adversely impacts site selection)
4.2.14 British Columbia, Canada:	1) Length data is not enough to differentiate 100% between passenger vehicles and trucks – one length bin needs to be evaluated with regards to how much of the traffic is trucks 2) Classification data is more expensive than length data and traffic behavior at sites of interest (specifically standing traffic near border crossings or during periods of congestion) negatively impacts the quality of the data 3) Confirming the incoming data stream against ground truth can be expensive
4.2.15 Maine	Current technology cannot accurately classify truck traffic in slow moving or stop-and-go urban traffic.
4.2.16 Utah	No Answer

Appendix 2-5 Other Comments

5.1 Virginia:	The survey seemed weighted towards determining verification steps for truck data collection in the field. While in Virginia we do validate performance in the field when the stations are set-up and whenever the data indicates there may be an issue, we place a significant effort on letting office data analysis (daily automated checks and manual review) help us achieve a quality data product. We have a custom twenty-one bin vehicle class table that helps us predict sensor failure, ultimately resulting in higher quality data. The survey addressed permanent equipment only and not short-term counts. Should there interest, in Virginia we have about 6,200 locations where we collect classification data in our coverage count (48 hour counts) program. For the most part, these are collected with road tubes. We have several quality assurance steps in place to ensure a quality data result, most notably a tightly defined class table that can separate two tail gaiting cars (most commonly used traffic counters will record this as one truck) and classify them correctly as two cars. Data from these traffic counts are used to create truck % estimates. Recognizing that a short-term count for truck estimation can have issues where trucks may be seasonal, planners and engineers have the option to request additional traffic counts if desired for a specific project.
5.2 Washington	The Arlington NB spreadsheet is an example of our WIM Calibration procedures used at each site using a truck of known weight, axle spacing and varying speeds.
5.3 New Jersey	- Attached is New Jersey's response to your survey regarding classification data. - We assume you saw the WIM Handbook at: www.ctre.iastate.edu/research/wim_pdf/Wimsummary.htm

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Appendix 3: UDOT-UTA-BYU Trucking Company Survey Form

UDOT·UTA·BYU Trucking Company Survey

Brigham Young University (BYU) is conducting a study on the accuracy level of truck traffic data on state highways on behalf of the Utah Department of Transportation (UDOT). With the help of Utah Trucking Association (UTA), UDOT is hoping to gather the most update information on commodity flow patterns in Utah.

1. Company Information (Information on origin)

a.	Company name			
b.	Truck carrier type of your company (circle one or more that apply)	Over-the-road carrier Less-than-truckload (LTL) carrier, Special freight carrier (Flatbed, Tanker, etc.) Private carrier		
c.	Contact person	Name: Phone: E-mail:		
d.	Company location (address with ZIP code)			
e.	Main terminal location (address with ZIP code)			
f.	Major commodities carried (in the order of highest tonnage, if possible)			
g.	Number of trucks	Small trucks (Straight/Setp Van)	Large trucks (48-ft to 53-ft Trailers)	Large trucks (Double and Triple Trailers)
		vehicles	vehicles	vehicles
h.	Annual total tonnage of commodities carried	tons/year		

2. Commodity Flow Patterns (Information on destinations)

a.	Peak operation time (example: 10:00 PM – 2:00 AM)		
b.	Percentage of trucks operating during the peak time? (If applicable, for example, gravel hauler, parcel delivery, etc.)		%
c.	Top three destinations (including point of origin) and primary points of access to national highway system (that is, primary points of access to main freight routes) Example: Salt Lake City (Exit 72) to St. George (Exit 5) via I-15	1st City/State	
		2nd City/State	
		3rd City/State	

Thank you for completing the survey! Please drop the completed survey at the UDOT booth. Or, please return to the completed survey to Dr. Saito by fax (801-422-0159), or to his research assistant (Thomas Jin) by e-mail (tgjin2004@hotmail.com) if you want to fill in later.

COMPANY INFORMATION WILL BE KEPT CONFIDENTIAL.

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Appendix 4: ATR Station Traffic Data and Ground Truth Traffic Data

Appendix 4-1 Sorted Ground Truth Data and ATR Station Traffic Data with Error Rate

	Satation	Route	M.P.	Collection Type	Direction	Time	First Date	Second Date		First Traffic Volume by Length					
										16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
1	306	I-15	269.xx	Length (Loops)	North	3:00-4:00PM	2008-05-30	2008-06-20	Ground Truth	3497	41	256	134	19	3947
									ATR Count	2944	779	147	142	31	4043
									Difference	-553	738	-109	8	12	96
									Error Rate	**-0.1581**	**18.0000**	**-0.4258**	**0.0597**	**0.6316**	**0.0243**
2	307	I-84	92.53	Length (Loops)	West	1:00-2:00PM	2008-05-13	2008-05-20	Ground Truth	235	4	48	68	14	369
									ATR Count	185	75	25	67	17	369
									Difference	-50	71	-23	-1	3	0
									Error Rate	**-0.2128**	**17.7500**	**-0.4792**	**-0.0147**	**0.2143**	**0.0000**
3	310	I-15	389.xx	Length (Loops)	South	8:00-9:00AM	2008-05-14	2008-06-11	Ground Truth	110	1	20	48	11	190
									ATR Count	108	11	18	36	18	191
									Difference	-2	10	-2	-12	7	1
									Error Rate	**-0.0182**	**10.0000**	**-0.1000**	**-0.2500**	**0.6364**	**0.0053**
4	316	89	403.xx	Length (Loops)	South	11:00-12:00PM	2008-05-13	2008-05-20	Ground Truth	849	16	56	18	9	948
									ATR Count	577	292	35	20	10	934
									Difference	-272	276	-21	2	1	-14
									Error Rate	**-0.3204**	**17.2500**	**-0.3750**	**0.1111**	**0.1111**	**-0.0148**
5	318	I-80	161.46	Length (Loops)	West	3:00-4:00PM	2008-05-06	2008-06-10	Ground Truth	220	1	38	74	4	337
									ATR Count	173	69	21	72	9	344
									Difference	-47	68	-17	-2	5	7
									Error Rate	**-0.2136**	**68.0000**	**-0.4474**	**-0.0270**	**1.2500**	**0.0208**
6	320	39	13.xx	Length (Loops)	West	3:00-4:00PM	2008-05-13	2008-05-20	Ground Truth	211	3	20	4	0	238
									ATR Count	132	98	9	5	0	244
									Difference	-79	95	-11	1	0	6
									Error Rate	**-0.3744**	**31.6667**	**-0.5500**	**0.2500**	**#DIV/0!**	**0.0252**
7	321	6	149.xx	Length (Loops)	East	3:00-4:00PM	2008-05-05	2008-06-09	Ground Truth	24	0	8	2	1	35
									ATR Count	20	5	6	3	1	35
									Difference	-4	5	-2	1	0	0
									Error Rate	**-0.1667**	**#DIV/0!**	**-0.2500**	**0.5000**	**0.0000**	**0.0000**
8	323	I-80	68.xx	Length (Loops)	West	10:00-11:00AM	2008-07-11	2008-07-18	Ground Truth	173	0	22	41	9	245
									ATR Count	168	15	15	36	19	253
									Difference	-5	15	-7	-5	10	8
									Error Rate	**-0.0289**	**#DIV/0!**	**-0.3182**	**-0.1220**	**1.1111**	**0.0327**
9	349	I-15	246.xx	Length (Loops)	South	10:00-11:00AM	2008-04-10	2008-05-08	Ground Truth	408	140	55	139	5	747
									ATR Count	537	150	36	120	44	887
									Difference	129	10	-19	-19	39	140
									Error Rate	**0.3162**	**0.0714**	**-0.3455**	**-0.1367**	**7.8000**	**0.1874**
10	350	189	5.xx	Length (Loops)	North	9:00-10:00AM	3008-05-30	2008-06-20	Ground Truth	1038	9	28	1	0	1076
									ATR Count	939	100	9	2	8	1058
									Difference	-99	91	-19	1	8	-18
									Error Rate	**-0.0954**	**10.1111**	**-0.6786**	**1.0000**	**#DIV/0!**	**-0.0167**
11	363	91	19.55	Length (Loops)	South	12:00-1:00PM	2008-05-14	2008-06-11	Ground Truth	437	10	42	19	1	509
									ATR Count	447	29	19	14	2	511
									Difference	10	19	-23	-5	1	2
									Error Rate	**0.0229**	**1.9000**	**-0.5476**	**-0.2632**	**1.0000**	**0.0039**

	Satation	Route	M.P.	Collection Type	Direction	Time	First Date	Second Date		Second Traffic Volume by Length					
										16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
1	306	I-15	269.xx	Length (Loops)	North	3:00-4:00PM	2008-05-30	2008-06-20	Ground Truth	3467	29	289	147	21	3953
									ATR Count	2582	582	143	163	38	3508
									Difference	-885	553	-146	16	17	-445
									Error Rate	**-0.2553**	**19.0690**	**-0.5052**	**0.1088**	**0.8095**	**-0.1126**
2	307	I-84	92.53	Length (Loops)	West	1:00-2:00PM	2008-05-13	2008-05-20	Ground Truth	260	5	40	49	13	367
									ATR Count	183	100	23	50	20	376
									Difference	-77	95	-17	1	7	9
									Error Rate	**-0.2962**	**19.0000**	**-0.4250**	**0.0204**	**0.5385**	**0.0245**
3	310	I-15	389.xx	Length (Loops)	South	8:00-9:00AM	2008-05-14	2008-06-11	Ground Truth	113	1	12	43	5	174
									ATR Count	111	16	6	35	16	184
									Difference	-2	15	-6	-8	11	10
									Error Rate	**-0.0177**	**15.0000**	**-0.5000**	**-0.1860**	**2.2000**	**0.0575**
4	316	89	403.xx	Length (Loops)	South	11:00-12:00PM	2008-05-13	2008-05-20	Ground Truth	844	23	61	16	7	951
									ATR Count	671	227	32	15	6	951
									Difference	-173	204	-29	-1	-1	0
									Error Rate	**-0.2050**	**8.8696**	**-0.4754**	**-0.0625**	**-0.1429**	**0.0000**
5	318	I-80	161.46	Length (Loops)	West	3:00-4:00PM	2008-05-06	2008-06-10	Ground Truth	312	7	57	100	5	481
									ATR Count	270	81	21	103	9	484
									Difference	-42	74	-36	3	4	3
									Error Rate	**-0.1346**	**10.5714**	**-0.6316**	**0.0300**	**0.8000**	**0.0062**
6	320	39	13.xx	Length (Loops)	West	3:00-4:00PM	2008-05-13	2008-05-20	Ground Truth	218	8	26	5	0	257
									ATR Count	113	120	15	6	0	254
									Difference	-105	112	-11	1	0	-3
									Error Rate	**-0.4817**	**14.0000**	**-0.4231**	**0.2000**	**#DIV/0!**	**-0.0117**
7	321	6	149.xx	Length (Loops)	East	3:00-4:00PM	2008-05-05	2008-06-09	Ground Truth	33	1	5	0	0	39
									ATR Count	29	8	1	0	0	38
									Difference	-4	7	-4	0	0	-1
									Error Rate	**-0.1212**	**7.0000**	**-0.8000**	**#DIV/0!**	**#DIV/0!**	**-0.0256**
8	323	I-80	68.xx	Length (Loops)	West	10:00-11:00AM	2008-07-11	2008-07-18	Ground Truth	143	3	29	56	8	239
									ATR Count	140	20	18	56	16	250
									Difference	-3	17	-11	0	8	11
									Error Rate	**-0.0210**	**5.6667**	**-0.3793**	**0.0000**	**1.0000**	**0.0460**
9	349	I-15	246.xx	Length (Loops)	South	10:00-11:00AM	2008-04-10	2008-05-08	Ground Truth	620	12	75	122	23	852
									ATR Count	521	146	46	123	27	863
									Difference	-99	134	-29	1	4	11
									Error Rate	**-0.1597**	**11.1667**	**-0.3867**	**0.0082**	**0.1739**	**0.0129**
10	350	189	5.xx	Length (Loops)	North	9:00-10:00AM	3008-05-30	2008-06-20	Ground Truth	920	11	46	7	0	984
									ATR Count	865	67	23	8	7	970
									Difference	-55	56	-23	1	7	-14
									Error Rate	**-0.0598**	**5.0909**	**-0.5000**	**0.1429**	**#DIV/0!**	**-0.0142**
11	363	91	19.55	Length (Loops)	South	12:00-1:00PM	2008-05-14	2008-06-11	Ground Truth	545	7	48	33	1	634
									ATR Count	558	32	23	23	5	641
									Difference	13	25	-25	-10	4	7
									Error Rate	**0.0239**	**3.5714**	**-0.5208**	**-0.3030**	**4.0000**	**0.0110**

	Satation	Route	M.P.	Collection Type	Direction	Time	First Date	Second Date		First Traffic Volume by Length					
										16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
12	401	I-15	22.xx	Length (Loops)	South	6:00-7:00PM	2008-06-16	2008-06-23	Ground Truth	417	3	36	109	5	570
									ATR Count	421	39	25	90	17	592
									Difference	4	36	-11	-19	12	22
									Error Rate	**0.0096**	**12.0000**	**-0.3056**	**-0.1743**	**2.4000**	**0.0386**
13	403	I-15	112.xx	Length (Loops)	North	11:00-12:00PM	2008-06-16	2008-06-23	Ground Truth	384	0	59	50	6	499
									ATR Count	364	27	39	53	6	489
									Difference	-20	27	-20	3	0	-10
									Error Rate	**-0.0521**	**#DIV/0!**	**-0.3390**	**0.0600**	**0.0000**	**-0.02004**
14	404	I-70	156.xx	Length (Loops)	West	7:00-8:00AM	2008-06-18	2008-06-25	Ground Truth	51	0	23	28	2	104
									ATR Count	39	20	13	27	4	103
									Difference	-12	20	-10	-1	2	-1
									Error Rate	**-0.2353**	**#DIV/0!**	**-0.4348**	**-0.0357**	**1.0000**	**-0.0096**
15	405	21	104.xx	Length (Loops)	East	1:00-2:00PM	2008-06-16	2008-06-23	Ground Truth	47	0	4	1	2	54
									ATR Count	41	6	2	2	2	53
									Difference	-6	6	-2	1	0	-1
									Error Rate	**-0.1277**	**#DIV/0!**	**-0.5000**	**1.0000**	**0.0000**	**-0.0185**
16	411	89	54.xx	Length (Loops)	West	9:00-10:00AM	2008-06-17	2008-06-24	Ground Truth	51	4	14	5	1	75
									ATR Count	41	14	2	11	7	75
									Difference	-10	10	-12	6	6	0
									Error Rate	**-0.1961**	**2.5000**	**-0.8571**	**1.2000**	**6.0000**	**0.0000**
17	412	11	0.xx	Length (Loops)	North	7:00-8:00AM	2008-06-17	2008-06-24	Ground Truth	109	3	15	0	4	131
									ATR Count	58	53	10	0	5	126
									Difference	-51	50	-5	0	1	-5
									Error Rate	**-0.4679**	**16.6667**	**-0.3333**	**#DIV/0!**	**0.2500**	**-0.0382**
18	421	191	130.xx	Length (Loops)	South	4:00-5:00PM	2008-06-17	2008-06-24	Ground Truth	265	2	23	30	0	320
									ATR Count	205	61	7	29	8	310
									Difference	-60	59	-16	-1	8	-10
									Error Rate	**-0.2264**	**29.5000**	**-0.6957**	**-0.0333**	**#DIV/0!**	**-0.0313**
19	431	28	28.xx	Length (Loops)	South	11:00-12:00PM	2008-05-05	2008-06-09	Ground Truth	37	2	11	14	6	70
									ATR Count	37	10	8	14	6	75
									Difference	0	8	-3	0	0	5
									Error Rate	**0.0000**	**4.0000**	**-0.2727**	**0.0000**	**0.0000**	**0.0714**
20	502	I-15	222.xx	Length (Loops)	North	1:00-2:00PM	2008-05-05	2008-06-09	Ground Truth	281	4	33	45	6	369
									ATR Count	158	36	33	39	9	275
									Difference	-123	32	0	-6	3	-94
									Error Rate	**-0.4377**	**8.0000**	**0.0000**	**-0.1333**	**0.5000**	**-0.2547**
21	507	6	239.xx	Length (Loops)	East	1:00-2:00PM	2008-05-09	2008-06-13	Ground Truth	375	4	54	35	17	485
									ATR Count	433	48	34	21	21	557
									Difference	58	44	-20	-14	4	72
									Error Rate	**0.1547**	**11.0000**	**-0.3704**	**-0.4000**	**0.2353**	**0.1485**
22	509	40	12.8	Length (Loops)	West	12:00-1:00PM	2008-05-06	2008-06-10	Ground Truth	421	6	60	27	17	531
									ATR Count	333	106	24	13	6	482
									Difference	-88	100	-36	-14	-11	-49
									Error Rate	**-0.2090**	**16.6667**	**-0.6000**	**-0.5185**	**-0.6471**	**-0.0923**

	Satation	Route	M.P.	Collection Type	Direction	Time	First Date	Second Date	Second Traffic Volume by Length						
										16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
12	401	I-15	22.xx	Length (Loops)	South	6:00-7:00PM	2008-06-16	2008-06-23	Ground Truth	426	1	31	131	7	596
									ATR Count	412	34	22	115	15	598
									Difference	-14	33	-9	-16	8	2
									Error Rate	**-0.0329**	**33.0000**	**-0.2903**	**-0.1221**	**1.1429**	**0.0034**
13	403	I-15	112.xx	Length (Loops)	North	11:00-12:00PM	2008-06-16	2008-06-23	Ground Truth	359	0	60	53	9	481
									ATR Count	347	29	31	54	13	474
									Difference	-12	29	-29	1	4	-7
									Error Rate	**-0.03343**	**#DIV/0!**	**-0.48333**	**0.01887**	**0.44444**	**-0.01455**
14	404	I-70	156.xx	Length (Loops)	West	7:00-8:00AM	2008-06-18	2008-06-25	Ground Truth	51	0	12	37	6	106
									ATR Count	37	20	4	36	7	104
									Difference	-14	20	-8	-1	1	-2
									Error Rate	**-0.2745**	**#DIV/0!**	**-0.6667**	**-0.0270**	**0.1667**	**-0.0189**
15	405	21	104.xx	Length (Loops)	East	1:00-2:00PM	2008-06-16	2008-06-23	Ground Truth	36	1	8	4	0	49
									ATR Count	33	7	6	4	0	50
									Difference	-3	6	-2	0	0	1
									Error Rate	**-0.0833**	**6.0000**	**-0.2500**	**0.0000**	**#DIV/0!**	**0.0204**
16	411	89	54.xx	Length (Loops)	West	9:00-10:00AM	2008-06-17	2008-06-24	Ground Truth	36	0	11	8	5	60
									ATR Count	53	10	7	4	5	79
									Difference	17	10	-4	-4	0	19
									Error Rate	**0.4722**	**#DIV/0!**	**-0.3636**	**-0.5000**	**0.0000**	**0.3167**
17	412	11	0.xx	Length (Loops)	North	7:00-8:00AM	2008-06-17	2008-06-24	Ground Truth	100	1	17	4	2	124
									ATR Count	48	62	11	4	3	128
									Difference	-52	61	-6	0	1	4
									Error Rate	**-0.5200**	**61.0000**	**-0.3529**	**0.0000**	**0.5000**	**0.0323**
18	421	191	130.xx	Length (Loops)	South	4:00-5:00PM	2008-06-17	2008-06-24	Ground Truth	297	1	35	21	1	355
									ATR Count	221	81	13	21	6	342
									Difference	-76	80	-22	0	5	-13
									Error Rate	**-0.2559**	**80.0000**	**-0.6286**	**0.0000**	**5.0000**	**-0.0366**
19	431	28	28.xx	Length (Loops)	South	11:00-12:00PM	2008-05-05	2008-06-09	Ground Truth	40	0	11	7	1	59
									ATR Count	39	6	6	7	1	59
									Difference	-1	6	-5	0	0	0
									Error Rate	**-0.0250**	**#DIV/0!**	**-0.4545**	**0.0000**	**0.0000**	**0.0000**
20	502	I-15	222.xx	Length (Loops)	North	1:00-2:00PM	2008-05-05	2008-06-09	Ground Truth	250	1	54	53	3	361
									ATR Count	183	71	32	55	15	356
									Difference	-67	70	-22	2	12	-5
									Error Rate	**-0.2680**	**70.0000**	**-0.4074**	**0.0377**	**4.0000**	**-0.0139**
21	507	6	239.xx	Length (Loops)	East	1:00-2:00PM	2008-05-09	2008-06-13	Ground Truth	403	0	48	46	8	505
									ATR Count	441	48	24	29	15	557
									Difference	38	48	-24	-17	7	52
									Error Rate	**0.0943**	**#DIV/0!**	**-0.5000**	**-0.3696**	**0.8750**	**0.1030**
22	509	40	12.8	Length (Loops)	West	12:00-1:00PM	2008-05-06	2008-06-10	Ground Truth	456	10	60	25	17	568
									ATR Count	375	116	36	20	6	553
									Difference	-81	106	-24	-5	-11	-15
									Error Rate	**-0.1776**	**10.6000**	**-0.4000**	**-0.2000**	**-0.6471**	**-0.0264**

	Satation	Route	M.P.	Collection Type	Direction	Time	First Date	Second Date		First Traffic Volume by Length					
										16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
23	510	218	5.7	Length (Loops)	East	10:00-11:00AM	2008-05-14	2008-07-02	Ground Truth	49	3	7	1	0	60
									ATR Count	32	26	3	1	0	62
									Difference	-17	23	-4	0	0	2
									Error Rate	**-0.3469**	**7.6667**	**-0.5714**	**0.0000**	**#DIV/0!**	**0.0333**
24	**611**	**I-15**	**259.xx**	**Length (Wave)**	**North**	**1:00-2:00PM**	**2008-05-30**	**2008-06-20**	Ground Truth	2372	21	212	119	19	2743
									ATR Count	1223	1200	134	103	68	2728
									Difference	-1149	1179	-78	-16	49	-15
									Error Rate	**-0.4844**	**56.1429**	**-0.3679**	**-0.1345**	**2.5789**	**-0.0055**
25	613	I-15	358.xx	Length (Loops)	South	2:00-3:00PM	2008-05-14	2008-06-11	Ground Truth	881	20	105	207	16	1229
									ATR Count	872	112	55	198	18	1255
									Difference	-9	92	-50	-9	2	26
									Error Rate	**-0.0102**	**4.6000**	**-0.4762**	**-0.0435**	**0.1250**	**0.0212**
26	**614**	**I-84**	**36.6**	**Length (Wave)**	**East**	**6:00-7:00AM**	**2008-05-14**	**2008-06-11**	Ground Truth	34	0	3	45	13	95
									ATR Count	4	32	3	22	40	101
									Difference	-30	32	0	-23	27	6
									Error Rate	**-0.8824**	**#DIV/0!**	**0.0000**	**-0.5111**	**2.0769**	**0.0632**
27	**615**	**I-80**	**99.5**	**Length (Wave)**	**East**	**3:00-4:00PM**	**2008-04-02**	**2008-05-07**	Ground Truth	570	239	73	80	2	964
									ATR Count	388	441	42	47	63	981
									Difference	-182	202	-31	-33	61	17
									Error Rate	**-0.3193**	**0.8452**	**-0.4247**	**-0.4125**	**30.5000**	**0.0176**
28	618	73	36.1	Length (Loops)	East	11:00-12:00PM	2008-05-30	2008-06-20	Ground Truth	705	5	44	9	0	763
									ATR Count	557	151	22	9	2	741
									Difference	-148	146	-22	0	2	-22
									Error Rate	**-0.2099**	**29.2000**	**-0.5000**	**0.0000**	**#DIV/0!**	**-0.0288**

	Satation	Route	M.P.	Collection Type	Direction	Time	First Date	Second Date		Second Traffic Volume by Length					
										16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
23	510	218	5.7	Length (Loops)	East	10:00-11:00AM	2008-05-14	2008-07-02	Ground Truth	81	0	11	3	0	95
									ATR Count	37	25	3	4	0	69
									Difference	-44	25	-8	1	0	-26
									Error Rate	**-0.5432**	**#DIV/0!**	**-0.7273**	**0.3333**	**#DIV/0!**	**-0.2737**
24	**611**	**I-15**	**259.xx**	**Length (Wave)**	**North**	**1:00-2:00PM**	**2008-05-30**	**2008-06-20**	Ground Truth	2485	20	205	139	27	2876
									ATR Count	1317	1179	135	114	77	2822
									Difference	-1168	1159	-70	-25	50	-54
									Error Rate	**-0.4700**	**57.9500**	**-0.3415**	**-0.1799**	**1.8519**	**-0.0188**
25	613	I-15	358.xx	Length (Loops)	South	2:00-3:00PM	2008-05-14	2008-06-11	Ground Truth	1004	17	89	203	18	1331
									ATR Count	962	128	60	213	14	1377
									Difference	-42	111	-29	10	-4	46
									Error Rate	**-0.0418**	**6.5294**	**-0.3258**	**0.0493**	**-0.2222**	**0.0346**
26	**614**	**I-84**	**36.6**	**Length (Wave)**	**East**	**6:00-7:00AM**	**2008-05-14**	**2008-06-11**	Ground Truth	22	2	5	50	7	86
									ATR Count	6	25	3	19	42	95
									Difference	-16	23	-2	-31	35	9
									Error Rate	**-0.7273**	**11.5000**	**-0.4000**	**-0.6200**	**5.0000**	**0.1047**
27	**615**	**I-80**	**99.5**	**Length (Wave)**	**East**	**3:00-4:00PM**	**2008-04-02**	**2008-05-07**	Ground Truth	837	38	85	109	27	1096
									ATR Count	494	414	56	62	79	1105
									Difference	-343	376	-29	-47	52	9
									Error Rate	**-0.4098**	**9.8947**	**-0.3412**	**-0.4312**	**1.9259**	**0.0082**
28	618	73	36.1	Length (Loops)	East	11:00-12:00PM	2008-05-30	2008-06-20	Ground Truth	649	6	44	10	4	713
									ATR Count	501	179	19	12	5	716
									Difference	-148	173	-25	2	1	3
									Error Rate	**-0.2280**	**28.8333**	**-0.5682**	**0.2000**	**0.2500**	**0.0042**

Appendix 4-2 Error Rate (Accuracy Level) without Station #411 (Extreme Outlier)

Appendix 4-2-1 Total

Total-Without	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.2004	20.1244	-0.4332	-0.0304	1.8509	0.0012
Variance	0.0472	416.9507	0.0251	0.0889	22.4007	0.0051
S D	0.2173	20.4194	0.1583	0.2982	4.7329	0.0717
UBCI	-0.1434	25.4726	-0.3917	0.0477	3.0905	0.0200
LBCI	-0.2573	14.7763	-0.4747	-0.1085	0.6113	-0.0176

Total-Without	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0573	-0.2113	0.0012
Variance	0.0097	0.0279	0.0051
S D	0.0983	0.1672	0.0717
UBCI	0.0831	-0.1675	0.0200
LBCI	0.0316	-0.2551	-0.0176

Note: UBCI = Upper bound of confidence interval
LBCI = Lower bound of confidence interval

Appendix 4-2-2 Highway Class

Interstate Highway	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.2096	21.1253	-0.3767	-0.1132	2.5234	0.0086
Variance	0.0599	464.9993	0.0227	0.0340	33.0225	0.0052
S D	0.2448	21.5638	0.1507	0.1843	5.7465	0.0718
UBCI	-0.1189	29.1127	-0.3209	-0.0449	4.6520	0.0352
LBCI	-0.3003	13.1380	-0.4325	-0.1814	0.3949	-0.0180

Interstate Highway	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0611	-0.1012	0.0086
Variance	0.0109	0.0056	0.0052
S D	0.1045	0.0751	0.0718
UBCI	0.0998	-0.0734	0.0352
LBCI	0.0224	-0.1290	-0.0180

NI Highway	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.1904	19.0759	-0.4941	0.0661	0.6740	-0.0068
Variance	0.0352	385.0908	0.0212	0.1393	2.4531	0.0052
S D	0.1876	19.6237	0.1455	0.3732	1.5663	0.0722
UBCI	-0.1209	26.3446	-0.4402	0.2044	1.2542	0.0200
LBCI	-0.2599	11.8071	-0.5480	-0.0721	0.0939	-0.0335

NI Highway	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0533	-0.3298	-0.0068
Variance	0.0087	0.0250	0.0052
S D	0.0931	0.1580	0.0722
UBCI	0.0877	-0.2713	0.0200
LBCI	0.0188	-0.3883	-0.0335

Appendix 4-2-3 By Traffic Volume

GT <100	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.3024	7.2333	-0.4226	0.0780	1.1795	-0.0025
Variance	0.0972	7.6056	0.0584	0.2440	4.1933	0.0108
S D	0.3118	2.7578	0.2417	0.4940	2.0478	0.1040
UBCI	-0.1091	8.9426	-0.2728	0.3842	2.4487	0.0620
LBCI	-0.4956	5.5240	-0.5724	-0.2281	-0.0897	-0.0670

GT <100	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0772	-0.2463	-0.0025
Variance	0.0190	0.0749	0.0108
S D	0.1378	0.2737	0.1040
UBCI	0.1627	-0.0766	0.0620
LBCI	-0.0082	-0.4159	-0.0670

100< GT< 300	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.2440	22.0000	-0.4058	-0.0190	0.8580	0.0121
Variance	0.0443	361.1111	0.0232	0.0267	0.4186	0.0010
S D	0.2106	19.0029	0.1523	0.1633	0.6470	0.0312
UBCI	-0.1134	33.7781	-0.3114	0.0822	1.2590	0.0314
LBCI	-0.3745	10.2219	-0.5002	-0.1202	0.4570	-0.0073

100< GT< 300	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0800	-0.1681	0.0121
Variance	0.0022	0.0165	0.0010
S D	0.0468	0.1286	0.0312
UBCI	0.1090	-0.0884	0.0314
LBCI	0.0510	-0.2478	-0.0073

300< GT< 500	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.1796	34.8690	-0.4461	-0.0401	1.2982	-0.0156
Variance	0.0250	853.0517	0.0351	0.0169	3.0208	0.0088
S D	0.1580	29.2070	0.1872	0.1299	1.7380	0.0941
UBCI	-0.0863	52.1293	-0.3355	0.0367	2.3254	0.0400
LBCI	-0.2730	17.6088	-0.5568	-0.1169	0.2711	-0.0711

300< GT< 500	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0353	-0.1594	-0.0156
Variance	0.0195	0.0066	0.0088
S D	0.1397	0.0812	0.0941
UBCI	0.1178	-0.1114	0.0400
LBCI	-0.0472	-0.2074	-0.0711

500< GT<1000	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.0970	12.7904	-0.4493	-0.1400	3.6012	0.0137
Variance	0.0298	120.0582	0.0092	0.0445	70.6908	0.0040
S D	0.1726	10.9571	0.0961	0.2110	8.4078	0.0630
UBCI	-0.0096	18.3354	-0.4007	-0.0332	7.8561	0.0456
LBCI	-0.1843	7.2453	-0.4979	-0.2468	-0.6537	-0.0182

500< GT<1000	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0653	-0.2730	0.0137
Variance	0.0054	0.0293	0.0040
S D	0.0737	0.1711	0.0630
UBCI	0.1026	-0.1864	0.0456
LBCI	0.0280	-0.3596	-0.0182

GT>1000	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.2406	22.7871	-0.4328	0.0536	1.1001	-0.0082
Variance	0.0373	472.5362	0.0143	0.1762	1.0729	0.0022
S D	0.1932	21.7379	0.1195	0.4197	1.0358	0.0464
UBCI	-0.1067	37.8507	-0.3500	0.3444	1.8179	0.0240
LBCI	-0.3745	7.7235	-0.5156	-0.2372	0.3823	-0.0403

GT>1000	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0195	-0.1770	-0.0082
Variance	0.0033	0.0079	0.0022
S D	0.0578	0.0890	0.0464
UBCI	0.0596	-0.1153	0.0240
LBCI	-0.0206	-0.2387	-0.0403

Appendix 4-2-4 By Data Collection Time Period

AM	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.2551	13.9946	-0.4184	-0.0269	1.8262	0.0127
Variance	0.0961	264.5445	0.0379	0.1356	5.3620	0.0089
S D	0.3100	16.2648	0.1946	0.3683	2.3156	0.0944
UBCI	-0.1119	21.5085	-0.3285	0.1432	2.8960	0.0563
LBCI	-0.3983	6.4806	-0.5083	-0.1971	0.7565	-0.0309

AM	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0768	-0.1610	0.0127
Variance	0.0138	0.0304	0.0089
S D	0.1175	0.1742	0.0944
UBCI	0.1311	-0.0805	0.0563
LBCI	0.0225	-0.2415	-0.0309

PM	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.1773	22.2316	-0.4394	-0.0318	1.8602	-0.0037
Variance	0.0268	461.6476	0.0204	0.0732	29.1690	0.0037
S D	0.1638	21.4860	0.1429	0.2706	5.4008	0.0606
UBCI	-0.1252	29.0631	-0.3940	0.0542	3.5774	0.0156
LBCI	-0.2294	15.4000	-0.4849	-0.1179	0.1429	-0.0229

PM	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0492	-0.2324	-0.0037
Variance	0.0080	0.0262	0.0037
S D	0.0895	0.1618	0.0606
UBCI	0.0776	-0.1810	0.0156
LBCI	0.0207	-0.2839	-0.0229

Appendix 4-2-5 By Data Collection Order

First Data Collection	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.1887	17.6684	-0.3966	-0.0088	2.3533	0.0060
Variance	0.0546	303.4860	0.0305	0.1371	42.4969	0.0057
S D	0.2337	17.4209	0.1747	0.3702	6.5190	0.0758
UBCI	-0.1021	24.1212	-0.3319	0.1283	4.7680	0.0341
LBCI	-0.2752	11.2157	-0.4613	-0.1460	-0.0613	-0.0220

First Data Collection	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0570	-0.1930	0.0060
Variance	0.0113	0.0256	0.0057
S D	0.1063	0.1599	0.0758
UBCI	0.0963	-0.1338	0.0341
LBCI	0.0176	-0.2523	-0.0220

Second Data Collection	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.2120	22.4688	-0.4698	-0.0520	1.3485	-0.0036
Variance	0.0414	533.0776	0.0178	0.0434	2.8423	0.0047
S D	0.2034	23.0885	0.1334	0.2082	1.6859	0.0685
UBCI	-0.1367	31.0209	-0.4204	0.0251	1.9729	0.0217
LBCI	-0.2874	13.9167	-0.5192	-0.1291	0.7240	-0.0290

Second Data Collection	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0577	-0.2295	-0.0036
Variance	0.0084	0.0307	0.0047
S D	0.0916	0.1752	0.0685
UBCI	0.0916	-0.1646	0.0217
LBCI	0.0237	-0.2944	-0.0290

Appendix 4-2-6 By Elapsed Time between Two Data Collections

One Week Elapsed	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.2120	25.1693	-0.4353	0.0562	0.8585	0.0004
Variance	0.0272	457.8717	0.0159	0.0626	1.6276	0.0007
S D	0.1650	21.3979	0.1259	0.2502	1.2758	0.0261
UBCI	-0.1431	34.1109	-0.3826	0.1608	1.3916	0.0113
LBCI	-0.2809	16.2276	-0.4879	-0.0483	0.3254	-0.0104

One Week Elapsed	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0553	-0.1860	0.0004
Variance	0.0020	0.0104	0.0007
S D	0.0449	0.1018	0.0261
UBCI	0.0741	-0.1435	0.0113
LBCI	0.0365	-0.2286	-0.0104

Three Weeks Elapsed	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.2846	32.7143	-0.4638	0.0229	1.3726	-0.0293
Variance	0.0269	432.4794	0.0079	0.0239	1.0874	0.0018
S D	0.1640	20.7961	0.0888	0.1546	1.0428	0.0423
UBCI	-0.1709	47.1253	-0.4023	0.1300	2.0952	0.0001
LBCI	-0.3982	18.3034	-0.5253	-0.0842	0.6500	-0.0586

Three Weeks Elapsed	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	-0.0083	-0.2561	-0.0293
Variance	0.0020	0.0130	0.0018
S D	0.0453	0.1141	0.0423
UBCI	0.0231	-0.1771	0.0001
LBCI	-0.0396	-0.3352	-0.0586

Four Weeks Elapsed	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.1494	7.1488	-0.3603	-0.2256	2.2790	0.0502
Variance	0.1348	25.2704	0.0328	0.0464	6.7284	0.0034
S D	0.3672	5.0270	0.1811	0.2155	2.5939	0.0579
UBCI	0.0781	10.2645	-0.2480	-0.0920	3.8867	0.0861
LBCI	-0.3770	4.0330	-0.4725	-0.3592	0.6713	0.0143

Four Weeks Elapsed	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.1139	-0.1206	0.0502
Variance	0.0074	0.0278	0.0034
S D	0.0859	0.1668	0.0579
UBCI	0.1671	-0.0173	0.0861
LBCI	0.0607	-0.2240	0.0143

Five Weeks Elapsed	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.1595	19.6889	-0.4214	-0.1480	2.9840	-0.0027
Variance	0.0301	611.0328	0.0359	0.0790	69.8595	0.0087
S D	0.1736	24.7191	0.1894	0.2810	8.3582	0.0934
UBCI	-0.0686	32.6376	-0.3222	-0.0008	7.3623	0.0463
LBCI	-0.2505	6.7403	-0.5206	-0.2952	-1.3943	-0.0516

Five Weeks Elapsed	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0696	-0.2416	-0.0027
Variance	0.0188	0.0511	0.0087
S D	0.1371	0.2260	0.0934
UBCI	0.1414	-0.1232	0.0463
LBCI	-0.0022	-0.3600	-0.0516

Seven Weeks Elapsed	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.4451	7.6667	-0.6494	0.1667	-	-0.1202
Variance	0.0193	-	0.0121	0.0556	-	0.0471
S D	0.1388	-	0.1102	0.2357	-	0.2171
UBCI	-0.2527	7.6667	-0.4966	0.4933	0.0000	0.1807
LBCI	-0.6374	7.6667	-0.8021	-0.1600	0.0000	-0.4211

Seven Weeks Elapsed	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	-0.0596	-0.5000	-0.1202
Variance	0.0612	0.0000	0.0471
S D	0.2475	0.0000	0.2171
UBCI	0.2834	-0.5000	0.1807
LBCI	-0.4025	-0.5000	-0.4211

Appendix 4-2-7 By ***Day of the Week***

Monday	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.1115	20.0000	-0.3627	0.1079	0.8487	-0.0178
Variance	0.0169	583.0000	0.0372	0.1190	1.8122	0.0064
S D	0.1299	24.1454	0.1929	0.3450	1.3462	0.0797
UBCI	-0.0381	33.6615	-0.2536	0.3031	1.6104	0.0273
LBCI	-0.1850	6.3385	-0.4719	-0.0873	0.0870	-0.0629

Monday	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0366	-0.1862	-0.0178
Variance	0.0158	0.0410	0.0064
S D	0.1256	0.2024	0.0797
UBCI	0.1076	-0.0716	0.0273
LBCI	-0.0345	-0.3007	-0.0629

Tuesday	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.2925	28.6815	-0.4869	-0.0188	0.6570	-0.0102
Variance	0.0151	548.3996	0.0133	0.0355	2.3973	0.0011
S D	0.1230	23.4179	0.1152	0.1885	1.5483	0.0336
UBCI	-0.2322	40.1563	-0.4305	0.0736	1.4157	0.0063
LBCI	-0.3528	17.2067	-0.5434	-0.1112	-0.1017	-0.0266

Tuesday	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0478	-0.2678	-0.0102
Variance	0.0015	0.0188	0.0011
S D	0.0384	0.1371	0.0336
UBCI	0.0666	-0.2006	0.0063
LBCI	0.0289	-0.3350	-0.0266

Wednesday	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.2700	7.1507	-0.4312	-0.1929	4.0341	0.0042
Variance	0.0851	20.3861	0.0390	0.0659	71.9389	0.0074
S D	0.2918	4.5151	0.1975	0.2567	8.4817	0.0862
UBCI	-0.1172	9.5159	-0.3277	-0.0585	8.4770	0.0493
LBCI	-0.4228	4.7856	-0.5346	-0.3274	-0.4089	-0.0410

Wednesday	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0748	-0.1818	0.0042
Variance	0.0122	0.0372	0.0074
S D	0.1106	0.1928	0.0862
UBCI	0.1328	-0.0808	0.0493
LBCI	0.0169	-0.2828	-0.0410

Thursday	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	0.0782	5.6190	-0.3661	-0.0642	3.9870	0.1002
Variance	0.1132	61.5522	0.0008	0.0105	29.0786	0.0152
S D	0.3365	7.8455	0.0291	0.1025	5.3925	0.1234
UBCI	0.5446	16.4924	-0.3257	0.0777	11.4605	0.2712
LBCI	-0.3881	-5.2543	-0.4064	-0.2062	-3.4866	-0.0709

Thursday	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.1545	-0.0520	0.1002
Variance	0.0197	0.0065	0.0152
S D	0.1402	0.0807	0.1234
UBCI	0.3488	0.0598	0.2712
LBCI	-0.0398	-0.1639	-0.0709

Friday	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.1468	24.1064	-0.4546	0.0255	1.0381	0.0135
Variance	0.0391	372.4372	0.0113	0.1300	0.5691	0.0044
S D	0.1977	19.2986	0.1063	0.3605	0.7544	0.0665
UBCI	-0.0350	35.0256	-0.3944	0.2295	1.4650	0.0511
LBCI	-0.2587	13.1872	-0.5147	-0.1785	0.6113	-0.0241

Friday	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0526	-0.2313	0.0135
Variance	0.0101	0.0160	0.0044
S D	0.1003	0.1265	0.0665
UBCI	0.1094	-0.1597	0.0511
LBCI	-0.0042	-0.3029	-0.0241

Appendix 4-2-8 By Data Collection Type

Inductive Loop	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.1568	19.1847	-0.4483	0.0154	0.9870	-0.0022
Variance	0.0310	383.7717	0.0236	0.0782	2.7999	0.0055
S D	0.1761	19.5901	0.1535	0.2797	1.6733	0.0739
UBCI	-0.1080	24.6148	-0.4057	0.0929	1.4508	0.0183
LBCI	-0.2056	13.7546	-0.4908	-0.0621	0.5232	-0.0227

Inductive Loop	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0557	-0.2318	-0.0022
Variance	0.0096	0.0269	0.0055
S D	0.0978	0.1639	0.0739
UBCI	0.0828	-0.1864	0.0183
LBCI	0.0286	-0.2773	-0.0227

Microwave	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.5489	27.2666	-0.3125	-0.3815	7.3223	0.0282
Variance	0.0451	755.9419	0.0245	0.0358	130.3318	0.0022
S D	0.2123	27.4944	0.1566	0.1891	11.4163	0.0467
UBCI	-0.3789	49.2667	-0.1872	-0.2302	16.4572	0.0656
LBCI	-0.7188	5.2665	-0.4378	-0.5328	-1.8127	-0.0092

Microwave	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0703	-0.0467	0.0282
Variance	0.0122	0.0071	0.0022
S D	0.1105	0.0845	0.0467
UBCI	0.1587	0.0209	0.0656
LBCI	-0.0181	-0.1143	-0.0092

Appendix 4-2-9 By Direction of Data Collection

East	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.2798	12.4378	-0.4431	-0.0547	4.5403	0.0112
Variance	0.0840	98.4208	0.0414	0.2217	97.3279	0.0096
S D	0.2898	9.9207	0.2036	0.4709	9.8655	0.0979
UBCI	-0.1280	17.6346	-0.3364	0.1920	9.7082	0.0624
LBCI	-0.4316	7.2410	-0.5497	-0.3013	-0.6275	-0.0401

East	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0730	-0.2574	0.0112
Variance	0.0169	0.0588	0.0096
S D	0.1300	0.2424	0.0979
UBCI	0.1411	-0.1304	0.0624
LBCI	0.0049	-0.3844	-0.0401

West	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.2216	21.5468	-0.4796	-0.0370	0.4786	-0.0003
Variance	0.0170	356.8066	0.0117	0.0376	0.4830	0.0013
S D	0.1303	18.8893	0.1084	0.1940	0.6950	0.0365
UBCI	-0.1534	31.4417	-0.4228	0.0646	0.8427	0.0189
LBCI	-0.2899	11.6520	-0.5364	-0.1387	0.1146	-0.0194

West	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0806	-0.2202	-0.0003
Variance	0.0013	0.0296	0.0013
S D	0.0366	0.1721	0.0365
UBCI	0.0997	-0.1301	0.0189
LBCI	0.0614	-0.3104	-0.0194

South	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.0588	15.8306	-0.4188	-0.0879	1.6149	0.0228
Variance	0.0225	404.7312	0.0221	0.0147	5.4399	0.0027
S D	0.1499	20.1179	0.1486	0.1212	2.3324	0.0524
UBCI	0.0147	25.6884	-0.3460	-0.0285	2.7578	0.0485
LBCI	-0.1322	5.9728	-0.4916	-0.1473	0.4721	-0.0029

South	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0818	-0.1837	0.0228
Variance	0.0047	0.0170	0.0027
S D	0.0687	0.1304	0.0524
UBCI	0.1155	-0.1198	0.0485
LBCI	0.0481	-0.2476	-0.0029

North	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.2752	32.2031	-0.3946	0.0891	1.1566	-0.0377
Variance	0.0369	657.6015	0.0255	0.1022	1.6129	0.0059
S D	0.1922	25.6437	0.1598	0.3197	1.2700	0.0770
UBCI	-0.1664	46.7124	-0.3042	0.2700	1.8752	0.0059
LBCI	-0.3839	17.6937	-0.4850	-0.0918	0.4381	-0.0813

North	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	-0.0168	-0.1853	-0.0377
Variance	0.0110	0.0078	0.0059
S D	0.1050	0.0881	0.0770
UBCI	0.0426	-0.1354	0.0059
LBCI	-0.0762	-0.2352	-0.0813

Appendix 4-3: Error Rate (Accuracy Level) with Station #411 (Extreme Outlier)

Appendix 4-3-1 Total

Total-With	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.1883	19.7239	-0.4395	-0.0163	1.9009	0.0068
Variance	0.0536	414.3138	0.0275	0.1181	21.8612	0.0067
S D	0.2315	20.3547	0.1657	0.3436	4.6756	0.0821
UBCI	-0.1276	25.0551	-0.3961	0.0737	3.1255	0.0283
LBCI	-0.2489	14.3927	-0.4830	-0.1063	0.6763	-0.0147

Total-With	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0687	-0.2097	0.0068
Variance	0.0180	0.0280	0.0067
S D	0.1340	0.1674	0.0821
UBCI	0.1038	-0.1658	0.0283
LBCI	0.0336	-0.2535	-0.0147

Appendix 4-3-2 By Highway Class

NI Highway	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.1669	18.3224	-0.5024	0.0880	0.9325	0.0050
Variance	0.0483	379.2422	0.0251	0.1919	3.7891	0.0086
S D	0.2198	19.4741	0.1583	0.4380	1.9466	0.0925
UBCI	-0.0855	25.5357	-0.4437	0.2502	1.6535	0.0393
LBCI	-0.2483	11.1091	-0.5610	-0.0743	0.2114	-0.0292

NI Highway	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0762	-0.3181	0.0050
Variance	0.0256	0.0270	0.0086
S D	0.1599	0.1644	0.0925
UBCI	0.1355	-0.2573	0.0393
LBCI	0.0170	-0.3790	-0.0292

Interstate Highway	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.2096	21.1253	-0.3767	-0.1132	2.5234	0.0086
Variance	0.0599	464.9993	0.0227	0.0340	33.0225	0.0052
S D	0.2448	21.5638	0.1507	0.1843	5.7465	0.0718
UBCI	-0.1189	29.1127	-0.3209	-0.0449	4.6520	0.0352
LBCI	0.0159	475.7828	-0.0961	0.0173	34.7456	0.0182

Interstate Highway	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0611	-0.1012	0.0086
Variance	0.0109	0.0056	0.0052
S D	0.1045	0.0751	0.0718
UBCI	0.0998	-0.0734	0.0352
LBCI	0.0479	-0.0215	0.0182

Appendix 4-3-3 By Traffic Volume

GT <100	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.2290	6.4444	-0.4539	0.1275	1.6346	0.0243
Variance	0.1292	9.8185	0.0642	0.3518	6.2768	0.0173
S D	0.3595	3.1335	0.2534	0.5931	2.5054	0.1317
UBCI	-0.0256	8.2174	-0.3105	0.4631	3.0522	0.0988
LBCI	-0.4324	4.6715	-0.5972	-0.2081	0.2171	-0.0502

GT <100	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.1269	-0.2330	0.0243
Variance	0.0545	0.0673	0.0173
S D	0.2336	0.2594	0.1317
UBCI	0.2590	-0.0862	0.0988
LBCI	-0.0053	-0.3798	-0.0502

100< GT< 300	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.2440	22.0000	-0.4058	-0.0190	0.8580	0.0121
Variance	0.0443	361.1111	0.0232	0.0267	0.4186	0.0010
S D	0.2106	19.0029	0.1523	0.1633	0.6470	0.0312
UBCI	-0.1134	33.7781	-0.3114	0.0822	1.2590	0.0314
LBCI	-0.3745	10.2219	-0.5002	-0.1202	0.4570	-0.0073

100< GT< 300	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0800	-0.1681	0.0121
Variance	0.0022	0.0165	0.0010
S D	0.0468	0.1286	0.0312
UBCI	0.1090	-0.0884	0.0314
LBCI	0.0510	-0.2478	-0.0073

300< GT< 500	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.1796	34.8690	-0.4461	-0.0401	1.2982	-0.0156
Variance	0.0250	853.0517	0.0351	0.0169	3.0208	0.0088
S D	0.1580	29.2070	0.1872	0.1299	1.7380	0.0941
UBCI	-0.0863	52.1293	-0.3355	0.0367	2.3254	0.0400
LBCI	-0.2730	17.6088	-0.5568	-0.1169	0.2711	-0.0711

300< GT< 500	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0353	-0.1594	-0.0156
Variance	0.0195	0.0066	0.0088
S D	0.1397	0.0812	0.0941
UBCI	0.1178	-0.1114	0.0400
LBCI	-0.0472	-0.2074	-0.0711

500< GT<1000	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.0970	12.7904	-0.4493	-0.1400	3.6012	0.0137
Variance	0.0298	120.0582	0.0092	0.0445	70.6908	0.0040
S D	0.1726	10.9571	0.0961	0.2110	8.4078	0.0630
UBCI	-0.0096	18.3354	-0.4007	-0.0332	7.8561	0.0456
LBCI	-0.1843	7.2453	-0.4979	-0.2468	-0.6537	-0.0182

500< GT<1000	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0653	-0.2730	0.0137
Variance	0.0054	0.0293	0.0040
S D	0.0737	0.1711	0.0630
UBCI	0.1026	-0.1864	0.0456
LBCI	0.0280	-0.3596	-0.0182

GT>1000	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.2406	22.7871	-0.4328	0.0536	1.1001	-0.0082
Variance	0.0373	472.5362	0.0143	0.1762	1.0729	0.0022
S D	0.1932	21.7379	0.1195	0.4197	1.0358	0.0464
UBCI	-0.1067	37.8507	-0.3500	0.3444	1.8179	0.0240
LBCI	-0.3745	7.7235	-0.5156	-0.2372	0.3823	-0.0403

GT>1000	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0195	-0.1770	-0.0082
Variance	0.0033	0.0079	0.0022
S D	0.0578	0.0890	0.0464
UBCI	0.0596	-0.1153	0.0240
LBCI	-0.0206	-0.2387	-0.0403

Appendix 4-3-4 By Data Collection Time

AM	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.2114	13.0367	-0.4397	0.0174	1.9939	0.0289
Variance	0.1141	251.5054	0.0444	0.2247	6.1033	0.0130
S D	0.3378	15.8589	0.2108	0.4740	2.4705	0.1141
UBCI	-0.0554	20.3631	-0.3424	0.2364	3.1352	0.0816
LBCI	-0.3675	5.7102	-0.5371	-0.2016	0.8526	-0.0238

AM	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.1099	-0.1616	0.0289
Variance	0.0380	0.0301	0.0130
S D	0.1950	0.1734	0.1141
UBCI	0.2000	-0.0815	0.0816
LBCI	0.0198	-0.2417	-0.0238

PM	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.1773	22.2316	-0.4394	-0.0318	1.8602	-0.0037
Variance	0.0268	461.6476	0.0204	0.0732	29.1690	0.0037
S D	0.1638	21.4860	0.1429	0.2706	5.4008	0.0606
UBCI	-0.1252	29.0631	-0.3940	0.0542	3.5774	0.0156
LBCI	-0.2294	15.4000	-0.4849	-0.1179	0.1429	-0.0229

PM	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0492	-0.2324	-0.0037
Variance	0.0080	0.0262	0.0037
S D	0.0895	0.1618	0.0606
UBCI	0.0776	-0.1810	0.0156
LBCI	0.0207	-0.2839	-0.0229

Appendix 4-3-5 By Data Collection Order

First Data Collection						
	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.1889	16.9790	-0.4131	0.0359	2.5119	0.0058
Variance	0.0526	299.4926	0.0370	0.1859	41.1434	0.0055
S D	0.2293	17.3059	0.1922	0.4312	6.4143	0.0744
UBCI	-0.1040	23.3891	-0.3419	0.1957	4.8878	0.0334
LBCI	-0.2739	10.5688	-0.4843	-0.1238	0.1360	-0.0217

	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0549	-0.1862	0.0058
Variance	0.0110	0.0260	0.0055
S D	0.1049	0.1611	0.0744
UBCI	0.0938	-0.1265	0.0334
LBCI	0.0161	-0.2458	-0.0217

Second Data Collection						
	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.1876	22.4688	-0.4660	-0.0686	1.2898	0.0078
Variance	0.0566	533.0776	0.0176	0.0491	2.7921	0.0082
S D	0.2379	23.0885	0.1325	0.2216	1.6710	0.0905
UBCI	-0.0995	31.0209	-0.4169	0.0135	1.9088	0.0413
LBCI	-0.2757	13.9167	-0.5151	-0.1507	0.6709	-0.0257

	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0824	-0.2332	0.0078
Variance	0.0252	0.0299	0.0082
S D	0.1588	0.1730	0.0905
UBCI	0.1412	-0.1691	0.0413
LBCI	0.0236	-0.2973	-0.0257

Appendix 4-3-6 By Elapsed Time between Two Data Collections

One Week Elapsed	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.1802	23.6580	-0.4512	0.0842	1.0964	0.0148
Variance	0.0459	459.4262	0.0228	0.1364	2.9746	0.0052
S D	0.2142	21.4342	0.1510	0.3693	1.7247	0.0718
UBCI	-0.0907	32.6148	-0.3881	0.2385	1.8172	0.0448
LBCI	-0.2697	14.7012	-0.5143	-0.0701	0.3757	-0.0152

One Week Elapsed	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0844	-0.1843	0.0148
Variance	0.0241	0.0121	0.0052
S D	0.1551	0.1098	0.0718
UBCI	0.1492	-0.1384	0.0448
LBCI	0.0196	-0.2302	-0.0152

Three Weeks Elapsed	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.2846	32.7143	-0.4638	0.0229	1.3726	-0.0293
Variance	0.0269	432.4794	0.0079	0.0239	1.0874	0.0018
S D	0.1640	20.7961	0.0888	0.1546	1.0428	0.0423
UBCI	-0.1709	47.1253	-0.4023	0.1300	2.0952	0.0001
LBCI	-0.3982	18.3034	-0.5253	-0.0842	0.6500	-0.0586

Three Weeks Elapsed	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	-0.0083	-0.2561	-0.0293
Variance	0.0020	0.0130	0.0018
S D	0.0453	0.1141	0.0423
UBCI	0.0231	-0.1771	0.0001
LBCI	-0.0396	-0.3352	-0.0586

Four Weeks Elapsed	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.1494	7.1488	-0.3603	-0.2256	2.2790	0.0502
Variance	0.1348	25.2704	0.0328	0.0464	6.7284	0.0034
S D	0.3672	5.0270	0.1811	0.2155	2.5939	0.0579
UBCI	0.0781	10.2645	-0.2480	-0.0920	3.8867	0.0861
LBCI	-0.3770	4.0330	-0.4725	-0.3592	0.6713	0.0143

Four Weeks Elapsed	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.1139	-0.1206	0.0502
Variance	0.0074	0.0278	0.0034
S D	0.0859	0.1668	0.0579
UBCI	0.1671	-0.0173	0.0861
LBCI	0.0607	-0.2240	0.0143

Five Weeks Elapsed	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.1595	19.6889	-0.4214	-0.1480	2.9840	-0.0027
Variance	0.0301	611.0328	0.0359	0.0790	69.8595	0.0087
S D	0.1736	24.7191	0.1894	0.2810	8.3582	0.0934
UBCI	-0.0686	32.6376	-0.3222	-0.0008	7.3623	0.0463
LBCI	-0.2505	6.7403	-0.5206	-0.2952	-1.3943	-0.0516

Five Weeks Elapsed	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0696	-0.2416	-0.0027
Variance	0.0188	0.0511	0.0087
S D	0.1371	0.2260	0.0934
UBCI	0.1414	-0.1232	0.0463
LBCI	-0.0022	-0.3600	-0.0516

Seven Weeks Elapsed	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.4451	7.6667	-0.6494	0.1667	-	-0.1202
Variance	0.0193	-	0.0121	0.0556	-	0.0471
S D	0.1388	-	0.1102	0.2357	-	0.2171
UBCI	-0.2527	7.6667	-0.4966	0.4933	0.0000	0.1807
LBCI	-0.6374	7.6667	-0.8021	-0.1600	0.0000	-0.4211

Seven Weeks Elapsed	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	-0.0596	-0.5000	-0.1202
Variance	0.0612	0.0000	0.0471
S D	0.2475	0.0000	0.2171
UBCI	0.2834	-0.5000	0.1807
LBCI	-0.4025	-0.5000	-0.4211

Appendix 4-3-7 By Day of the Week

Monday	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.1115	20.0000	-0.3627	0.1079	0.8487	-0.0178
Variance	0.0169	583.0000	0.0372	0.1190	1.8122	0.0064
S D	0.1299	24.1454	0.1929	0.3450	1.3462	0.0797
UBCI	-0.0381	33.6615	-0.2536	0.3031	1.6104	0.0273
LBCI	-0.1850	6.3385	-0.4719	-0.0873	0.0870	-0.0629

Monday	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0366	-0.1862	-0.0178
Variance	0.0158	0.0410	0.0064
S D	0.1256	0.2024	0.0797
UBCI	0.1076	-0.0716	0.0273
LBCI	-0.0345	-0.3007	-0.0629

Tuesday	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.2387	26.9361	-0.5024	0.0304	1.0175	0.0109
Variance	0.0496	554.9263	0.0214	0.1505	4.2719	0.0076
S D	0.2228	23.5569	0.1463	0.3880	2.0669	0.0874
UBCI	-0.1295	38.4789	-0.4307	0.2205	2.0302	0.0537
LBCI	-0.3479	15.3932	-0.5741	-0.1597	0.0047	-0.0319

Tuesday	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0887	-0.2552	0.0109
Variance	0.0325	0.0212	0.0076
S D	0.1803	0.1456	0.0874
UBCI	0.1770	-0.1838	0.0537
LBCI	0.0003	-0.3265	-0.0319

Wednesday	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.2700	7.1507	-0.4312	-0.1929	4.0341	0.0042
Variance	0.0851	20.3861	0.0390	0.0659	71.9389	0.0074
S D	0.2918	4.5151	0.1975	0.2567	8.4817	0.0862
UBCI	-0.1172	9.5159	-0.3277	-0.0585	8.4770	0.0493
LBCI	-0.4228	4.7856	-0.5346	-0.3274	-0.4089	-0.0410

Wednesday	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0748	-0.1818	0.0042
Variance	0.0122	0.0372	0.0074
S D	0.1106	0.1928	0.0862
UBCI	0.1328	-0.0808	0.0493
LBCI	0.0169	-0.2828	-0.0410

Thursday	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	0.0782	5.6190	-0.3661	-0.0642	3.9870	0.1002
Variance	0.1132	61.5522	0.0008	0.0105	29.0786	0.0152
S D	0.3365	7.8455	0.0291	0.1025	5.3925	0.1234
UBCI	0.5446	16.4924	-0.3257	0.0777	11.4605	0.2712
LBCI	-0.3881	-5.2543	-0.4064	-0.2062	-3.4866	-0.0709

Thursday	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.1545	-0.0520	0.1002
Variance	0.0197	0.0065	0.0152
S D	0.1402	0.0807	0.1234
UBCI	0.3488	0.0598	0.2712
LBCI	-0.0398	-0.1639	-0.0709

Friday	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.1468	24.1064	-0.4546	0.0255	1.0381	0.0135
Variance	0.0391	372.4372	0.0113	0.1300	0.5691	0.0044
S D	0.1977	19.2986	0.1063	0.3605	0.7544	0.0665
UBCI	-0.0350	35.0256	-0.3944	0.2295	1.4650	0.0511
LBCI	-0.2587	13.1872	-0.5147	-0.1785	0.6113	-0.0241

Friday	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0526	-0.2313	0.0135
Variance	0.0101	0.0160	0.0044
S D	0.1003	0.1265	0.0665
UBCI	0.1094	-0.1597	0.0511
LBCI	-0.0042	-0.3029	-0.0241

Appendix 4-3-8 By Data Collection Type

Inductive Loop	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.1450	18.7569	-0.4548	0.0293	1.0877	0.0042
Variance	0.0377	380.8104	0.0261	0.1102	3.3152	0.0073
S D	0.1942	19.5144	0.1616	0.3320	1.8208	0.0853
UBCI	-0.0912	24.1660	-0.4100	0.1213	1.5924	0.0279
LBCI	-0.1988	13.3478	-0.4996	-0.0627	0.5830	-0.0194

Inductive Loop	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0685	-0.2292	0.0042
Variance	0.0189	0.0271	0.0073
S D	0.1375	0.1645	0.0853
UBCI	0.1066	-0.1836	0.0279
LBCI	0.0304	-0.2748	-0.0194

Microwave	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.5489	27.2666	-0.3125	-0.3815	7.3223	0.0282
Variance	0.0451	755.9419	0.0245	0.0358	130.3318	0.0022
S D	0.2123	27.4944	0.1566	0.1891	11.4163	0.0467
UBCI	-0.3789	49.2667	-0.1872	-0.2302	16.4572	0.0656
LBCI	-0.7188	5.2665	-0.4378	-0.5328	-1.8127	-0.0092

Microwave	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0703	-0.0467	0.0282
Variance	0.0122	0.0071	0.0022
S D	0.1105	0.0845	0.0467
UBCI	0.1587	0.0209	0.0656
LBCI	-0.0181	-0.1143	-0.0092

Appendix 4-3-9 By Direction of Data Collection

East	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.2798	12.4378	-0.4431	-0.0547	4.5403	0.0112
Variance	0.0840	98.4208	0.0414	0.2217	97.3279	0.0096
S D	0.2898	9.9207	0.2036	0.4709	9.8655	0.0979
UBCI	-0.1280	17.6346	-0.3364	0.1920	9.7082	0.0624
LBCI	-0.4316	7.2410	-0.5497	-0.3013	-0.6275	-0.0401

East	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0730	-0.2574	0.0112
Variance	0.0169	0.0588	0.0096
S D	0.1300	0.2424	0.0979
UBCI	0.1411	-0.1304	0.0624
LBCI	0.0049	-0.3844	-0.0401

West	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.1702	19.6421	-0.4983	0.0182	0.8989	0.0224
Variance	0.0486	353.4396	0.0216	0.1628	2.9948	0.0083
S D	0.2205	18.8000	0.1468	0.4034	1.7305	0.0911
UBCI	-0.0548	29.4902	-0.4214	0.2296	1.8054	0.0701
LBCI	-0.2857	9.7941	-0.5752	-0.1931	-0.0076	-0.0254

	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.1226	-0.2126	0.0224
Variance	0.0342	0.0297	0.0083
S D	0.1849	0.1724	0.0911
UBCI	0.2195	-0.1223	0.0701
LBCI	0.0258	-0.3029	-0.0254

South	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.0588	15.8306	-0.4188	-0.0879	1.6149	0.0228
Variance	0.0225	404.7312	0.0221	0.0147	5.4399	0.0027
S D	0.1499	20.1179	0.1486	0.1212	2.3324	0.0524
UBCI	0.0147	25.6884	-0.3460	-0.0285	2.7578	0.0485
LBCI	-0.1322	5.9728	-0.4916	-0.1473	0.4721	-0.0029

South	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	0.0818	-0.1837	0.0228
Variance	0.0047	0.0170	0.0027
S D	0.0687	0.1304	0.0524
UBCI	0.1155	-0.1198	0.0485
LBCI	0.0481	-0.2476	-0.0029

North	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total
Average	-0.2752	32.2031	-0.3946	0.0891	1.1566	-0.0377
Variance	0.0369	657.6015	0.0255	0.1022	1.6129	0.0059
S D	0.1922	25.6437	0.1598	0.3197	1.2700	0.0770
UBCI	-0.1664	46.7124	-0.3042	0.2700	1.8752	0.0059
LBCI	-0.3839	17.6937	-0.4850	-0.0918	0.4381	-0.0813

North	16-ft and 30-ft	Truck (Over 30-ft)	Total
Average	-0.0168	-0.1853	-0.0377
Variance	0.0110	0.0078	0.0059
S D	0.1050	0.0881	0.0770
UBCI	0.0426	-0.1354	0.0059
LBCI	-0.0762	-0.2352	-0.0813

Appendix 4-4: Difference in Number of Vehicles (ATR Traffic Data – Ground Truth)

Appendix 4-4-1 Total - with Station #411 (Extreme Outlier)

	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-112.02	126.64	-21.93	-5.05	8.46	-3.89	-0.78
Variance	63612.96	58001.25	671.52	125.80	229.89	4648.39	185.94
S D	252.22	240.83	25.91	11.22	15.16	68.18	13.64
UBCI	-45.96	189.72	-15.14	-2.12	12.44	13.96	2.79
LBCI	-178.08	63.56	-28.72	-7.99	4.49	-21.75	-4.35

	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	14.63	-18.52	-3.89	-0.78
Variance	3723.66	476.00	4648.39	185.94
S D	61.02	21.82	68.18	13.64
UBCI	30.61	-12.80	13.96	2.79
LBCI	-1.36	-24.23	-21.75	-4.35

Appendix 4-4-2 Total - without Station #411 (Extreme Outlier)

	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-116.30	130.96	-22.44	-5.28	8.67	-4.39	-0.88
Variance	65484.36	59657.55	688.67	128.17	237.06	4813.37	192.53
S D	255.90	244.25	26.24	11.32	15.40	69.38	13.88
UBCI	-48.04	196.11	-15.44	-2.26	12.77	14.12	2.82
LBCI	-184.55	65.82	-29.44	-8.30	4.56	-22.89	-4.58

	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	14.67	-19.06	-4.39	-0.88
Variance	3857.25	485.11	4813.37	192.53
S D	62.11	22.03	69.38	13.88
UBCI	31.23	-13.18	14.12	2.82
LBCI	-1.90	-24.93	-22.89	-4.58

Appendix 4-4-3 By Highway Class - with Station #411 (Extreme Outlier)

Interstate Highway	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-172.61	187.18	-29.29	-8.18	15.75	-7.14	-1.43
Variance	116763.80	105964.08	1156.29	206.52	338.49	8958.57	358.34
S D	341.71	325.52	34.00	14.37	18.40	94.65	18.93
UBCI	-46.04	307.75	-16.69	-2.86	22.56	27.92	5.58
LBCI	-299.18	66.60	-41.88	-13.50	8.94	-42.20	-8.44

Interstate Highway	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	14.57	-21.71	-7.14	-1.43
Variance	6913.74	734.21	8958.57	358.34
S D	83.15	27.10	94.65	18.93
UBCI	45.37	-11.68	27.92	5.58
LBCI	-16.23	-31.75	-42.20	-8.44

NI Highway	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-51.43	66.11	-14.57	-1.93	1.18	-0.64	-0.13
Variance	5204.11	4586.03	99.37	29.48	19.71	488.46	19.54
S D	72.14	67.72	9.97	5.43	4.44	22.10	4.42
UBCI	-24.71	91.19	-10.88	0.08	2.82	7.54	1.51
LBCI	-78.15	41.02	-18.26	-3.94	-0.47	-8.83	-1.77

NI Highway	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	14.68	-15.32	-0.64	-0.13
Variance	671.49	214.23	488.46	19.54
S D	25.91	14.64	22.10	4.42
UBCI	24.28	-9.90	7.54	1.51
LBCI	5.08	-20.74	-8.83	-1.77

Appendix 4-4-4 By Highway Class - without Station #411 (Non-Interstate Highway)

NI Highway	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-55.65	70.42	-15.08	-2.15	1.04	-1.42	-0.28
Variance	5345.92	4681.69	102.31	29.10	20.28	511.45	20.46
S D	73.12	68.42	10.12	5.39	4.50	22.62	4.52
UBCI	-27.55	96.72	-11.19	-0.08	2.77	7.27	1.45
LBCI	-83.76	44.12	-18.97	-4.23	-0.69	-10.12	-2.02

NI Highway	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	14.77	-16.19	-1.42	-0.28
Variance	710.50	219.04	511.45	20.46
S D	26.66	14.80	22.62	4.52
UBCI	25.02	-10.50	7.27	1.45
LBCI	4.52	-21.88	-10.12	-2.02

Appendix 4-4-5 By Data Collection Time - with Station #411 (Extreme Outlier)

AM	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-20.28	34.56	-9.72	-5.22	9.28	8.61	1.72
Variance	2430.80	1102.73	62.92	97.12	143.04	1199.78	47.99
S D	49.30	33.21	7.93	9.86	11.96	34.64	6.93
UBCI	2.50	49.90	-6.06	-0.67	14.80	24.61	4.92
LBCI	-43.05	19.21	-13.39	-9.78	3.75	-7.39	-1.48

AM	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	14.28	-5.67	8.61	1.72
Variance	1107.74	42.94	1199.78	47.99
S D	33.28	6.55	34.64	6.93
UBCI	29.65	-2.64	24.61	4.92
LBCI	-1.10	-8.69	-7.39	-1.48

PM	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-155.47	170.26	-27.71	-4.97	8.08	-9.82	-1.96
Variance	87409.12	79631.82	862.48	142.35	275.53	6246.42	249.86
S D	295.65	282.19	29.37	11.93	16.60	79.03	15.81
UBCI	-61.47	259.99	-18.37	-1.18	13.36	15.31	3.06
LBCI	-249.48	80.54	-37.05	-8.77	2.80	-34.95	-6.99

PM	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	14.79	-24.61	-9.82	-1.96
Variance	5026.12	569.43	6246.42	249.86
S D	70.90	23.86	79.03	15.81
UBCI	37.33	-17.02	15.31	3.06
LBCI	-7.75	-32.19	-34.95	-6.99

Appendix 4-4-6 By Data Collection Time - without Station #411 (Extreme Outlier) (AM)

AM	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-23.25	37.63	-9.94	-6.00	10.06	8.50	1.70
Variance	2645.80	1159.32	68.73	100.93	155.00	1347.60	53.90
S D	51.44	34.05	8.29	10.05	12.45	36.71	7.34
UBCI	1.95	54.31	-5.88	-1.08	16.16	26.49	5.30
LBCI	-48.45	20.94	-14.00	-10.92	3.96	-9.49	-1.90

AM	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	14.38	-5.88	8.50	1.70
Variance	1231.05	46.12	1347.60	53.90
S D	35.09	6.79	36.71	7.34
UBCI	31.57	-2.55	26.49	5.30
LBCI	-2.82	-9.20	-9.49	-1.90

Appendix 4-4-7 By Data Collection Order - with Station #411 (Extreme Outlier)

First Data Collection	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-100.54	123.71	-20.46	-5.61	9.00	6.11	1.22
Variance	57183.52	63103.69	579.37	94.17	255.56	1752.47	70.10
S D	239.13	251.20	24.07	9.70	15.99	41.86	8.37
UBCI	-11.96	216.76	-11.55	-2.01	14.92	21.61	4.32
LBCI	-189.11	30.67	-29.38	-9.20	3.08	-9.40	-1.88

First Data Collection	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	23.18	-17.07	6.11	1.22
Variance	2576.60	475.99	1752.47	70.10
S D	50.76	21.82	41.86	8.37
UBCI	41.98	-8.99	21.61	4.32
LBCI	4.38	-25.15	-9.40	-1.88

Second Data Collection	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-123.50	129.57	-23.39	-4.50	7.93	-13.89	-2.78
Variance	72125.00	55029.22	784.10	161.44	212.14	7509.06	300.36
S D	268.56	234.58	28.00	12.71	14.57	86.65	17.33
UBCI	-24.02	216.46	-13.02	0.21	13.32	18.20	3.64
LBCI	-222.98	42.68	-33.76	-9.21	2.53	-45.99	-9.20

Second Data Collection	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	6.07	-19.96	-13.89	-2.78
Variance	4856.88	489.29	7509.06	300.36
S D	69.69	22.12	86.65	17.33
UBCI	31.89	-11.77	18.20	3.64
LBCI	-19.74	-28.16	-45.99	-9.20

Appendix 4-4-8 By Data Collection Order - without Station #411 (Extreme Outlier)

First Data Collection	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-103.89	127.93	-20.78	-6.04	9.11	6.33	1.27
Variance	59055.95	65014.99	598.79	92.42	265.03	1818.38	72.74
S D	243.01	254.98	24.47	9.61	16.28	42.64	8.53
UBCI	-12.22	224.11	-11.55	-2.41	15.25	22.42	4.48
LBCI	-195.55	31.75	-30.01	-9.66	2.97	-9.75	-1.95

First Data Collection	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	24.04	-17.70	6.33	1.27
Variance	2654.27	482.68	1818.38	72.74
S D	51.52	21.97	42.64	8.53
UBCI	43.47	-9.42	22.42	4.48
LBCI	4.60	-25.99	-9.75	-1.95

Second Data Collection	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-128.70	134.00	-24.11	-4.52	8.22	-15.11	-3.02
Variance	74111.68	56575.46	799.26	167.64	217.79	7754.72	310.19
S D	272.23	237.86	28.27	12.95	14.76	88.06	17.61
UBCI	-26.02	223.72	-13.45	0.37	13.79	18.11	3.62
LBCI	-231.39	44.28	-34.78	-9.40	2.66	-48.33	-9.67

Second Data Collection	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	5.30	-20.41	-15.11	-3.02
Variance	5026.22	502.40	7754.72	310.19
S D	70.90	22.41	88.06	17.61
UBCI	32.04	-11.95	18.11	3.62
LBCI	-21.45	-28.86	-48.33	-9.67

Appendix 4-4-9 By Data Collection Elapsed Period-with Station #411 (Extreme Outlier)

One Week Elapsed	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-48.77	60.55	-13.00	-1.50	3.45	0.73	0.15
Variance	4453.33	4496.35	65.24	31.79	15.12	86.21	3.45
S D	66.73	67.05	8.08	5.64	3.89	9.28	1.86
UBCI	-20.89	88.57	-9.62	0.86	5.08	4.61	0.92
LBCI	-76.66	32.53	-16.38	-3.86	1.83	-3.15	-0.63

One Week Elapsed	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	11.77	-11.05	0.73	0.15
Variance	120.47	68.52	86.21	3.45
S D	10.98	8.28	9.28	1.86
UBCI	16.36	-7.59	4.61	0.92
LBCI	7.19	-14.50	-3.15	-0.63

Three Weeks Elapsed	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-525.63	511.88	-61.50	-1.63	18.25	-58.63	-11.73
Variance	231405.70	221472.70	2274.57	169.41	398.21	26271.41	1050.86
S D	481.05	470.61	47.69	13.02	19.96	162.08	32.42
UBCI	-192.28	837.99	-28.45	7.39	32.08	53.69	10.74
LBCI	-858.97	185.76	-94.55	-10.64	4.42	-170.94	-34.19

Three Weeks Elapsed	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	-13.75	-44.88	-58.63	-11.73
Variance	20658.79	1405.55	26271.41	1050.86
S D	143.73	37.49	162.08	32.42
UBCI	85.85	-18.90	53.69	10.74
LBCI	-113.35	-70.85	-170.94	-34.19

Four Weeks Elapsed	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-4.80	47.10	-18.50	-10.60	12.60	25.80	5.16
Variance	3276.62	2168.99	257.61	138.04	234.49	1791.96	71.68
S D	57.24	46.57	16.05	11.75	15.31	42.33	8.47
UBCI	30.68	75.97	-8.55	-3.32	22.09	52.04	10.41
LBCI	-40.28	18.23	-28.45	-17.88	3.11	-0.44	-0.09

Four Weeks Elapsed	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	42.30	-16.50	25.80	5.16
Variance	1874.90	377.83	1791.96	71.68
S D	43.30	19.44	42.33	8.47
UBCI	69.14	-4.45	52.04	10.41
LBCI	15.46	-28.55	-0.44	-0.09

Five Weeks Elapsed	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-63.29	81.86	-18.07	-9.43	9.00	0.07	0.01
Variance	10572.22	10003.52	169.30	216.42	445.54	1525.30	61.01
S D	102.82	100.02	13.01	14.71	21.11	39.06	7.81
UBCI	-9.42	134.25	-11.26	-1.72	20.06	20.53	4.11
LBCI	-117.15	29.46	-24.89	-17.13	-2.06	-20.39	-4.08

Five Weeks Elapsed	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	18.57	-18.50	0.07	0.01
Variance	1929.49	333.19	1525.30	61.01
S D	43.93	18.25	39.06	7.81
UBCI	41.58	-8.94	20.53	4.11
LBCI	-4.44	-28.06	-20.39	-4.08

Seven Weeks Elapsed	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-30.50	24.00	-6.00	0.50	0.00	-12.00	-2.40
Variance	364.50	2.00	8.00	0.50	0.00	392.00	15.68
S D	19.09	1.41	2.83	0.71	0.00	19.80	3.96
UBCI	-4.04	25.96	-2.08	1.48	0.00	15.44	3.09
LBCI	-56.96	22.04	-9.92	-0.48	0.00	-39.44	-7.89

Seven Weeks Elapsed	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	-6.50	-5.50	-12.00	-2.40
Variance	312.50	4.50	392.00	15.68
S D	17.68	2.12	19.80	3.96
UBCI	18.00	-2.56	15.44	3.09
LBCI	-31.00	-8.44	-39.44	-7.89

Appendix 4-4-10 By Data Collection Elapsed Period - without Station #411 (Extreme Outlier) (One Week Elapsed)

One Week Elapsed	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-54.00	65.60	-13.50	-1.75	3.50	-0.15	-0.03
Variance	4586.53	4673.83	67.53	31.78	15.74	76.87	3.07
S D	67.72	68.37	8.22	5.64	3.97	8.77	1.75
UBCI	-24.32	95.56	-9.90	0.72	5.24	3.69	0.74
LBCI	-83.68	35.64	-17.10	-4.22	1.76	-3.99	-0.80

One Week Elapsed	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	11.60	-11.75	-0.15	-0.03
Variance	113.62	68.30	76.87	3.07
S D	10.66	8.26	8.77	1.75
UBCI	16.27	-8.13	3.69	0.74
LBCI	6.93	-15.37	-3.99	-0.80

Appendix 4-4-11 By Data Collection Day of the Week – with Station #411 (Extreme Outlier)

Monday	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-20.83	22.08	-9.08	-2.75	3.25	-7.33	-1.47
Variance	1385.79	388.45	90.81	52.57	22.75	807.33	32.29
S D	37.23	19.71	9.53	7.25	4.77	28.41	5.68
UBCI	0.23	33.23	-3.69	1.35	5.95	8.74	1.75
LBCI	-41.90	10.93	-14.48	-6.85	0.55	-23.41	-4.68

Monday	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	1.25	-8.58	-7.33	-1.47
Variance	970.75	65.72	807.33	32.29
S D	31.16	8.11	28.41	5.68
UBCI	18.88	-4.00	8.74	1.75
LBCI	-16.38	-13.17	-23.41	-4.68

Tuesday	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-77.88	91.94	-18.13	-0.88	1.13	-3.81	-0.76
Variance	4394.92	4388.33	100.25	18.92	29.98	229.63	9.19
S D	66.29	66.24	10.01	4.35	5.48	15.15	3.03
UBCI	-45.39	124.40	-13.22	1.26	3.81	3.61	0.72
LBCI	-110.36	59.48	-23.03	-3.01	-1.56	-11.24	-2.25

Tuesday	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	14.06	-17.88	-3.81	-0.76
Variance	129.66	248.52	229.63	9.19
S D	11.39	15.76	15.15	3.03
UBCI	19.64	-10.15	3.61	0.72
LBCI	8.48	-25.60	-11.24	-2.25

Wednesday	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-49.29	70.93	-16.21	-12.07	14.21	7.57	1.51
Variance	9431.45	10565.46	223.41	251.15	443.26	255.03	10.20
S D	97.12	102.79	14.95	15.85	21.05	15.97	3.19
UBCI	1.59	124.77	-8.38	-3.77	25.24	15.94	3.19
LBCI	-100.16	17.08	-24.04	-20.37	3.19	-0.79	-0.16

Wednesday	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	21.64	-14.07	7.57	1.51
Variance	742.25	274.53	255.03	10.20
S D	27.24	16.57	15.97	3.19
UBCI	35.91	-5.39	15.94	3.19
LBCI	7.37	-22.75	-0.79	-0.16

Thursday	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	15.00	72.00	-24.00	-9.00	21.50	75.50	15.10
Variance	25992.00	7688.00	50.00	200.00	612.50	8320.50	332.82
S D	161.22	87.68	7.07	14.14	24.75	91.22	18.24
UBCI	238.44	193.52	-14.20	10.60	55.80	201.92	40.38
LBCI	-208.44	-49.52	-33.80	-28.60	-12.80	-50.92	-10.18

Thursday	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	87.00	-11.50	75.50	15.10
Variance	5408.00	312.50	8320.50	332.82
S D	73.54	17.68	91.22	18.24
UBCI	188.92	13.00	201.92	40.38
LBCI	-14.92	-36.00	-50.92	-10.18

Friday	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-343.08	351.58	-46.17	-4.08	14.58	-27.17	-5.43
Variance	220223.72	197078.27	1977.24	137.90	284.45	19146.52	765.86
S D	469.28	443.93	44.47	11.74	16.87	138.37	27.67
UBCI	-77.56	602.76	-21.01	2.56	24.13	51.12	10.22
LBCI	-608.60	100.40	-71.33	-10.73	5.04	-105.46	-21.09

Friday	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	8.50	-35.67	-27.17	-5.43
Variance	14850.27	1159.33	19146.52	765.86
S D	121.86	34.05	138.37	27.67
UBCI	77.45	-16.40	51.12	10.22
LBCI	-60.45	-54.93	-105.46	-21.09

Appendix 4-4-12 By Data Collection Day of the Week – without Station #411 (Extreme Outlier) (Tuesday)

Tuesday	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-89.50	103.64	-19.57	-1.14	0.86	-5.71	-1.14
Variance	3878.73	3883.02	95.19	17.36	32.59	219.91	8.80
S D	62.28	62.31	9.76	4.17	5.71	14.83	2.97
UBCI	-56.88	136.28	-14.46	1.04	3.85	2.05	0.41
LBCI	-122.12	71.00	-24.68	-3.33	-2.13	-13.48	-2.70

Tuesday	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	14.14	-19.86	-5.71	-1.14
Variance	121.52	250.44	219.91	8.80
S D	11.02	15.83	14.83	2.97
UBCI	19.92	-11.57	2.05	0.41
LBCI	8.37	-28.15	-13.48	-2.70

Appendix 4-4-13 By Data Collection Loop Type –with Station #411 (Extreme Outlier)

Inductive Loop	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-67.70	82.42	-20.36	-2.16	4.00	-3.80	-0.76
Variance	23181.28	16969.64	619.30	49.93	52.57	5146.12	205.84
S D	152.25	130.27	24.89	7.07	7.25	71.74	14.35
UBCI	-25.50	118.53	-13.46	-0.20	6.01	16.08	3.22
LBCI	-109.90	46.31	-27.26	-4.12	1.99	-23.68	-4.74

Inductive Loop	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	14.72	-18.52	-3.80	-0.76
Variance	4151.47	481.19	5146.12	205.84
S D	64.43	21.94	71.74	14.35
UBCI	32.58	-12.44	16.08	3.22
LBCI	-3.14	-24.60	-23.68	-4.74

Microwave	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-481.33	495.17	-35.00	-29.17	45.67	-4.67	-0.93
Variance	289252.67	289182.97	1088.00	112.97	153.47	699.47	27.98
S D	537.82	537.76	32.98	10.63	12.39	26.45	5.29
UBCI	-50.99	925.46	-8.61	-20.66	55.58	16.50	3.30
LBCI	-911.68	64.87	-61.39	-37.67	35.75	-25.83	-5.17

Microwave	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	13.83	-18.50	-4.67	-0.93
Variance	274.97	520.30	699.47	27.98
S D	16.58	22.81	26.45	5.29
UBCI	27.10	-0.25	16.50	3.30
LBCI	0.56	-36.75	-25.83	-5.17

Appendix 4-4-14 By Data Collection Type –without Station #411 (Extreme Outlier) (Inductive Loop)

Inductive Loop	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-70.67	85.44	-20.88	-2.29	4.04	-4.35	-0.87
Variance	23935.25	17459.27	638.20	50.55	54.38	5353.43	214.14
S D	154.71	132.13	25.26	7.11	7.37	73.17	14.63
UBCI	-26.90	122.82	-13.73	-0.28	6.13	16.34	3.27
LBCI	-114.43	48.06	-28.02	-4.30	1.96	-25.05	-5.01

Inductive Loop	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	14.77	-19.13	-4.35	-0.87
Variance	4320.31	491.64	5353.43	214.14
S D	65.73	22.17	73.17	14.63
UBCI	33.37	-12.85	16.34	3.27
LBCI	-3.82	-25.40	-25.05	-5.01

Appendix 4-4-15 By Data Collection Direction – with Station #411 (Extreme Outlier)

East	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-60.64	79.71	-12.50	-11.43	13.50	8.64	1.73
Variance	11643.17	11658.22	139.35	265.49	453.65	654.25	26.17
S D	107.90	107.97	11.80	16.29	21.30	25.58	5.12
UBCI	-4.12	136.27	-6.32	-2.89	24.66	22.04	4.41
LBCI	-117.17	23.15	-18.68	-19.96	2.34	-4.76	-0.95

East	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	19.07	-10.43	8.64	1.73
Variance	1176.53	162.26	654.25	26.17
S D	34.30	12.74	25.58	5.12
UBCI	37.04	-3.76	22.04	4.41
LBCI	1.10	-17.10	-4.76	-0.95

West	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-42.57	58.07	-16.21	-1.50	1.71	-0.50	-0.10
Variance	1489.49	1636.38	102.34	21.96	38.84	258.27	10.33
S D	38.59	40.45	10.12	4.69	6.23	16.07	3.21
UBCI	-22.35	79.26	-10.92	0.95	4.98	7.92	1.58
LBCI	-62.79	36.88	-21.51	-3.95	-1.55	-8.92	-1.78

West	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	15.50	-16.00	-0.50	-0.10
Variance	81.96	286.00	258.27	10.33
S D	9.05	16.91	16.07	3.21
UBCI	20.24	-7.14	7.92	1.58
LBCI	10.76	-24.86	-8.92	-1.78

South	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-37.13	69.88	-18.69	-5.44	6.06	14.69	2.94
Variance	8000.92	6145.98	160.50	68.40	97.00	1346.23	53.85
S D	89.45	78.40	12.67	8.27	9.85	36.69	7.34
UBCI	6.70	108.29	-12.48	-1.39	10.89	32.67	6.53
LBCI	-80.95	31.46	-24.90	-9.49	1.24	-3.29	-0.66

South	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	32.75	-18.06	14.69	2.94
Variance	1373.13	212.33	1346.23	53.85
S D	37.06	14.57	36.69	7.34
UBCI	50.91	-10.92	32.67	6.53
LBCI	14.59	-25.20	-3.29	-0.66

North	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-352.83	337.08	-43.92	-1.25	13.67	-47.25	-9.45
Variance	210714.15	204127.72	2155.72	112.20	306.97	17560.20	702.41
S D	459.04	451.80	46.43	10.59	17.52	132.51	26.50
UBCI	-93.11	592.72	-17.65	4.74	23.58	27.73	5.55
LBCI	-612.56	81.45	-70.19	-7.24	3.75	-122.23	-24.45

North	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	-15.75	-31.50	-47.25	-9.45
Variance	13748.02	1285.18	17560.20	702.41
S D	117.25	35.85	132.51	26.50
UBCI	50.59	-11.22	27.73	5.55
LBCI	-82.09	-51.78	-122.23	-24.45

Appendix 4-4-16 By Data Collection Direction – without Station #411 (Extreme Outlier) (West)

West	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-50.25	66.08	-17.58	-1.92	1.50	-2.17	-0.43
Variance	1276.93	1443.72	103.72	20.08	43.91	267.61	10.70
S D	35.73	38.00	10.18	4.48	6.63	16.36	3.27
UBCI	-30.03	87.58	-11.82	0.62	5.25	7.09	1.42
LBCI	-70.47	44.58	-23.35	-4.45	-2.25	-11.42	-2.28

West	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	15.83	-18.00	-2.17	-0.43
Variance	62.88	304.55	267.61	10.70
S D	7.93	17.45	16.36	3.27
UBCI	20.32	-8.13	7.09	1.42
LBCI	11.35	-27.87	-11.42	-2.28

Appendix 4-4-17 By Traffic Volume-with Station #411 (Extreme Outlier)(Ground Truth Data)

GT<100	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-9.83	13.42	-4.00	-4.08	5.67	1.17	0.23
Variance	244.33	90.27	10.36	122.27	145.88	106.33	4.25
S D	15.63	9.50	3.22	11.06	12.08	10.31	2.06
UBCI	-0.99	18.79	-2.18	2.17	12.50	7.00	1.40
LBCI	-18.68	8.04	-5.82	-10.34	-1.17	-4.67	-0.93

GT<100	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	3.58	-2.42	1.17	0.23
Variance	102.99	12.27	106.33	4.25
S D	10.15	3.50	10.31	2.06
UBCI	9.33	-0.44	7.00	1.40
LBCI	-2.16	-4.40	-4.67	-0.93

100<GT<300	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-32.50	41.50	-7.70	-2.50	4.10	2.90	0.58
Variance	1376.72	1356.28	9.34	19.39	19.21	32.54	1.30
S D	37.10	36.83	3.06	4.40	4.38	5.70	1.14
UBCI	-9.50	64.33	-5.81	0.23	6.82	6.44	1.29
LBCI	-55.50	18.67	-9.59	-5.23	1.38	-0.64	-0.13

100<GT<300	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	9.00	-6.10	2.90	0.58
Variance	22.89	9.43	32.54	1.30
S D	4.78	3.07	5.70	1.14
UBCI	11.97	-4.20	6.44	1.29
LBCI	6.03	-8.00	-0.64	-0.13

300<GT<500	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-46.91	59.00	-20.18	-1.27	5.00	-4.36	-0.87
Variance	2109.89	518.60	78.76	24.42	9.80	1439.25	57.57
S D	45.93	22.77	8.87	4.94	3.13	37.94	7.59
UBCI	-19.76	72.46	-14.94	1.65	6.85	18.06	3.61
LBCI	-74.05	45.54	-25.43	-4.19	3.15	-26.78	-5.36

300<GT<500	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	12.09	-16.45	-4.36	-0.87
Variance	1967.09	78.87	1439.25	57.57
S D	44.35	8.88	37.94	7.59
UBCI	38.30	-11.21	18.06	3.61
LBCI	-14.12	-21.70	-26.78	-5.36

500<GT<1000	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-71.07	104.53	-23.40	-8.87	8.27	9.47	1.89
Variance	10770.35	6716.84	48.11	109.55	343.21	1815.84	72.63
S D	103.78	81.96	6.94	10.47	18.53	42.61	8.52
UBCI	-18.55	146.01	-19.89	-3.57	17.64	31.03	6.21
LBCI	-123.59	63.06	-26.91	-14.16	-1.11	-12.10	-2.42

500<GT<1000	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	33.47	-24.00	9.47	1.89
Variance	1297.41	222.86	1815.84	72.63
S D	36.02	14.93	42.61	8.52
UBCI	51.70	-16.45	31.03	6.21
LBCI	15.24	-31.55	-12.10	-2.42

GT>1000	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-531.00	537.38	-66.25	-7.75	23.25	-44.38	-8.88
Variance	235295.14	206291.70	1944.50	444.50	542.50	28260.84	1130.43
S D	485.07	454.19	44.10	21.08	23.29	168.11	33.62
UBCI	-194.86	852.12	-35.69	6.86	39.39	72.12	14.42
LBCI	-867.14	222.63	-96.81	-22.36	7.11	-160.87	-32.17

GT>1000	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	6.38	-50.75	-44.38	-8.88
Variance	22558.27	1227.07	28260.84	1130.43
S D	150.19	35.03	168.11	33.62
UBCI	110.45	-26.48	72.12	14.42
LBCI	-97.70	-75.02	-160.87	-32.17

Appendix 4-4-18 By Traffic Volume-without Station #411 (Extreme Outlier) (GT<100)

GT<100	16 Feet	30 Feet	50 Feet	79 Feet	> 79 Feet	Total	Average
Average	-12.50	14.10	-3.20	-5.10	6.20	-0.50	-0.10
Variance	210.72	107.21	4.84	136.99	174.40	91.39	3.66
S D	14.52	10.35	2.20	11.70	13.21	9.56	1.91
UBCI	-3.50	20.52	-1.84	2.15	14.39	5.43	1.09
LBCI	-21.50	7.68	-4.56	-12.35	-1.99	-6.43	-1.29

GT<100	16-ft and 30-ft	Truck (Over 30-ft)	Total	Average
Average	1.60	-2.10	-0.50	-0.10
Variance	59.16	10.77	91.39	3.66
S D	7.69	3.28	9.56	1.91
UBCI	6.37	-0.07	5.43	1.09
LBCI	-3.17	-4.13	-6.43	-1.29