



Rapidly Deployable Low-Cost Traffic Data and Video Collection Device

Final Report

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Executive Summary

Transportation practitioners, planners and researchers lack the availability of an easily deployable, non-intrusive, portable, low-cost device for traffic data collection and video recording at intersections and arterials as well as temporary remote surveillance. The necessary data usually includes volumes, speeds, classification, turning movements, queue size and length, conflicting movements, and time headways. They also include recording of traffic characteristics, accidents and other special situations. A visual record of traffic characteristics at intersections, arterials, or other locations can also be used for extensive analysis and research leading to improved safety and control practices. In this report, the development and demonstration of a low-cost, practical, rapidly deployable video recording and data collection device is presented along with the design, deployment, and data extraction process. Its major advantage at intersections is that only one unit can cover an entire intersection up to 5 lanes per incoming approach wide (20 incoming lanes total), which should be sufficient for the overwhelming majority of intersections. In addition, it has the potential of extracting turning movements automatically including optional lanes through advanced machine vision or radar sensors.

To develop the prototype, we first consulted with a panel of practitioners, researchers, and engineers in the area of traffic data collection to determine functional specifications of the portable system. Additionally, an existing apparatus was modified to collect video recordings from three urban intersection sites. Pole height as well as camera positioning with respect to the intersection and signal pole locations, and field of view was assessed. The data were used to first evaluate a previously developed tracking algorithm to determine the most suitable algorithm to use for automated traffic measurement extraction. The tracking algorithm did not provide suitable accuracy for thru and turning movement counts utilizing the existing apparatus. A widely available commercial machine vision system was therefore utilized for the remainder of the study.

An intersection lane-approach topology was developed and used to facilitate the selection of actual field site locations. Based on this topology four sites were secured that range from single/double lane mixed approaches, typical of urban intersections, to wide arterials with isolated and mixed turn lanes. All intersections experience heavy levels of peak hour traffic volumes.

A prototype data recording apparatus was then developed using a self-raising extensible mast and custom fabricated base to elevate the camera to a maximum height of approximately 30 feet above the road surface. The apparatus is designed to be secure-clamped to sign, light or traffic signal poles. An interface was developed to configure daily recording schedules and operation of other hardware in order to utilize battery power as efficiently as possible. Approximately 40 hours of traffic video can be stored before battery swapping/recharging is necessary. The apparatus was successfully deployed and left unattended for one to two weeks at a time at the four selected intersections and one mid-block site to collect video under a variety of traffic and environmental conditions. Standard traffic measurements (speeds, counts, vehicle classification) using a widely available commercial machine vision system were then extracted and compared

with ground truth data. A statistical analysis was then performed to determine the accuracy of the extracted measurements.

The findings of this study demonstrate volumes at arterials can be automatically extracted with an aggregate mean percent error within 10 percent of the ground truth measurements. The mid-block experiment determined the ability of the apparatus to extract vehicle speed and class upstream of an intersection. The findings from that experiment indicated the lane closest to the apparatus matched ground truth speeds reasonably well but degraded as the cross lane distance from the camera increased. Classification for private vehicles was correct over 90% of the time while larger vehicle class assignments resulted in much larger errors. Limitations and sources of errors, which affect the measurement accuracy of the machine vision system, are discussed. This study demonstrated that a rapidly deployable stand-alone apparatus for collecting traffic video data at or near arterial intersections is feasible and reliable.

A. Introduction

This report is aimed at demonstrating a low-cost, non-intrusive, portable and easily deployed traffic data and video collection device. Our focus is the acquisition of basic traffic information necessary in data collection for signal timing optimization. Such data collection primarily involves tedious, intensive and unregulated manual labor, which is undoubtedly error prone and expensive. The current standards used for performance monitoring and signal optimization is rarely carried out and fails to meet the needs of transportation officials, but more importantly drivers and passengers. In response, our research has found the most optimal device must be capable of supplying both scheduled video and verifiable data for optimization of signal timing.

Currently, few intersections are instrumented with sensors to collect some of the aforementioned data— in particular, traffic volumes. Temporary counting and classification devices have severe limitations, in that the data they can extract are usually constrained to point measurements of volume, speed and classification. Furthermore, they suffer from the difficulty in installation as they are intrusive, requiring interruption of traffic flow and have inherent safety concerns. Thus, most required data collection is typically performed manually and is therefore of uncertain quality and accuracy not to mention without methods of data verification. Cost and time considerations are overlooked at a small fraction of intersections, which are instrumented with sensors for collecting traffic data such as volumes, speeds and classification. The currently deployed sensors for collecting such information are expensive, permanent, intrusive and difficult to deploy.

Cost aside, intrusive systems such as embedded sensors and temporary counting and classification devices such as loops have their benefits, however, the safety and disruptive nature of their installation continues to make them a poor choice for gathering regularly collected data. Furthermore, since the data they can extract is usually constrained to point measurements of volume, speed and classification which needs to be collected at all arterials on a much more frequent basis, such data collection is often is not performed and historical records for important studies at major arterials or corridors is generally lacking.

Recently introduced non-intrusive systems such as Light Detection and Ranging (LIDAR) and radar are used in permanent installations and although they are suitable for portable traffic data collection they have not as yet been packaged for this application due to cost and integration limitations.

It is worth noting that existing data collection devices have no surveillance or video recording capabilities for visual observations and verification. In short, the need for inexpensive, portable, rapidly deployable, easy to use devices for traffic data collection that can be used on demand has been well established among practitioners as well as researchers.

Responding to the needs of transportation officials and also meeting data collection requirements we are presenting an option that considers price, occlusion and obstruction with very simple portable deployment. Desired specifications as well as the prototype design used at several urban intersection test sites as a means of field deployment for data collection are also presented here along with accuracy of volumes, speeds and classification test results.

B. Background

There are several methods through which vehicle counts are currently obtained such as traditional manual counting [2], and tube counting or less common acoustic or radar and machine vision counting. Manual counting is generally assisted using a push button interface device to register and record each passing vehicle (for example, JAMAR Manual counter DB-400). While each counting device costs are modest, there is a recurring cost of manual counting, which is a time consuming and costly logistical process, especially when the recording period is long and/or the number of intersections is large. Furthermore, the accuracy of the recorded measurements from manual counting is difficult to verify without visual records.

Tubular counters such as the JAMAR Trax series record vehicle counts through air pulses sent through rubber tubes mounted on the roadway. The JAMAR Trax system currently costs between three and five thousand dollars but has only a small recurring cost of setup and tube replacement. Tubular vehicle counting is relatively inexpensive and accurate, however, it has drawbacks such as intrusive setup, an inability to detect turning movements, heavy vehicles breaking the tubes and a theft prone design; in addition it has no video recording and verification capabilities. Due to limitations in advanced data collection ability and furthermore, inabilities for tubular counters to be non-intrusive, tubular counters are not tested in this study.

Acoustic counting is inaccurate leading to radar counting as a better alternative. Both use a technology similar to sonar, which sends out pulses of sound and then collects the variation in each returning pulse to detect objects in the range. Another technology that is similar in principle is Light Detection and Ranging (LIDAR), which is based on measuring the time-of-flight of an emitted infrared laser directed pulse that is reflected off the target (e.g., vehicles). While radar and LIDAR can be accurate methods of vehicle detection and are non-intrusive, both have limited use as they, like tubular counters, only detect a single location on the roadway and thus can only potentially collect volume, speed and classification data with no turning movement collection option. LIDAR units are new and thus no commercially available vehicle counting sensor readily exists. Furthermore, LIDAR is very expensive and cannot detect vehicle movements throughout an area as large as an intersection and thus have no applicability in this study. Similar to LIDAR, radar's suitability and use at intersections has not been established, radar, like LIDAR has no potential for collecting an entire intersection from a single location or with a single unit thus creating a deployment cost far exceeding that of other sensors. Radar counters such as the Remote Traffic Microwave Sensor (RTMS) presently cost between four and five thousand dollars and require a more complex integration aspect for deployment than other existing devices such as machine vision. Due to cost and more importantly utility limitations for advanced data collection with the portable system being designed and tested in this study, LIDAR, radar and acoustic counters were not tested.

Machine vision technology utilizes image-based camera sensors in order to detect vehicles in real-time or by post-processing the video. This technology has the greatest potential since camera sensors are ubiquitous and cost effective as they have the capability of detecting several different traffic measurements at multiple locations within the road facility with a single sensor (speeds, counts, headways, etc.). Furthermore, they are non-intrusive, and, capable of providing visual records for verification and storage. Like RTMS, most commercially available machine vision

systems are designed primarily for traffic management rather than as an ‘off-line’ traffic measurement and analysis tool [1]. Their cost is comparable or lower than RTMS. A review on these and similar commercially available non-intrusive traffic measurement sensors may be found in [2] and [3].

Based on such considerations and its versatility (which includes a number of new detection-types and Boolean detection logic) video sensors are most suitable for non-intrusive portable data collection at intersections. While a few experimental portable, image-based, traffic measurement systems have been developed [4], none is commercially available. In addition there is a liberal interpretation regarding the usage of the term ‘portable’ in the literature. For the purposes of this report, we evaluate the degree of portability by the ability to move, assemble power, configure, or disassemble the system within a short time period, in the order of 15 minutes or less. This is because if the period were longer, the ease of setup and portability would be compromised. In terms of the latter, one adult should be able to carry out the entire deployment process alone without the assistance of lifting machinery. Finally in terms of simplicity, operation of the system should require little training in the order of 4 hours or less.

Non-intrusive traffic measurement infers that vehicular traffic is not disrupted during installation or removal. This means that safety is never compromised during the deployment process. Furthermore, portable systems must be capable of unattended operation for extended periods. Previously developed video based systems are basically one-of-a-kind and tend to be trailer-based extendable pole mast systems with battery storage (and possibly solar array apparatus). The pole mast sections foldout to various configurations for allowing detection equipment to be erected [5].

Another approach used for intersection traffic data analysis and surveillance consists of a van equipped with rooftop mast. In this configuration the camera, machine vision processing, transmission, and recording components are located inside the vehicle [4]. Such a ‘drive and park’ deployment system contains readily available power from the vehicle along with ample storage; this represents a complete ‘mobile laboratory’ rather than a low-cost data collection device. A site-based permanent camera was necessary to collect video data under inclement conditions such as rain or snow. Using this setup the feasibility of extracting turning and thru lane counts at urban intersections using either a previous commercially available strip-region based video tracking algorithm or a commercial tripwire video detection machine vision system was assessed. The measurement accuracy of the turning movement tripwire technique developed was too complex and not sufficient to be used in practice at larger intersections. Conversely, the tracking algorithm produced accurate measurements but was too difficult and cumbersome to configure. Nevertheless, the ability to record and extract all required data on site was successfully demonstrated. The cost of this van system was approximately \$100,000 dollars. Arguably the degree of portability for this and other trailer-based systems is limited because of the difficulties securing and positioning them at urban streets as well as rapidly deploying them at multiple intersections. Furthermore, parking at distances far from the intersection requires increasing mast height for placing cameras.

Recently a portable system was developed and deployed on high-rise building rooftops along a 1.5 mile long freeway ‘commons’ site in Minneapolis for digitally recording live accidents while simultaneously extracting traffic data in order to study accident dynamics [5]. This system

consists of one or more commercial machine vision sensors (Autoscope) and manual, vari-focal video cameras affixed to a 6' pole mast. The base of the pole mast consists of a 3.5x3.5 ft² weighted platform (250 lbs) and a 2'x 2'x 2' environmentally controlled enclosure. The system provides real-time collection, storage, and transmission of vehicle headways, speeds, length classification, and volume counts generated by the Autoscope video sensor as well as storing MPEG4 encoded video (DivX v.5.1) [5]. The video recording and transmission is implemented on a small footprint (MicroITX) PC. Other off the shelf media conversion hardware connects the PC and machine vision sensors to an 802.16 30 mbps 2-way radio, which wirelessly transmits all data back to a remote location for further post processing and analysis. Laboratory experiments revealed that the power consumption from the machine vision sensor and communications hardware was approximately 30 Watts (PC and camera-hardware temperature control was not considered). External power was readily available at each site. Current traffic measurements for such a system were based on Autoscope's data extraction system. The accuracies are acceptable and in accordance with the hardware's operational parameters. Although some of the design and deployment aspects of this portable system provide important relevant information, this system is not deployable for all practical purposes at intersections as it lacks easy camera installation, weatherization and autonomy. Furthermore, the cost is relatively high (\$15,000) but without stand alone features such as power, cabinet, camera pole, etc.

'Hand-erected' extendable mast designs supporting side-fire radar traffic counting and speed sensors powered by deep cycle batteries also recently developed [6]. The pole systems with a side-fire radar sensor (RDMS) cost approximately \$6,000, are easily stored, and can be quickly transported to multiple sites (sensor faces at a 90 degree angle to the traffic flow). The mast is mounted on existing infrastructure. A deep cycle battery can enable the RDMS to collect data for approximately three days. Although this system is the most space saving and least intrusive of all previously mentioned systems, the system has no surveillance or video recording capabilities. In addition, the radar sensors tested are not suitable for detecting stopped vehicles, queues, and turning movements; i.e. not suitable for intersections.

In conclusion, although aspects of each of the designs and experiments provide useful knowledge to guide the rationale for the prototype design and development, none of the previous efforts have fully addressed all of the aforementioned concerns including; cost, intrusiveness, portability, reliability and performance. In light of this, the functional specifications and thus the remainder of this report are specifically tailored to address and mitigate these and other concerns voiced by transportation practitioners we consulted.

C. Functional Specifications

Before exploring design alternatives for the apparatus, we developed through a series of meetings with transportation engineers at the University of Minnesota and traffic engineers from the Minnesota Department of Transportation (Mn/DOT) a set of specifications for our apparatus. Functional specifications related to size, weight, durability, portability, and data collection capabilities were essential in the development of the device. Such specifications are governed by minimum capabilities that should result in a useful system as well as ideal specifications, which significantly advance state-of-the-practice for traffic measurements at urban intersections and mid-block locations. The specifications are defined by nine criteria:

1. Traffic data collection and measurement	6. Data organization format
2. Volume and geometric limitations	7. Setup and portability
3. Speed	8. Environmental conditions
4. Classification level	9. Cost.
5. Time periods and scheduling	

Such specifications were developed and presented to local traffic consultants with Professional Engineering certification and Mn/DOT technicians involved with regular vehicle data collection, for review and comment prior to the design stage and are described below as well as studying requirements within the Minnesota Manual on Uniform Traffic Control Devices (2005) [6].

Traffic Data Collection and Measurement Specifications

- All standard traffic measurements such as volume, classifications and speed must be collected at the lane level.

It is desirable for the apparatus to at least have the ability to extract turnings at intersections.

Volume and Geometric Limitations

- The accuracy range for volume counts must be at least 85% and preferably, 95% of actual. This specification is standard practice.
- The system should be able to handle road widths up to eight lanes or up to 100 feet.

The rationale for the desired roadway width of 100 feet is that the prevailing maximum number of lanes on arterials in Minnesota is eight lanes. This means that if a median is included the maximum road width should be 100 feet. Therefore, the system must be able to handle up to eight lane arterials or intersection approaches up to eight lanes total including

any and all turning lanes. Subject to the 100 feet limitation, the system should have the capability to handle isolated turning lanes separated by a median.

- The system should be able to handle up to four intersection approaches simultaneously.

This is due to time and cost considerations as well as efficiency since the user should not have to replicate the installation at the same site. When conditions do not allow, it is desirable to collect at least two approaches such that no more than two installations are necessary at a given site.

Mn/DOT frequently is required to collect per-lane volumes for arterials, which contain four lanes in each direction. This is because these arterials carry high volumes of traffic, which significantly impacts demand patterns on Freeways and other highway facilities. For example, Mn/DOT's portable detection system uses a side-fire Remote Traffic Microwave Sensor radar system (RTMS) [7] collects total intersection volume and per-lane volume counts for up to four lane roads (although product literature for this device will claim the device can measure up to 8 lanes). The minimum, and perhaps more feasible, number of lanes at either intersection or mid-block locations are four lanes; as previously noted, other portable measurement systems achieve this in practice. Lastly, the system should have the capability to simultaneously count isolated near right turn lanes; such traffic data are necessary in order to better assess alternative intersection designs. Note that intersections of interest to practitioners with fewer than four approaches have been identified for our study.

Speed

- The speed accuracy is only needed at mid-block locations with minimum required mean accuracy of 90 percent.

Vehicular traffic speeds located within the intersection is of little value to practitioners in so far as these measurements have little impact on assessing demands and travel behaviors. However, speed measurements are occasionally collected at mid-block locations before intersections. The current portable traffic measurement data collection system utilized by Mn/DOT has the capability to measure and aggregate vehicle speeds as long as vehicle speeds are traveling more than 5 miles per hour.

Classification Level

- Vehicle classification must include at least three classes for passenger vehicles, trucks and buses. The mean accuracy should be no less than 85 percent.

Here, Buses and semi-tractor-trailers are both of the same class while trucks such as municipal vehicles are of a separate class. Data classifications, which would comply with FHWA thirteen classes, would be desirable particularly for mid-block location traffic measurements [8]. Note that the thirteen classifications are stratified by number of axles and the length between each axle. In practice, due to time constraints and the difficulty in distinguishing all 13 classes, typically no more than 5 classes are obtained during temporary field site data traffic data collection efforts. For intersections 5 classes is more than sufficient

for most studies. Autoscope, a commercially available video processing system and the device used in this study, is capable of delineating five class types based on vehicle length.

Time Periods and Scheduling

- The standard traffic measurements require sampling periods must be user specified to one of the following: 1 minute, 5 minute, 15 minute, 1 hour, or daily (24 hour) increments.

Based on historical records for traffic warrants used for signal retiming [9], a 15-minute interval was selected to be the standard for all data counts in this study.

The system must be able to be deployed in the field and operational (for scheduled recordings) for at least a month during which it must be able to record at least 48 total hours of scheduled video and data without power, memory or other maintenance.

Based on discussion with traffic practitioners, 48 hours of total video is to be considered a practical lower bound capability of the system. A desirable recording schedule for signal retiming would consist of eight hours per day broken into three scheduled peak periods (see time periods below) then a minimum of six days are needed to meet the 48 hours of required data collection. Ideally, practitioners voiced a desire to have two weeks of deployment over which, recording and data collection would take place mid week (Tuesday, Wednesday, Thursday) during only peak hours as follows: 6:30 – 9:30AM, 11:00AM-1:00PM, and 3:30-6:30PM.

Another goal voiced by practitioners is to measure, without revisiting the test site, the beginning/end week conditions (Monday/Friday), or quantify non-peak conditions. For example, the Minnesota Department of Transportation (Mn/DOT) will occasionally collect traffic volume data during off-peak periods over a 24 to 48 hours period. In conclusion, the system must have the ability for a myriad of user-scheduling and sampling periods for all standard traffic measurements under consideration. This applies to advanced traffic measurements, such as vehicle delay and turning counts) as well.

Data Organization Format

- The system should produce data in a standard presentation format.

The most desired format is a table, which collates all data row-wise; into the desired time period (5 minute, 15 minute, etc.) for each approach (or lane) and in each direction (columns). From these data other aggregate measurements can be tabulated such as: hourly/daily measurements on a per-approach (or lane) or summated approach (or lane) basis.

Set Up and Portability

- The system should be compact and lightweight with a footprint measuring no more than 2' x 1.5'.

Since the minimum sidewalk clearance between signal poles and the edge of the sidewalk is five feet, a maximum are footprint for the apparatus should not exceed 2 x 1.5 feet in order to ensure adequate clearance for wheelchairs as well as pedestrians. Total dimensional specifications are also critical for hauling multiple systems in a practitioner's vehicle and storage of multiple systems within such vehicles will be required for wider scale deployment across multiple intersections (described next).

- The system should be storable in a standard size mini-van.

The apparatus should be easily transportable in vehicles such as minivans and cargo vans. A general capability voiced by field engineers is that the apparatus should easily disassemble in order to maximize storage efficiency both at base facilities and within the vehicle. For example, the maximum cargo length of a stock Dodge Caravan is reported to 8 feet in length, with a maximum width of 47.5 inches, and a maximum height of 39.5 inches. This includes a total cargo capacity of 144.2 cubic feet. Other similar vehicles were checked; for example, the Toyota Sienna maximum length is 6.5 feet (which was the minimum of all the vans checked) whereas a typical cargo van has a cargo capacity of 12 feet by 4 feet by 4 feet.

- The system should be cartable by a single person and deployable within fifteen minutes with no part weighing more than 60 lbs.

It is assumed that all field sites will have some infrastructure (sign, signal, or light poles) for the apparatus to be affixed. An acceptable complete set up time of no more than fifteen minutes was determined; anything longer will nullify its utility especially for very short studies where only a few hours of data are needed. A desirable weight for the total system is 75 lbs. Or, at least, the system or individual components can be quickly transported on-foot to the field site.

There should not be any exposed power or communication cables. No other external power supplies should be required to operate the system for various time periods discussed above. If additional power via batteries needs to be replaced or added, there should be no interruption in the data collection at the site. Furthermore, available power should be managed as efficiently as possible and conserved during times of system idling where no data collection is taking place.

Video imaging vehicle detection accuracy will improve as camera height is increased within the range of 20 to 40 ft above the roadway. The highest camera height seen for minimizing cross-lane occlusion was 38 feet for adjacent lanes, and 150-foot downlane approach distances [10]. Large intersections with more than 4 lanes per direction may still require multiple cameras, thus height restraints can remain within the 28 ft minimum parameter, which was obtained with the modified apparatus. It is worth noting here that while multiple cameras at a single intersection would be ideal, cost and integration limitations for this study are such that only a single camera is required for this system.

Environmental Conditions

- The system should be of industrial quality and able to stand adverse weather including winds up to 70 mph, hail, snow, rain, sleet, humidity and extreme cold and heat.

The desired minimum survivability wind load characteristics should be at least 70 mph, which are structural design constraints used by Mn/DOT for their signal and light pole designs and in correspondence with Mn/DOT field engineers. The desirable environmental range for operability during data collection should equal commercially available video-based traffic detection systems published from other video-based traffic sensing systems. For example, the Autoscope Terra has an operable temperature/humidity operational range from -29 degrees Fahrenheit to 140 degrees Fahrenheit at 100% relative humidity per MIL-E 5400T paragraph 4.3.24.4. The system should operate under day/nighttime lighting conditions. However, initially, there is no need for field collection during heavy snow or precipitation.

Cost

- The total system building costs including hardware, software and labor cannot exceed \$8,000.

Practitioners present at our panel meetings voiced that a total cost of approximately \$8,000 dollars per system including both software and hardware would be acceptable. Other portable traffic measurement systems that were previously deployed were similar in cost [11].

D. Prototype Design and Deployment Procedure

In order to fully understand the components and necessary areas of focus for the design and implementation process and furthermore, to minimize issues encountered during these processes, an initial field test was completed by modifying an existing apparatus [11] to collect initial field test video data. This will be described next. Then the subsequent design of the prototype developed for this study will be described. Based on the prototype design, the steps required to deploy the system will be summarized.

The apparatus was primarily designed to deploy side-fire radar sensors at an approximate height of 17 feet above the road surface. This was achieved by coupling two eight-foot length aluminum poles. From the field tests, in addition to geometric and occlusion analysis [12] we determined that a desirable minimum elevation height of 28 feet for the cameras is required. This was achieved by adding an additional 8' pole section using an identical coupler and modifying the sensor mounting bracket to hold a video camera. The base of the mast was then mounted to a signal pole approximately four feet above the sidewalk. The pole base mount was hinged to act as a fulcrum to lift the mast the mast into vertical position.

The field test device was very primitive and supplied insight as to the needs of a more industrial system. The initial deployment of the existing apparatus required constant supervision and weighted heavily upon existing infrastructure. In addition, hoisting the mast into the vertical position proved to be more difficult than anticipated due to the counter acting torque of the pole weight. This created some safety concerns because hoisting the mast in this manner often interfered with pedestrians or vehicles passing underneath. Nevertheless, three hours of video recording were obtained from the testing and the recorded video was then analyzed to determine the needs of our prototype including quality of the recorded video and durability of the pole and apparatus as a whole.

Based on this initial field test it was clear that to design such a system the limiting factors are constrained by cost, size, weight, stability, and data recording functionality. The resulting system, which meets our functional specifications, cost \$7800 to construct. Due to conflict with University policy regarding intellectual property rights, a more itemized cost breakdown is not available at this time. The system digitally records MPEG4 video from the camera upwards of 45 hours without power or data storage replacement. The system base box is a NEMA-4 enclosure with a footprint of 24 inches in height by 20 inches length by 12 inches deep. It was built from off the shelf components with custom machined parts added as necessary. A self-raising mast with internal cables elevates the 640x480 CCD video camera between 28 to 30 feet above the pavement surface (Figures 1 & 2). The components in the box are the DVR computer, the power management microprocessor, and the deep cycle batteries, which contained no moving parts for optimal utilization in the field (Figures 3 & 4). Software for the DVR and microprocessor were built upon open source software.



Figure 1: System deployed at Site 4



Figure 2: The cabinet with mounted components



Figure 3: Inside of cabinet (batteries, DVR and microprocessor)

- Telescopic pole and hydraulic / air pump
- Cabinet
 - DVR
 - Power Management System
 - Batteries
- Camera
- Cart

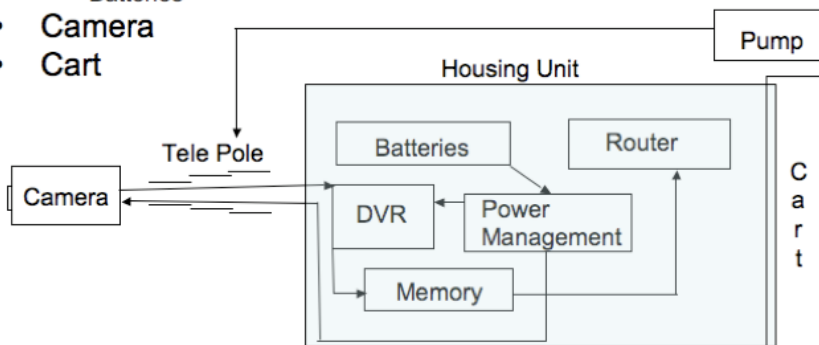


Figure 4: Diagram of components organization

The deployment procedure is organized into 12 steps. This deployment process is performed in reverse order to remove the system from the site. It should be noted that at present twisting the pole before it is locked into place achieves pan adjustments. Table 1 describes the set up deployment procedure for the current apparatus.

Table 1: Apparatus Deployment Procedure

Steps	Apparatus Deployment Procedure
1) Unload Base	The base box is placed upright on the sidewalk or other stable hard surface.
2) Elevate Base	The base box is elevated allowing the trolley frame to roll underneath by lowering the base legs.
3) Latch Base to Trolley	The base box is latched to the trolley with buckles located on the left and right sides of the box.
4) Mobilize Base	The legs are elevated and trolley wheels locked.
5) Attach Batteries	The batteries are placed in the base box.
6) Attach Camera and Pole to Base	The camera mount is latched to the top of the mast (if removed for transport) and the pole is slipped into the base mount of the base-box.
7) Transport Apparatus to Test Location	The wheels are unlocked and the entire system is wheeled to the appropriate location at the site which point it is backed up to the pole at which point the wheels are then re-locked.
8) Mounting Bracket	The pole mounting attachment described earlier is adjusted, fastened and secured to the site infrastructure.
9) Remove Cart from Base	The wheel mounts are removed while the feet are lowered lifting the box off of the cart as which point the cart is removed.
10) Raise Mast	Raise mast with a manual air pump.
11) Power System	The system is then powered and booted with the appropriate options set.
12) Lock Apparatus	The box is padlocked at the front, back and top door.

A group of five students were asked to deploy the apparatus to validate the deployment time constraint of 15 minutes. After a 30 minute training session each was asked to deploy the apparatus without assistance. Each student was successfully able to deploy the apparatus without assistance in under 15 minutes for setup and well as 15 minutes for removal. The average setup and removal time was 11:42 and 8:51 respectively.

E. Test Site Selection and Data Collection

In this section a background of historical data collections, environmental factors and approach topologies preface how test site selection and data collection are coordinate. It is important to remember that the main objective of the video recordings is to obtain accurate traffic data from recorded video observations. Another objective is to evaluate automated extraction, as a means to equal or surpass manual counts and reduce the time and effort required. Part of this evaluation requires analyzing the factors that affected the automated extracted traffic measurements. Such factors, which affect manual and automated traffic data extraction from the video, have been categorized as controllable or uncontrollable [13]. The traffic characteristics (traffic volumes, classes, etc.) wind, weather, and environment lighting are uncontrollable factors. Camera location is controllable to some extent however for a myriad of practical reasons very rarely can optimal positions be achieved in real life field deployments. Therefore, during the site selection process we performed occlusion analysis to determine the proper camera placement. This was accomplished with the objective of covering an entire intersection with a single camera while still being able to evaluate video image processing for data extraction and deployment feasibility at typical intersections [12]. Following engineering practice, three daily periods (AM, PM and off-peak) were selected. Specifically at all sites, mid-week (Tue,Wed.,Th) and weekend data were collected at three counting periods {0600-0900, 1100-1300 and 1530-1830}. A total of 106 hours were recorded and analyzed between August 2007 and May 2008 at both arterial and highway locations in the Twin Cities metropolitan area. These locations will be described in details later in this report. For this study automated traffic measurement extraction was not analyzed during extreme rain or poor lighting (pre-sunrise and dusk) although it should be noted that the system collected video data reliably during these time periods and was suitable for manual counting from the recorded video. Each site was selected based on requirements found in the functional specifications alongside recommendations from practitioners.

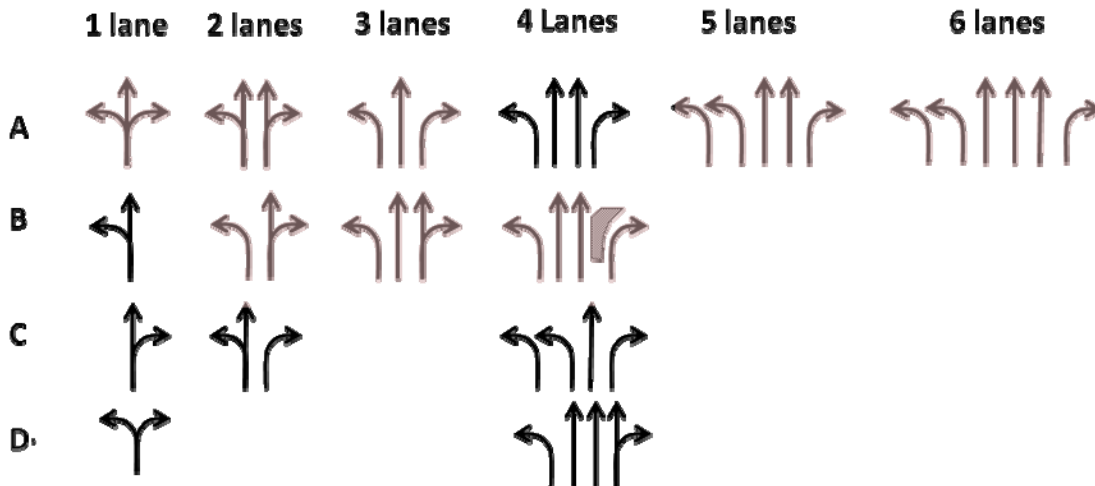
During the selected data collection periods lighting varied especially during sunrise and sunset thereby affecting counting accuracy. Sunset occurred later than 7:41PM after the time of data collection, i.e., after the PM peak period therefore no recording was necessary during or after sunset. Sunrise, however, varied between 6:53AM and 5:30 AM, while collection starts as early as 6:00 AM thus introducing lighting variation. For example, midweek data collections during the first week of April yield approximately one hour of pre-sunrise conditions. Similar effects will occur on later sites, including a post-sunset recording on Site 4. This should be a noted point in the results for understanding how light and shadows effects may hinder the results gathered from such video. In regards to the apparatus developed here, all hardware components were industrial quality; to be sure, since the initial deployment, the equipment was left unattended for data acquisition and video recording for upwards of three weeks under adverse environmental conditions such as extreme heat and cold, wind, rain, snow, and even hail without incident.

Topology

Due to the many combinations of approach design configurations at intersections and the maximum number of lanes specified (eight per approach) it is evident that a large number of intersections would be needed to satisfy testing requirements for all possible intersection designs. This is because there are fifteen common intersection approach lane configurations and commonly four approaches per intersection. Therefore, the possible intersection designs are

combination 15, 4 at a time. For this reason we developed the methodology described next to minimize the number of test sites needed.

Table 2: Topological Representation of Urban Intersection Approaches



By strategically selecting intersection sites, which include typical geometric layout complexities, we ensured that the system would have the ability to accurately extract traffic measurements in the majority of intersections. This was accomplished in cooperation with transportation practitioners present at our panel meetings. Initially, we identified fifteen intersection approach types, which are prevalent within the Twin Cities metropolitan area. From the set of fifteen a topology was identified in order to reduce the number of representative intersection types, which actually needed to be selected for testing the new portable video-based traffic measurement system (Table 1). For example, if the system can successfully be used to extract traffic measurements at a single-lane approach type A, then all subsequent single lane approach types B through D should produce results of similar accuracy. Considering type A can cover all two-lane approaches, i.e. all other two-lane approach types are similar. Finally at three-lane approaches, testing types B will cover a three-lane type A configuration.

Lane and intersection geometry may also influence measurement accuracy. For example, 5, and 6 lane topologies in Table 1 do not contain shared lane approaches, which is typical at high volume arterials. Such arterials commonly utilize dedicated turn and thru lanes. Therefore, experimentally validating a 2-lanes type B and 5-lane type A configurations will also validate 4-lane type B, C and D. Finally isolated right turn lanes represent another unique geometry not included.

Based on the above reasoning one only needs 4 test intersections consisting of only eight approach types. Through careful selection of intersection approach geometries, we were able to identify four intersections, which included the eight approach-types, which are shaded in Table 1. The approach geometries covered by each site are indicated in the right column of Table 2. We started with initial field volume data collection and video recording experiments at Site 1, which includes the shared single and two-lane approach configurations. We then progressively added lanes by collecting the same information and testing at Site 2. The effects of increasing

the number of approaches shown in Table 1 were analyzed from the collected data at Sites 3 and 4.

Each of the four intersection sites will be described in detail next. In addition, a fifth arterial site will be described below. This fifth site is a mid-block location used for testing the extraction of speed, classification, and volume upstream of a signalized intersection. The apparatus was deployed for more than 700 hours for all the sites tested under a variety of weather conditions. Experimental results from the first four sites will be presented first, followed by results from the mid-block traffic measurement experiment.

Table 3: Selected Intersection Sites and Their Approach Geometries.

Site	Location (Main & Side)	Approaches Types
1	CSAH 5 & Ottawa Ave, Saint Louis Park	2 x 2-lanes-A, 2 x 1-lane-A
2	CSAH 5 & Louisiana Ave S, Saint Louis Park	2 x 3-lanes-A, 2 x 3-lanes-B
3	CSAH 51 and Co. Rd B., Roseville	1 x 4-lanes-B, 1 x 5-lanes-A, 2 x 3-lanes-B
4	State HWY 262 and 66 th St., Brooklyn Center	5-lanes-A, 6-lanes-A, 3-lanes-A, 2-lanes-B

Site Descriptions

Site 1, Minnetonka Boulevard (CSAH5) and Ottawa Ave S, has two, single shared lane approaches running North and Southbound on the side street, Ottawa Ave S, and two, two lane shared approaches running East and Westbound on Minnetonka Boulevard (Figure 5). This site was used to run experiments to extract traffic measurements on single and double mixed lane traffic flows. The circled portion was associated with the largest approach count measurement errors. The system was deployed at this site for a total of 106 hours. The weather conditions during the deployment period varied from sunny to overcast with a maximum wind speed of 16 mph.

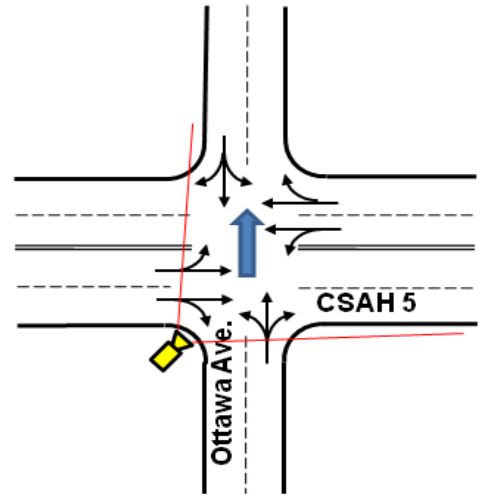


Figure 5: Site 1 - Apparatus camera view of County HWY 5 and Ottawa Ave.

Site 2, Louisiana Ave S and County State Aid Highway 5 (Minnetonka Blvd) consist of an East and Westbound (2-lane A) with exclusive right turn pockets and a mixed straight and left turn lane as well as an East and Westbound single mixed lane for left, right or straight movements. The Northbound and Southbound approach consists of 3-lanes; an exclusive left turn lane, a middle straight only lane, and a mixed straight and right turn, right lane (Figure 6). This site was used to run experiments to extract traffic measurements on two and three lane mixed traffic flows. The system was deployed at this site for a total of 106 hours. The weather conditions during the deployment period varied from sunny to overcast with a maximum wind speed of 22 mph.

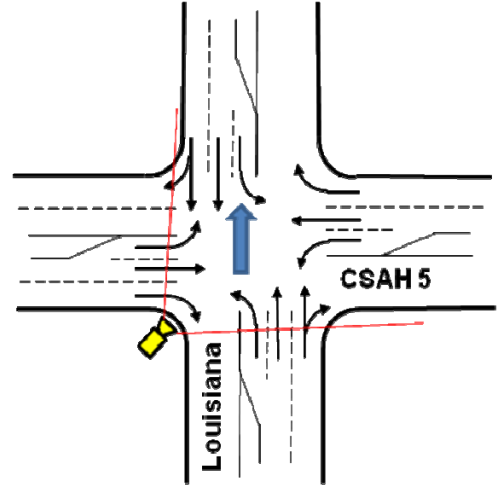


Figure 6: Site 2 - Apparatus camera view of County HWY 5 & Louisiana Ave. S

Site 3, the intersection of Snelling Avenue and County Road B, consists of a Southbound 5 lane approach with two isolated lefts and right (5-lanes, A), plus a 4-lane Northbound approach with near-side isolated right turn (4-lanes-B). This site was used to run experiments to extract isolated right turn traffic flows as well as the other mainline lane flows on upwards of 4 and 5 lanes. The circled right turn movements at the top of the video image had the largest count errors. This was also predicted by the occlusion analysis. The system was deployed at this site for a total of 106 hours. The weather conditions during the deployment period varied from sunny to heavy rain and thunderstorms with a maximum wind speed of 43 mph.

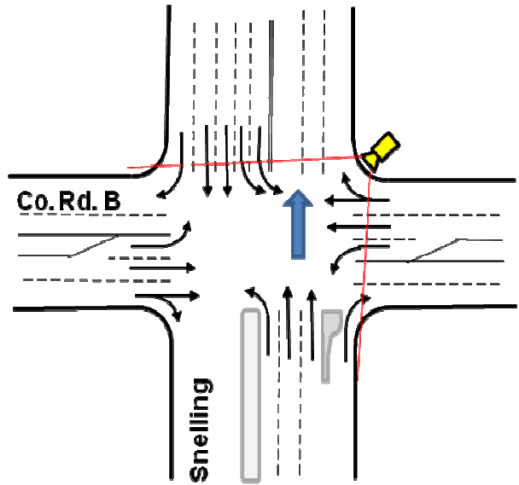


Figure 7: Site 3 - Apparatus camera view of Minnesota State Highway 51 (Snelling Ave.) and County Road B

The circled right turn movements in Figure 6 at the top of the video image had the largest count errors. This was also predicted by the occlusion analysis.

Site 4, Highway 252 and 66th Ave North, the largest intersection lane geometry configuration for the urban arterial candidates being considered here, consists of a North bound 6-lane approach with two exclusive left turn lanes and one exclusive right (6 lanes-A). The circled approaches in the geometry schematic in Figure 8 could not be counted with the single camera set up. The occlusion analysis predicted that the other possible set up location for this sight on the south east corner of the intersection contained significant cross lane occlusion errors. For the configuration deployed as illustrated in Figure 8, the camera height and field of view was not able to adequately capture the NE or WS right movements. The system was deployed at this site for a total of 106 hours. The weather conditions during the deployment period varied from sunny to heavy fog with a maximum wind speed of 17 mph.

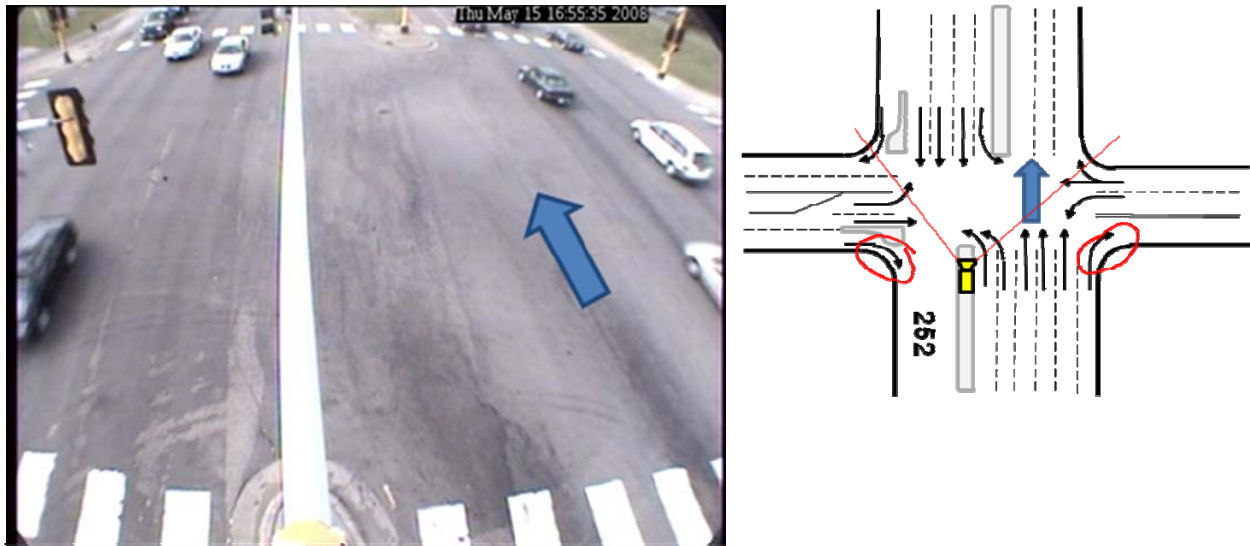


Figure 8: Site 4 - Apparatus camera view of Minnesota State Highway 252 and 66th Ave. N

Site 5, SE University Ave. near SE 16th Ave., is the location utilized for mid-block detection. It consists of only an eastbound 3-lane one-way arterial approximately 250 feet before a signalized intersection (3 lanes-B). The system was deployed at this site for a total of 5 hours. The weather conditions during the deployment period varied from sunny to overcast with a maximum wind speed of 13 mph.

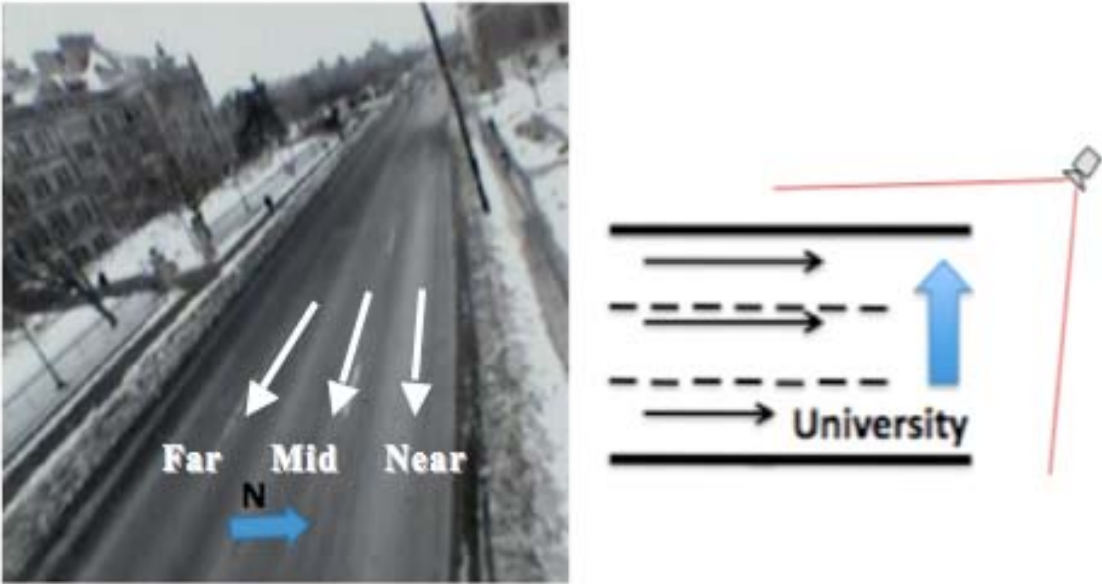


Figure 9: Site 5 - Apparatus camera view of SE University Ave. and SE 17th Ave.

F. Ground Truth Process

In order to analyze the collected data a ground truth process was carried out. The resulting measurement errors between the ground truth and the automated extracted data were then analyzed using several statistics. The ground truth procedures for each traffic measurement are described below.

Volume

Each test requires a ground truth by which the test results can be compared. For turning a volume counts a visual ground truth of the video files was carried out using a JAMAR Technologies Inc. manual counting box. After each set of video files were manually ground truthed, a random subset of those files underwent a second round of visual ground truthing which was then compared to the first set to ensure the data was accurate. When errors were found the entire set underwent a second round of ground truthing to ensure the error was negligible. Such a ground truth process is far less prone to error as the video files can be stopped at the end of any data interval and the video could then be rewound to isolate known error or for any instance where the counter needed a break. Such manual counts were then imported into Microsoft excel where they were compared to the test data. For all volume counts analyzed herein, volume counts were aggregated and tabulated every 15 minutes (thus the data intervals were always 15 minutes).

The variability between the ground truth and the extracted volume counts were analyzed using the R^2 correlation coefficient and Pearson's R. Under or over counting trends were examined using the Mean Percent Error (MPE) relative to the ground truth measurements. Overall counting accuracy was quantified using the Mean Absolute Percent Error (MAPE). The error proportions for both the MPE and MAPE are relative to the ground truth 15-minute approach count value.

Vehicle Speed and Classification

For mid-block testing the ground truth required a series of methods. For classification, prior to any testing, the collected video was viewed and the vehicle classification ground truth was collected manually. As stated above, the volume was ground truthed manually using a JAMAR Technologies Inc. manual counting box. Lastly, the vehicle speed was ground truthed manually by setting markers on the video at set distances and then calculating the number of frames it took each vehicle to travel from the upstream marker to the downstream marker. The following equation was used to estimate vehicle space mean speed in miles per hour, denoted S_{mph} .

$$(1) \quad S_{mph} = \left(\frac{d_m \times f_s}{t_{us} - t_{ds}} \right) \times \frac{3600 \text{ sec}}{\text{hr}} \times \frac{1 \text{ mile}}{5280 \text{ ft}}$$

Where d_m is the distance between markers, f_s is the video file frame rate (frames per second), t_{us} and t_{ds} are the times at which the vehicle crossed the upstream and downstream marker respectively.

The variability between the ground truth and the extracted mean speeds were analyzed using the R^2 correlation coefficient and Pearson's R. Under or over estimates in speed were examined using the Mean Percent Error (MPE) relative to the ground truth measurements. Overall counting accuracy was quantified using the Mean Absolute Percent Error (MAPE). Three classification levels (private vehicles, recreation vehicles, and heavy vehicles) were used for this experiment. Including the initialization interval, 2 hours and 15 minutes of video were analyzed for this experiment.

G. Data and Occlusion Analysis Methodology

Ground truth data was obtained manually using a JAMAR counting device from the 106 hours of video recordings. Tabulated every 15 minutes, the manual counts were tested for accuracy by randomly selecting three hours of recording to have another person extract the same information. Subsequently the two data sets were compared to test the manual accuracy. The comparison yielded counting errors of less than one percent.

Video from Site 3 at Snelling Ave. and CTY Rd B, (Figure 7) and Site 4 at HWY 252 and 66th St., (Figure 8) required multiple passes in order to carry out manual ground truthing. The extreme number of lanes per approach at these intersections in conjunction with the high volumes of vehicles passing through these intersections during peak periods made manual counting difficult. Though counting of half the intersection at each pass, the data collected were ensured to be accurate and was later checked for accuracy through the method stated above.

Several studies were consulted [14], [15] for understanding the affects of camera placement on traffic measurement errors extracted from video image sequences. Specifically, these studies [14], [15] focus on predicting and analyzing the affects of occlusion between ‘overlapping’ vehicles. For example, TTI [15] utilized mathematical models and concluded that occlusion comes into play immediately beyond the first lane and thus is a major issue. Other studies developed analytical techniques based on modeling most vehicle classes, the road or intersection geometries, camera placement, and optics [15]. Occlusion analysis for camera aspects pointing laterally across lanes as well as pointing longitudinally down the lane was developed [14]. We utilized the analytical method formulated by [14] which was based on dense vehicular traffic even at safe space headways. Camera height, lateral offset position from the roadway, and camera angle were varied in order to determine their individual or combined effects on background and total occlusion errors. Background occlusion occurs when vehicles are too closely spaced together for the video to see any spacing between them. Total occlusion exists when a larger vehicle inhibits any view of a smaller vehicle behind it. All occlusion findings are based on the use of CCD analog cameras (used in practice) in regular viewing mode. The mathematical model developed in reference [14] was applied to our test sites to understand the potential occlusion issues that would be faced upon deployment.

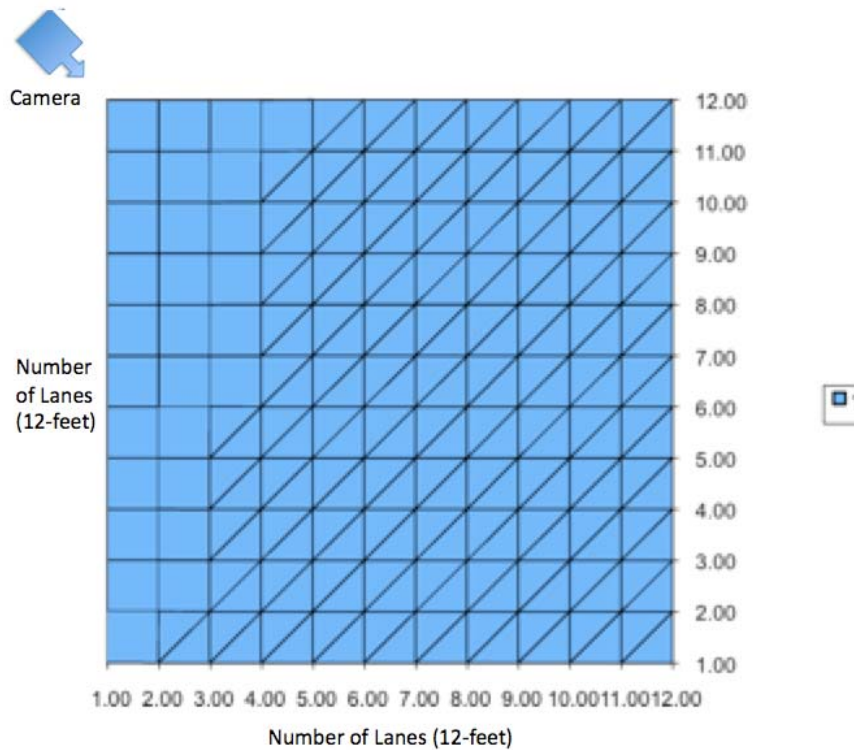


Figure 10: Graphical occlusion potential (per lane) from camera

As stated above, the above graph (Figure 10) is used to understand the threshold in which any form of occlusion can be expected. It assumes the camera is of standard offset from the intersection (roughly 12 feet) and 35 feet high at what would be (0,0). The image shows cross hashes where occlusion can exist given standard headways, thus at lane two horizontal and two vertical from the camera, there is no real potential for occlusion but at three across and two vertical there is potential for occlusion. Using this as a road map against the layout of the intersections, we can determine where occlusion will likely exist. Given the above analysis, occlusion is not avoidable as all test intersections contain some amount of occlusion and thus require visible analysis to determine the intensity of the potential occlusion. Based on the aforementioned analytical models and visual observations, we determined the occlusion affects at all sites, which are as follows:

Site 1: No total occlusion exists; however, background occlusion occurs if and only if a through moving truck on the down lane approach coincides with a car making a right turn on the far approach (the approach farthest from the camera). This occlusion is unlikely to cause problems, as there is ample time for the video-processing algorithm to differentiate the two vehicles. The minimum height for the video camera to be placed for best results is at least 30 feet. This should prevent total occlusion and minimize background occlusion based on the mathematical occlusion modeling.

Site 2: Total Cross lane occlusion exists anywhere but the closest lane to the camera as shown at the top right image of Figure 3. Based on the mathematical occlusion data, the far down lane is highly susceptible to total occlusion in certain areas of movement. The empirical data from

videos already collected show a larger intersection with similar points of interest regarding occlusion, meaning such occlusion can exist. In a larger intersection that resembles Site 4, total occlusion exists on a limited basis and not for the duration of vehicular movement through the entirety of the intersection, whereas, at this site it will depend on the percentage of large vehicles seen in the video and which lanes these large vehicles occupy.

Site 3: Total down lane and cross lane occlusion exists in the farthest (from the camera) three lanes. Cross lane occlusion seems to suggest more of a problem due to constant similarities between adjacent vehicles thus making two vehicles appear to be one. Color differentiation may not be enough in this case if partial occlusion gives way to total occlusion during vehicle travel through the intersection. It is likely that two camera setups will be needed for more accurate counting.

Site 4: The occlusion is very similar to Site 3 except that the separated turning counts if they can be captured on the video will be very accurate, from the image it appears that only two of the turning movements will be visible thus only they can be counted. There is no occlusion on the separated right turns of which only one if the top left corner of the image can be seen, however the multiple through lanes unless directly next to the camera mount all have partial occlusion. The far lane on each direction can have total occlusion if semi-tracker trailers are present. Two cameras will most likely be needed here, however, a second system was not available for testing.

The “peak hour factor” or PHF, which is a term used for peak hour characteristics, was used in the occlusion study to estimate the magnitude of occlusion error, as speeds are more uniform when this factor increases the probability of error prone areas are more in parallel. This increase has not been considered in previous studies and could pose additional questions for future consideration such as the possible use of infrared cameras. As the PHF increases density increases, therefore causing “downlane” occlusion to increase substantially; however, upon deployment it was found that because of the camera placement selections such occlusion issues were minimal and they did not play a significant role in the data accuracy. For example, there were consistently areas in which occlusion did not persist unless semi-tractor trailers were involved which made up less than 5 percent volumes typical at urban test sites.

H. Data Collection and Testing

As mentioned previously in the report, before the first prototype was built, a modified system was deployed to further understand deployment issues and practical camera configurations. In addition, the collected data were also used to test the feasibility of an available machine vision tracking algorithm to separate turning and thru movements from three intersections. The advantage of using the tracking algorithm is that approach counts and turning counts are automatically extracted with minimal set-up time. The basis of the algorithm is extracting and tracking blob representations of foreground vehicles from the background scene [12,13]. The research team developed efficient camera calibration procedure as part of the tracking algorithm, which inherently defined thru and turning movements for tracked vehicles in the intersection [13].

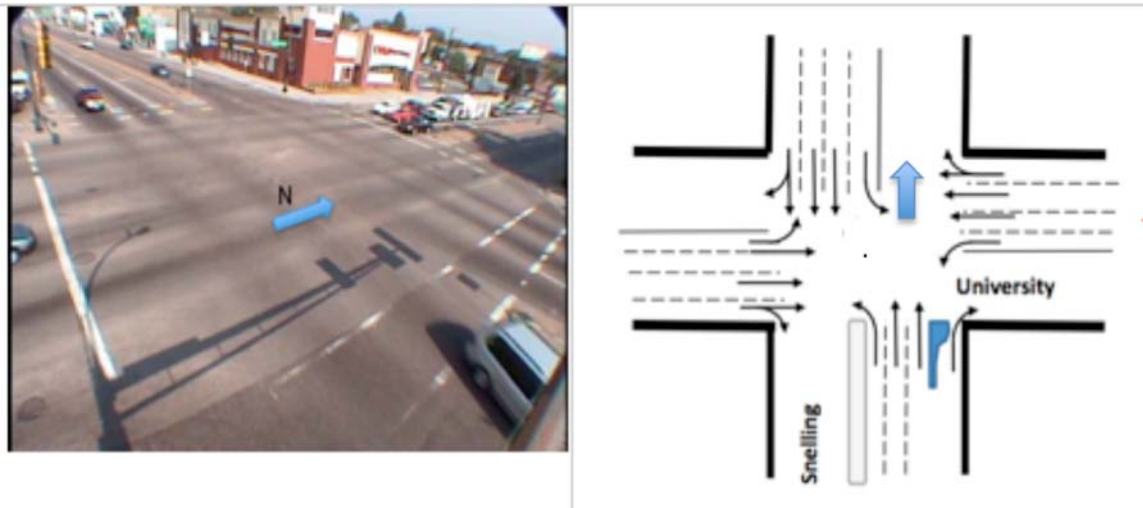


Figure 11: Tracking Site A at University Ave. and HWY 51 (Snelling Ave.)

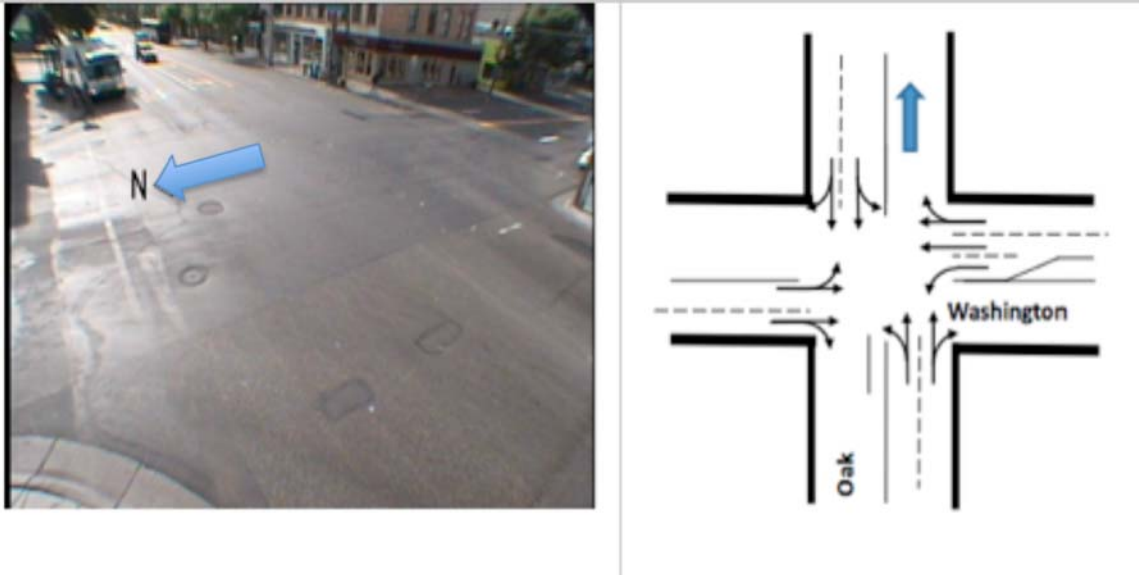


Figure 12: Tracking Site B: Oak St. & Washington Ave. Note the mixed left/thru for the North- and Southbound approaches.

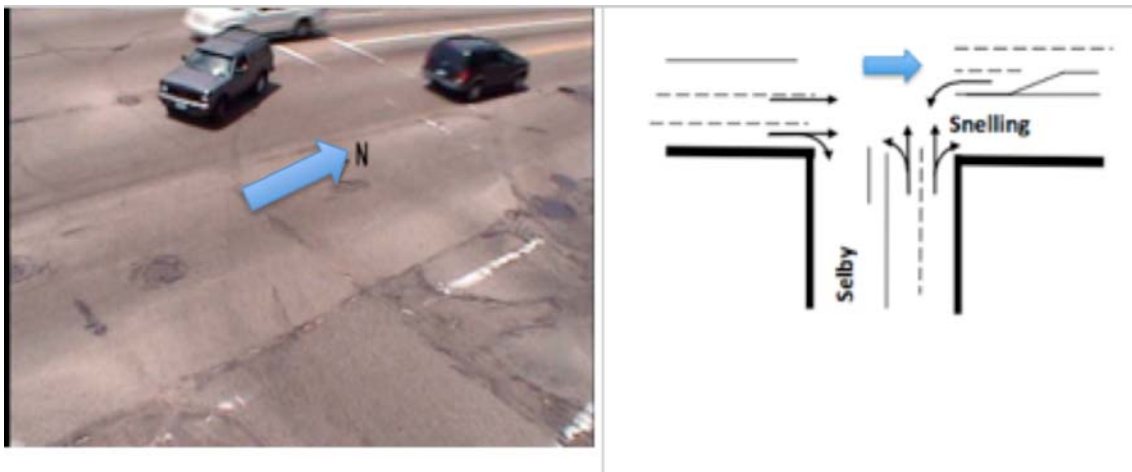


Figure 13: Tracking Site C: Half of the intersection of Selby St. and Snelling Ave.

Three separate one-hour video recordings from each of three intersection sites were examined. The three intersections were comparable in size and number of lanes per approach to intersections in the aforementioned intersection field data collection sites (Figures 11-13). For Tracking Site C, only half the intersection was recorded in order to test the affects this might have on tracking accuracy and the test results show similar error to other sites. Under all circumstances, significant counting errors resulted for many of the vehicle movements.

Variability in counting errors was not attributed to levels of traffic volume, cross lane or down lane occlusion, or intersection geometry. Note that uncompressed digital video as well as MPEG4 video with similar bit rate and quality settings used with the current prototype were also tested with no consistent patterns of measurement errors observed. Tables 3 – 5 summarize the results.

Table 4: University Ave. and Snelling Ave. (Tracking Site A) Results

University and Snelling														
Ground Truth														
Start Time	Duration	Total	S-N	N-S	W-E	E-W	W-N	W-S	E-N	E-S	S-W	S-E	N-W	N-E
10:00:00 AM	15	631	180	104	67	77	12	32	30	29	29	32	13	26
10:15:00 AM	15	612	154	93	56	84	13	46	23	29	41	32	18	23
10:30:00 AM	15	710	180	122	61	104	12	30	35	39	44	36	19	28
10:45:00 AM	15	700	183	122	81	90	14	38	25	35	39	40	9	24
Totals	60	2653	697	441	265	355	51	146	113	32	153	140	59	101
Extracted														
Start Time	Duration	Total	S-N	N-S	W-E	E-W	W-N	W-S	E-N	E-S	S-W	S-E	N-W	N-E
10:00:00 AM	15	1010	179	278	195	200	20	31	16	26	27	27	1	10
10:15:00 AM	15	1007	178	277	174	218	28	28	14	30	27	15	3	15
10:30:00 AM	15	1155	201	345	206	208	32	37	15	27	34	24	4	22
10:45:00 AM	15	1180	222	392	206	187	31	34	11	32	34	18	3	10
Total	60	4352	780	1292	781	813	111	130	56	115	122	84	11	57
Hourly % Accuracy		61	89	34.13	34	44	46	89	50	87	80	60	19	56
Total Miscounts		1699	85	851	516	458	60	30	57	19	31	56	48	44
Average % Accuracy		57.3	%											
Miscount Total		2255	of	2653	actual vehicles				=	85	%			

Table 5: Tracking Site B: Oak St. and Washington Ave. Results

Oak and Washington														
Ground Truth														
Start Time	Duration	Total	W-E	E-W	N-S	S-N	N-E	N-W	S-E	S-W	W-N	W-S	E-N	E-S
10:00:00 AM	15	323	53	106	42	11	5	26	9	5	29	13	3	21
10:15:00 AM	15	302	81	103	40	9	4	17	5	10	19	12	4	18
10:30:00 AM	15	267	57	81	32	6	2	20	10	8	13	21	5	12
10:45:00 AM	15	256	49	74	27	15	2	16	12	3	19	13	5	21
Total	60	1148	220	364	141	41	13	79	36	26	80	59	17	72
Extracted														
Start Time	Duration	Total	W-E	E-W	N-S	S-N	N-E	N-W	S-E	S-W	W-N	W-S	E-N	E-S
10:00:00 AM	15	628	159	144	65	53	2	13	37	11	69	25	32	18
10:15:00 AM	15	540	125	164	48	44	4	11	32	14	46	15	26	11
10:30:00 AM	15	490	102	133	52	42	5	10	33	18	50	23	13	9
10:45:00 AM	15	434	130	103	35	17	8	8	28	11	51	13	19	11
Total	60	2092	516	544	200	156	19	42	130	54	216	76	90	49
Hourly % Accuracy		54.9	42.6	66.9	71	26	68	53	28	48	37	78	19	68
Total Miscounts		944	296	180	59	115	12	37	94	28	136	17	73	23
Average % Accuracy		50.4	%											
Miscount Total		1070	of	1148	actual vehicles				=	93	%			

Table 6: Tracking Site C: Half Intersection of Selby St. and Snelling Ave. Results

Snelling and Selby														
Ground Truth														
Start Time	Duration	Total	S-N	N-S	W-E	E-W	W-N	W-S	E-N	E-S	S-W	S-E	N-W	N-E
10:00:00 AM	15	438	184	97	20	26	10	0	40	7	7	6	0	41
10:15:00 AM	15	396	147	80	23	27	11	0	43	10	4	2	0	49
10:30:00 AM	15	404	174	73	29	19	7	0	43	6	4	6	0	43
10:45:00 AM	15	410	174	80	26	15	7	0	41	6	4	6	0	51
Totals	60	1648	679	330	98	87	35	0	167	29	19	20	0	184
Extracted														
Start Time	Duration	Total	S-N	N-S	W-E	E-W	W-N	W-S	E-N	E-S	S-W	S-E	N-W	N-E
10:00:00 AM	15	536	217	87	84	84	3	10	1	21	3	19	0	7
10:15:00 AM	15	572	209	116	90	76	3	3	1	20	14	28	0	12
10:30:00 AM	15	549	201	125	73	80	4	7	0	13	9	26	0	11
10:45:00 AM	15	516	181	94	84	88	2	4	1	20	7	24	1	10
Total	60	2173	808	422	331	328	12	24	3	74	33	97	1	40
Hourly % Accuracy		75.8	84	78.2	30	27	292	0	1.8	39	58	21	0	22
Total Miscounts		525	129	112	233	241	23	24	164	45	22	77	1	144
Average % Accuracy		54.2	%											
Miscount Total		1215	of	1648	actual vehicles			=	74	%				

Based on the above results, it is the recommendation of this study to avoid using the above tracking algorithm in respect to the apparatus and site experiments completed herein. Previous studies by Tarko and Lyles (2002) demonstrated that volume counts with simple ‘tripwire’ presence detectors utilizing a commercially and widely available machine vision system yield more accurate and reliable results [16]. Furthermore, based on the miscount data shown above, the actual accuracy of the tracking algorithm was often below 30 percent. In some approaches under-counting and over-counting over the prescribed sample interval (15 minutes) canceled each other out, which led to hourly accumulated traffic volume counts that were very close to the ground truth count measurements. Thus the hourly aggregated measurement accuracy does not represent the actual performance of the algorithm for these experiments. The success of such a tracking system relies heavily on the camera placement. If a camera were placed more directly or high above the intersection, thus eliminating vehicle occlusion, the data would more likely match the ground truth data because blob separation from the overlapping vehicles would most likely have been better. Note the previous studies, which tested this algorithm utilizing a bucket truck, elevated the camera over 45 feet above the intersection.

Since results from video recorded were not of sufficient accuracy the existing approach did not prove to be ready for deployment with the prototype. There are no commercially available video sensors for vehicle tracking as technology is not yet mature. We used the most widely commercially available sensor (Autoscope), which was recommended by traffic practitioners consulted during the hardware selection process. Autoscope was selected as the appropriate tripwire detection system for this study as it was successfully used in a previous study by Tarko and Lyles (2002) [14] in which it demonstrated strong potential for use in a full intersection single camera application. Within the sensor's proprietary software we developed a special logic for extracting approach volumes at intersections. This sensor already provides other traffic measurements such as volumes, speeds, headway, and classification and there accuracy has been established over the years. The methodologies developed and tested to extract approach counts utilizing this device with the field collected data will be described next.

The Autoscope RackVision 2004 detection system is a 'presence' detection system, which utilizes a video image-processing unit (VPU). Autoscope has user-friendly software with a basic software development kit (SDK) where virtual detectors (tracking strips) can be placed in the camera field of view in a similar manner to loops on the roadside. The virtual detectors read color and illumination of pixels in order to compare an active object on a stationary background. The hardware can then collect streaming data from the detector using the VPU to help in data collection of actuated signal timing. Newly developed detectors which track the specific movement of pixels called directional detectors, are of much use as they activate only when an object passes over the tracking strip in the proper direction. Furthermore, developed detectors collect the speed and classification of vehicles by tracking the movement of vehicles and using calibrated pixel and geometry to detect information from the pixel movement. With a maximum of 32 overlap-able detectors per camera, a series of detection zones can be established. Furthermore, detectors can be combined into logical operations including (AND, OR, NAND, NOR, and N of M).

Upon operation, detectors, which can be visible if desired, change color when active for easy checking of proper function. Data can then be generated from active detectors to obtain volume, occupancy, headways, speed and vehicle classification. Using an internal program called 'Data Collector', interval data aggregation over a specified time period or per detection event can be obtained and analyzed.

The Autoscope machine vision system is designed for use with live or recorded video for streaming data acquisition. Presence detectors can be used across a lane of traffic to emulate the same functionality as a loop detector or along a lane of traffic for directional detection whereby only cars moving along the selected direction will trigger the detector. Autoscope hardware was designed for each video to process a single approach of traffic whereby cars moving perpendicular to traffic flow are not seen. For this reason and as the analysis to follow will demonstrate, directional presence detectors were a poor choice for detecting vehicles moving perpendicular to the primary direction of traffic flow. This implies that the Autoscope was inevitably not an ideal choice for monitoring of an intersection through non-ideal camera placement with the intent of a single camera monitoring all four approaches simultaneously. Despite such drawbacks, we designed simple, repeatable, detector configurations that generally

produced accurate data extraction, which exceeded the 85 percent accuracy sought by traffic practitioners by upwards of 5 percent (approximately 90 percent accuracy thus an MPE of less than 10 percent). The following summarizes the derivation for such a detector configuration. They are compiled in the order in which they were tested with all previously collected videos. It is important to note that video collected before sunrise and dusk were not used for the automated extraction experiments because detection accuracy was problematic during these periods.

Machine Vision Volume Data Detector Configuration and Results

As mentioned earlier, the operational aspects of Autoscope from the SDK detectors to the algorithm shadow processing were designed in with one camera per approach in mind whereby little to no occlusion exists. As previously mentioned volume counts were aggregated into 15-minute intervals for each approach. These counts would then be compared against the ground truth to determine the accuracy of using Autoscope as a vehicle counting system. In order to extract such counts detectors were placed throughout the intersection in a progressive manner described below.

This first configuration consisted of presence detectors placed just prior to the stop-bar at each approach such that each lane had its own detector. The detectors were then attached to the detector stations (the boxes with 011 101) which then recorded the information on the data collector as described earlier in this chapter. Site 1 was used for the detector logic experiments because the intersection consists entirely of mixed thru and turning movements as well as having the fewest lanes to compare and analyze the different detector configurations and thus provided a reasonable starting data set by which to compare with the other sites.

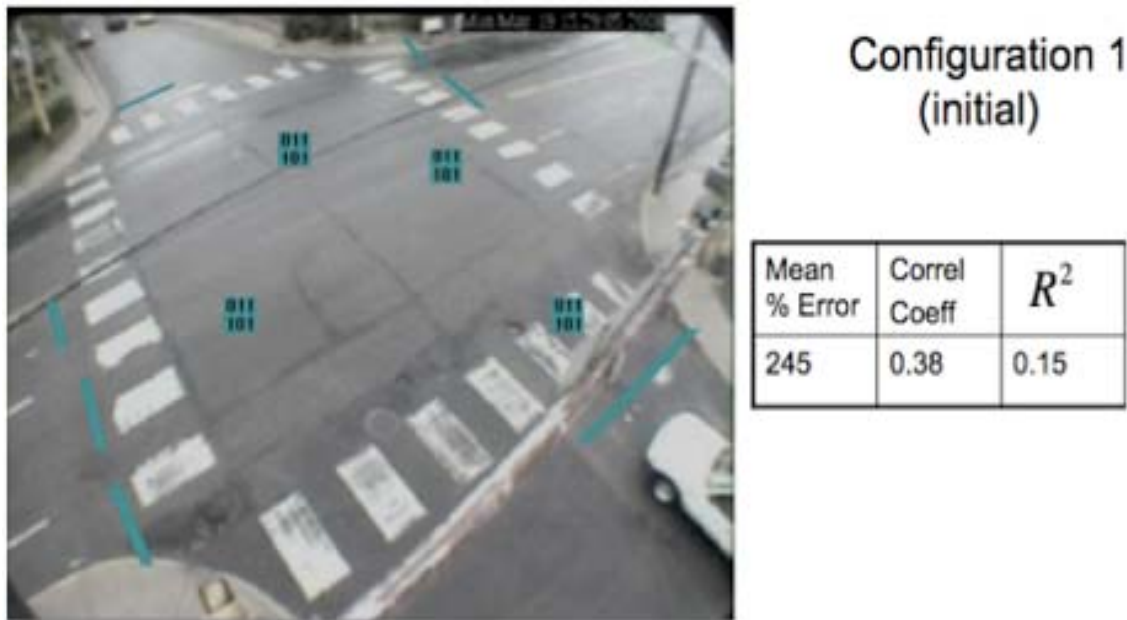


Figure 14: Site 1 - Configuration 1 - one presence detector per lane at Site 1

In this first configuration a baseline was established for issues that in general exist with collecting data using one camera at an intersection. From the results it can be seen that occlusion, shadows and other issues existed with this setup, as the accuracy is very poor, with a MPE of 245 percent and an R^2 value of 0.15.

Next, configuration two was tested. In this configuration, the presence detectors from configuration 1 were replaced with directional detectors. In this case, directional detectors were also placed just prior to the stop-bar such that they would extend just inside of the stop-bar. In essence a vehicle would trigger the directional detectors just as they entered the intersection. Again, each detector was connected to a station detector as described in configuration 1.

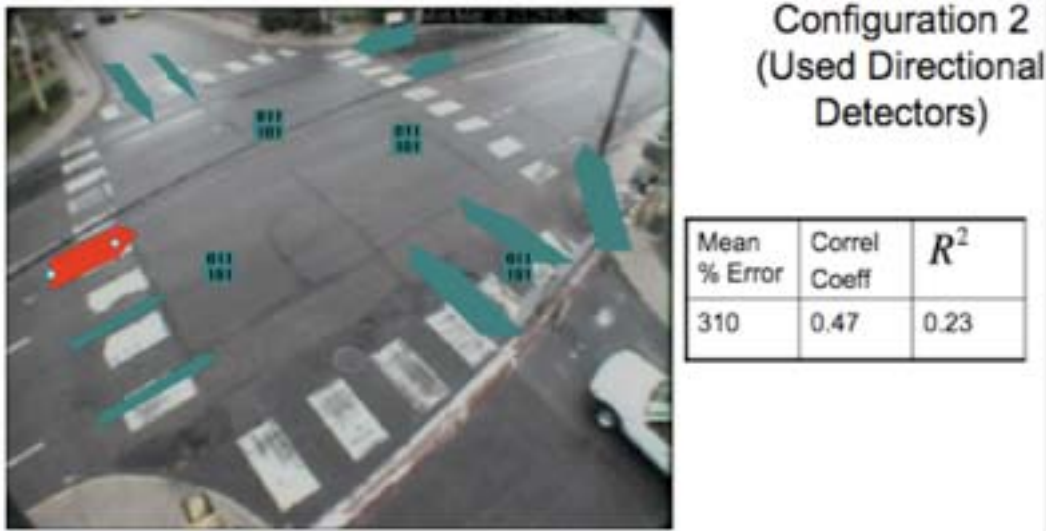


Figure 15: Site 1 - Configuration 2 - one presence detector per lane at Site 1

On this second configuration, the directional detectors are used in place of the presence detectors in the first configuration. This setup established the accuracy with which advanced detectors performed. As the results show, shadows, occlusion and high-speed vehicles greatly limited the effectiveness of the directional detector. From watching the video process, it was visible that high-speed vehicles were the primary source of error with this configuration as the detectors failed to recognize vehicles at such a high velocity.



Configuration 3
(multiple Directional Detectors)

Mean % Error	Correl Coeff	R^2
107	0.49	0.24

Figure 16: Site 1 - Configuration 3 - two directional detectors (in series) per lane

This third configuration attempted to counter the high-speed vehicle error by placing two directional detectors in series. These detectors were placed one in front of the other starting from behind the stop bar. Oftentimes both missed the vehicle or other similar errors occurred. These errors made the detector layout and calibration process of the series of detectors very difficult and unfortunately showed little improvement from configuration 2 with still over 107 percent MPE. MAPE for this site (with this configuration) can be seen later on in Figure 21.



Configuration 4
(Optimal)
(combination)

Mean % Error	Correl Coeff	R^2
9.96	0.80	0.65

Figure 17: Site 1 - Configuration 4 - combination of presence and directional detectors - one per lane

In this 4th configuration, by combining both presence and directional detectors it was possible to eliminate the high-speed error of the directional detectors while maintaining the utility of the directional detector on the optional lanes and or on lanes where occlusion and opposing traffic may interfere with accurate counting. As Figure 17 shows, the presence detectors were placed even further behind the stop bar than in configuration 1 and the directional detectors were used where high-speed vehicles were less likely to be an issue such as turning lanes.



Figure 18: Site 1 – Configuration 5 – combination of presence and directional detectors – one per lane with shadow processing

Similar to configuration 4, this configuration utilizes both presence and directional detectors, however, for this experiment the shadow processing system was activated and thus the MPE and R squared are slightly improved. The data indicated that the shadow processing resulted in little improvement from the previous configuration and therefore was not utilized for the other site experiments. The MAPE can be seen later on in the statistics for all approaches (see Figure 21 for MAPE of this site).

All configurations were created by a brief “trial and error” placement of detectors and observing the vehicles passing over the detector to insure each detector was detecting vehicles properly. In addition, the Autoscope calibration process carried out prior to detector layout takes into account the size of the intersection and automatically sizes the detectors. It was necessary for many approaches to increase or decrease the detector size in order to adjust its coverage area from the default. The detector placements and configurations at the other three sites accompany the results below.

Final Detector Configuration Results

The fourth configuration, which utilized single directional detectors indicated the most accurate measurements and can be set up and calibrated in a short amount of time. Below is the machine vision acquired data and a breakdown followed by analysis.

The detector layout utilizing the far lane directional detectors used at Ottawa and Minnetonka for data extraction is illustrated in Figure 19. Following each detector configuration will be the per-direction volume results for each site.



Figure 19: Site 1 - Detector configuration

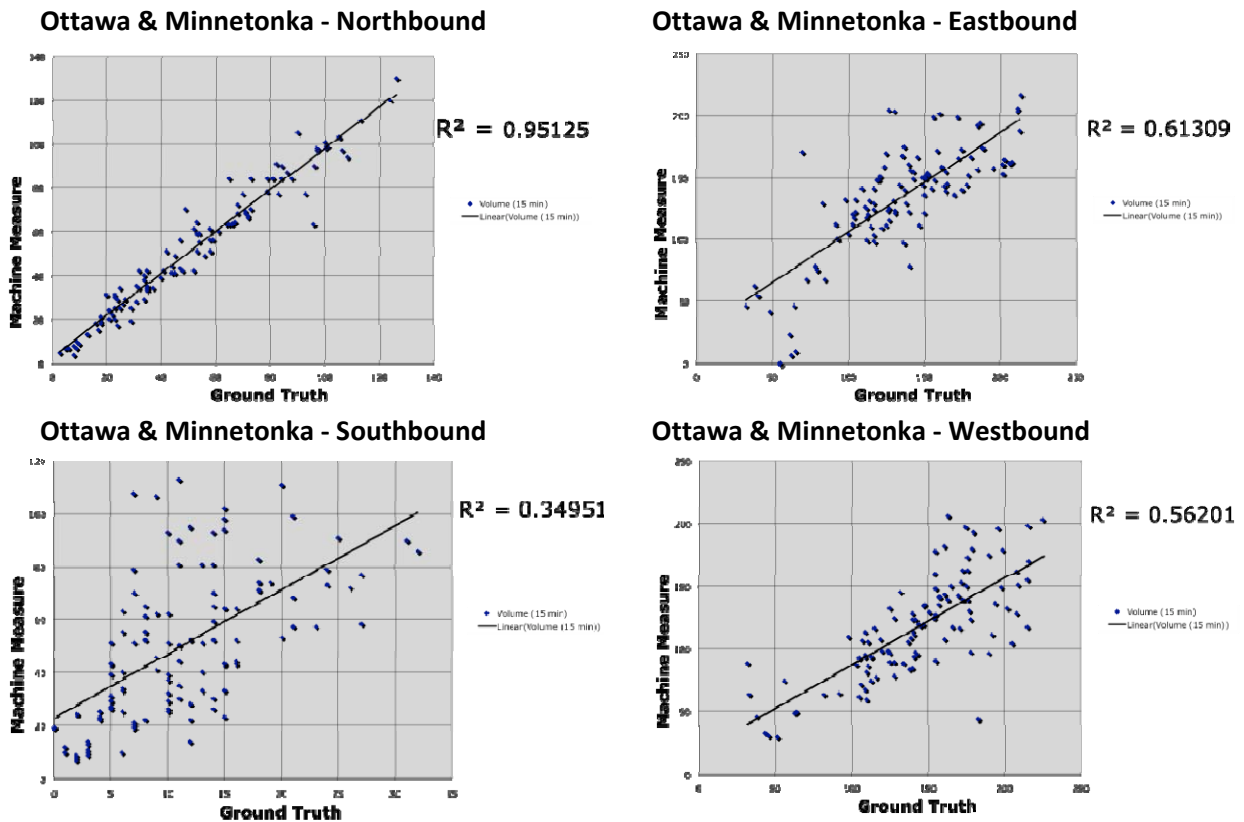


Figure 20: Configuration 4 - CSAH 5 (Minnetonka Blvd.) and Ottawa Ave. - results scatter plots (per approach)

Ottawa and Minnetonka is the first site for data extraction and thus the least difficult types of approaches. Furthermore, the intersection is smaller than the other sites and thus allows for more detail in the video (increased number of pixels per square foot). The data from Figure 20 and summarized in Figure 21 demonstrates the accuracy obtainable from the approaches nearest to the camera (northbound) and thus an R squared value near 1. The occlusion, which was later verified visually, was consistently a problem for the detectors on these approaches. What is most interesting is the error in the far approach (southbound) data which was later visually confirmed to be a detector glitch causing the occlusion errors to compound to nearly 405 percent MPE. This means that while errors from an approach a similar distance from the camera (westbound) was as high as 15.7 percent MPE and 23.7 percent MAPE, the use of directional detectors at cross traffic prone occlusion sites was the major source of the error. This specific approach will be discussed in further detail later on in this chapter.

Ottawa & Minnetonka (OM)

OM	RSQ	C C	ABS%Error	Mean %Error
NB	0.9512522	0.9753216	11.8879809	2.985640614
EB	0.6130878	0.7829992	19.1562282	0.774192894
SB	0.3495081	0.5911921	404.616799	404.6167986
WB	0.5620129	0.7496752	23.7225753	15.76012738
Total	0.6189652	0.774797	114.845896	106.0341899
Total -South	0.7087843	0.8359987	18.2555948	6.506653629

Ottawa & Minnetonka (OM)



Figure 21: Site 1 - Minnetonka Blvd. and Ottawa Ave. - ground truth comparisons for all four approaches

The anomalous data involving the southbound approach of Ottawa and Minnetonka will be discussed in further detail later on in this section, however, it should be noted that the MPE of the intersection as a whole was only 6.5 percent, which is within an acceptable range according to practitioners.

Next is the intersection of Louisiana Ave. and Minnetonka Boulevard (Site 2), which is slightly larger in geometry than Site 1 and with a slightly more complex approach configuration. At this intersection there are clearly defined turning lanes and again, by placing detectors just prior to the stop bars, the accuracy was improved from the original configurations as described earlier. Occlusion and shadows were a major concern at this intersection, which could not be easily mitigated with the developed detector configuration. The result was a pattern of both slight over and under counting. The southbound approaches (upper left hand corner of image with movements toward the camera) experienced large over counting. The reason for this will be discussed later.

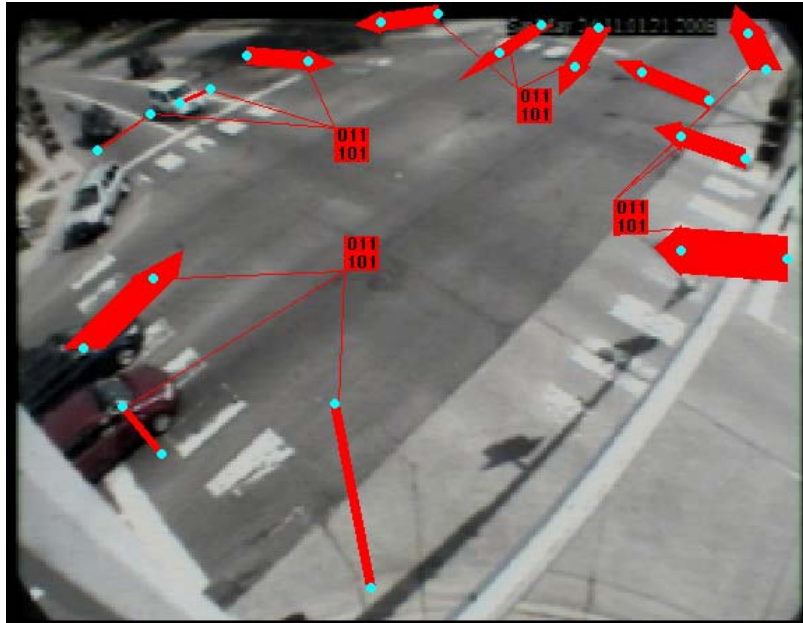


Figure 22: Site 2 - Detector configuration

The above detector configuration shown in Figure 22 yielded the results written and analyzed below which show a pattern of both slight over and under counting for the other intersection sites as well. Issues in accuracy using the above detector configuration were likely attributed to shadows and occlusion; however, it is unlikely that ‘trip-wire’ type machine vision systems can improve on such accuracy due primarily to occlusions and cross-lane shadows.

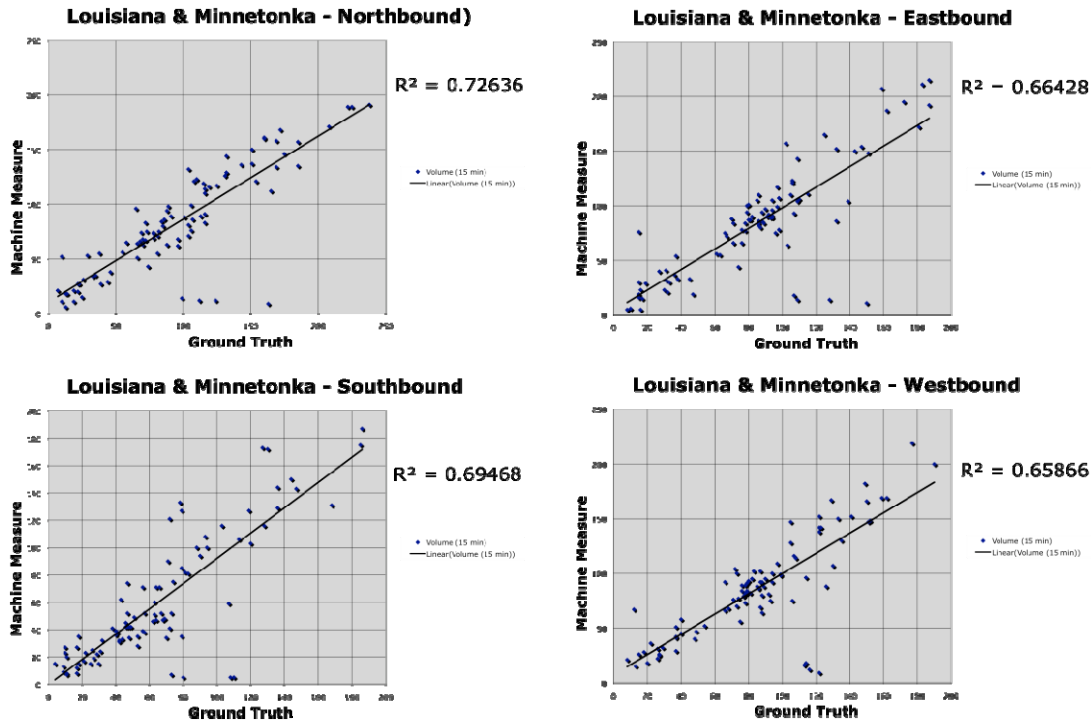


Figure 23: Configuration 4 - Louisiana Ave. and Minnetonka Blvd. - ground truth comparisons for all four approaches

The above figure (Figure 23) shows the volume data points per 15-minute interval, which were collected at each approach using the above detector configuration. While the R squared values are not ideal (values of 1.0), the mean percent error, which is commonly used in conjunction with traffic signal optimization, is low in percent error and shown below (Figure 24). This means the data collected would have significant advantages to traffic engineers responsible for optimizing traffic signal timing.

Louisiana & Minnetonka (LM)

LM	RSQ	C C	ABS%Error	Mean %Error
NB	0.7263604	0.8522678	26.2459521	2.514386261
EB	0.664281	0.8150343	25.4740943	3.913851546
SB	0.6946829	0.8334764	31.8978267	1.77169683
WB	0.658655	0.8115757	24.8268032	10.04351475
Total	0.6857307	0.8280886	27.1111691	4.560862348

Louisiana & Minnetonka (LM)

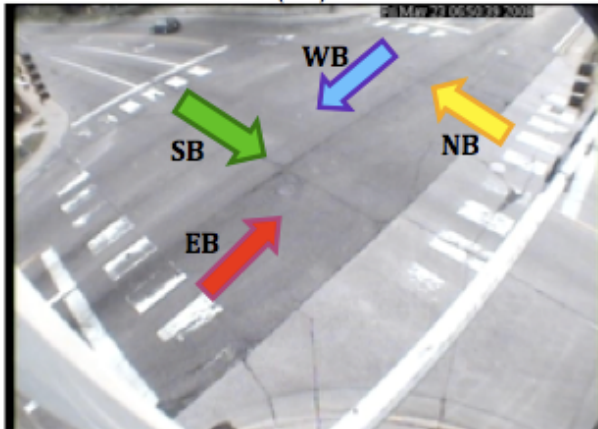


Figure 24: Site 2 - Louisiana Ave. and Minnetonka Blvd. - ground truth comparisons for all four approaches

As show above in Figure 24, the mean absolute percent error (MAPE) and mean percent error (MPE) are significantly different. This means the error per data point found was both below and above the ground truth data. Such errors can be attributed to glitches in the detectors. We visually confirmed that these errors were caused by shadows, closely following vehicles and ‘glitches’ in the detectors (phantom counts and other seemingly random miscounts).

Below is the detector layout used on Snelling Ave. and County Road B. While very basic in design, we found that increased detectors only hindered the accuracy of the volume data that was collected. It is clear from this layout that while near to the camera approaches were able to utilize presence detectors only, far approaches required directional detectors.



Figure 25: Site 3 - Detector configuration for Snelling Ave. and County Road B (Site 3)

Given the glitches seen in directional detectors from the previous configurations we expected that more error would occur in approaches that used such directional detectors. Errors persisted despite attempts to combine the use of directional and presence detectors on these approaches. Furthermore, use of both directional and presence detectors became hindering to the accuracy because presence detectors gave many false positives and directional detectors missed vehicles all together. The extracted traffic count errors at this site were consistent with the previously discussed occlusion analysis which predicted occlusion would be more pronounced on the far lanes particularly when viewed from the corner of the intersection.

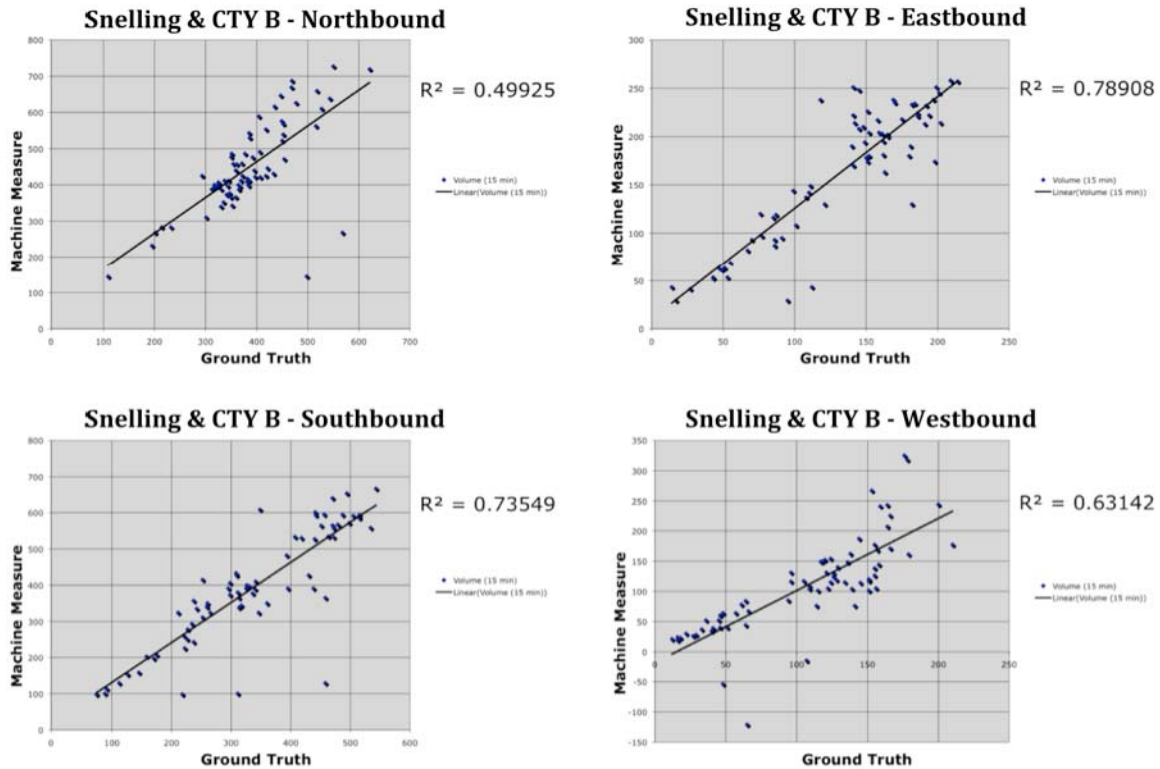


Figure 26: Site 4 – Snelling Ave. and County Road B - Ground truth comparisons for all four approaches

There are fewer data points from this intersection than the other sites due to weather and extreme wind issues experienced during while deployed at the site. These situations created conditions whereby no reasonable data could be obtained. On one day in particular, the weather caused the camera to fog and no data was collected. This was due to a small leak, which formed in the protective housing for the camera, which was later repaired.

A pattern seen in the errors shown above (Figure 26), demonstrate that with higher volumes, there was also larger error. Such a pattern is expected to stem from closely following vehicles. This means that the detectors failed to reset between each vehicle and thus double counted vehicles or miscounted them when shadows could be seen. Visible confirmation of these errors shows occlusion to be a major source of error, one that can only be fixed through better data acquisition techniques and or the use of tracking the vehicles such that moments of occlusion do not confuse the detectors and create error.

Snelling & CTY B (SC)

SC	RSQ	C C	ABS%Error	Mean %Error
NB	0.4992507	0.7065767	21.3672801	17.7409958
EB	0.7890772	0.8883002	31.8807616	26.97294822
SB	0.735493	0.8576089	24.1852168	17.42497808
WB	0.6314185	0.7946185	31.235981	0.520503122
Total	0.6638099	0.8117761	27.1673099	15.6648563

Snelling & CTY B (SC)

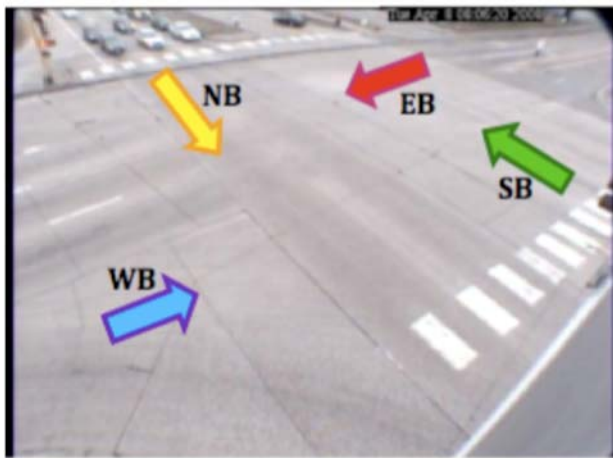


Figure 27: Configuration 4 – Snelling Ave. and County Road B - results (per approach)

The above data is important in revealing the source of errors in the volume counts. Most importantly, the westbound approach (nearest to the camera) had a very high mean absolute percent error (MAPE) and a very low mean percent error (MPE) thus as was confirmed visually, a pattern of occlusion and shadow errors are the primary cause of the errors and not the directional detectors because this approach did not use directional detectors. This demonstrates the difficulty to obtain accurate counts at large intersections where the pixel resolution is inadequate to discriminate between vehicles in the foreground and the background.

Below is the detector layout for Site 4, Hwy 252 and 66th Street. The blue and red detectors were colored for the sake of visibility and were not different than any other directional detectors. Here it is evident that only directional detectors could yield data given the size of the intersection and thus the potential for occlusion. By placing the camera on the median, the occlusion was minimized particularly on the mainline approaches. However, the result of this deployed location is the inability to observe and thus detect some of the lanes on the eastbound and northbound approaches (the top of the screen is north). Therefore, while some data was missing due to the camera placement, the extracted measurements were improved by the resulting camera vantage point at this location. Below is a summary of the findings.

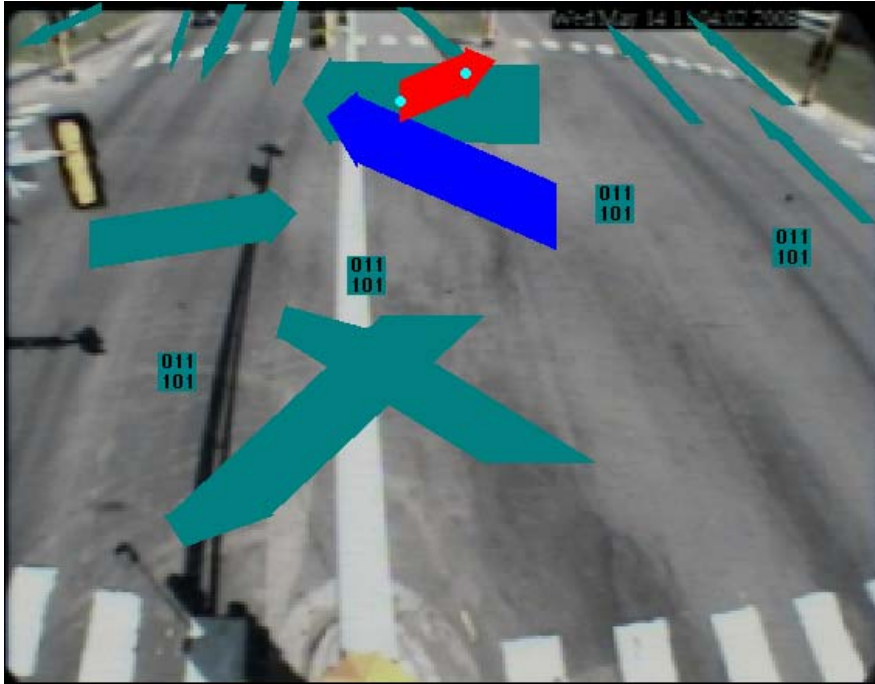


Figure 28: Site 4 - Detector configuration

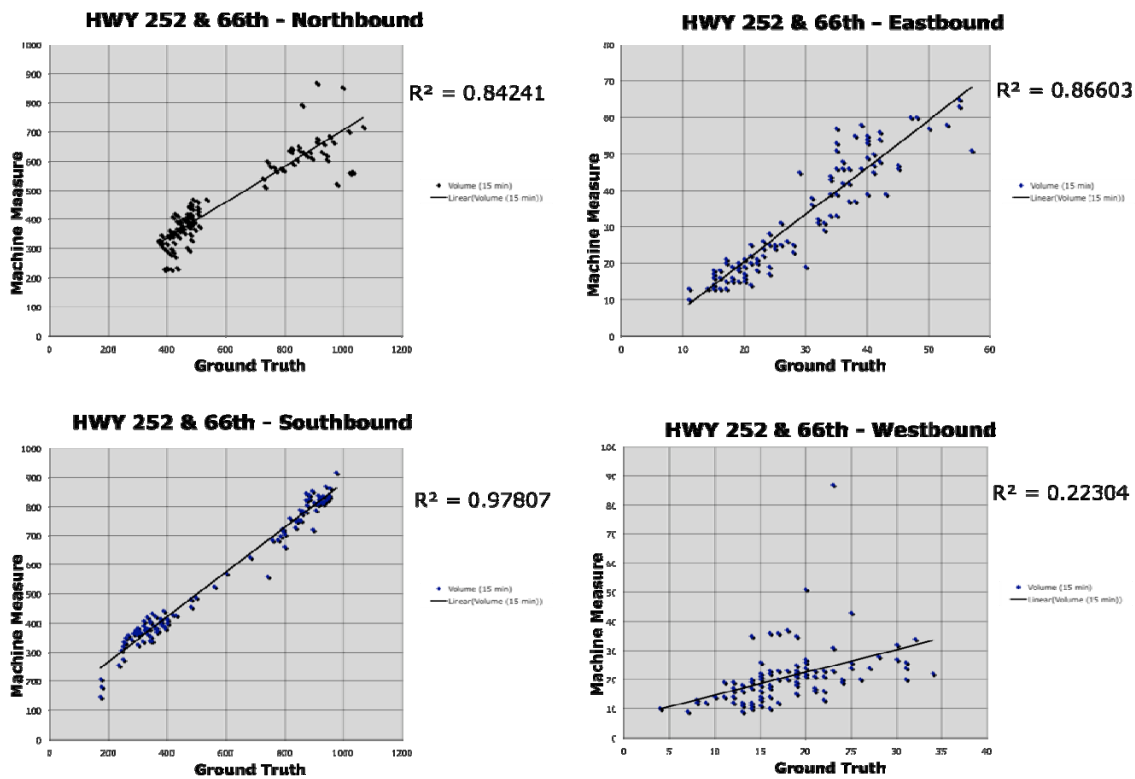


Figure 29: Configuration 4 – HWY 252 and 66th St. – scatter plots (per approach)

This data, excluding the westbound approach, which will be discussed below, showed high detection accuracy. This can be attributed to the minimization of occlusion and thus the increase in visibility of vehicles traveling through this intersection. The directional detector errors observed at Site 1 (Ottawa and Minnetonka (CSAH 5)) southbound approach was again observed in the Site 4 HWY 252 and 66th westbound approach. The data therefore suggests a systematic error with this type of detector rather than occlusion or other factors. With exception to the eastbound approach, the extracted traffic measurements appear to be accurate and despite high-density traffic, occlusion errors seemed to be minimal and are summarized below (Figure 30).

HWY 252 & 66th (25266)

25266	RSQ	C C	ABS%Error	Mean%Error
NB	0.9780672	0.9889728	12.3262103	2.574053633
EB	0.8660337	0.9306093	16.8423729	7.571206935
SB	0.842408	0.9178279	21.7255654	21.72556541
WB	0.2230381	0.4722691	32.0996514	20.70129919
Total	0.7273868	0.8274198	20.74845	13.14303129

HWY 252 & 66th (25266)

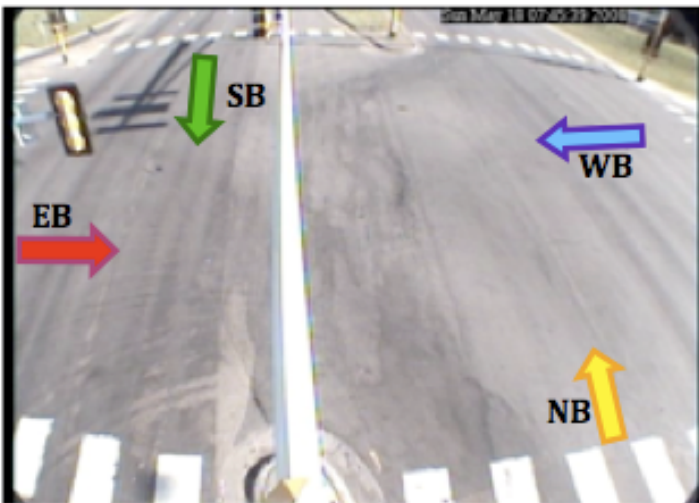


Figure 30: Configuration 4 - HWY 252 and 66th St. - results (per approach)

At this intersection, the approaches all used directional detectors rather than presence detectors. Due to the size of the intersection and the high speed of vehicles, such detectors did not encounter occlusion and thus the issues causing error were not present. As a result the accuracies were high.

Directional Detector Error

Substantial errors impacted the Site 1 (Ottawa and Minnetonka) – Southbound (SB) approach (OM-SB) on the aggregate data for all intersections which is highlighted by the red arrow on Figure 31. Several experiments in which we adjusted the location and direction of this detector did not reduce this particular error. Interestingly the glitch in the directional detector for the other site approaches was not nearly as revealing as this particular case. For this reason it was important for volume accuracy to be calculated with and without this approach data so that the overall system accuracy and the potential accuracy if the glitch were fixed could be seen and highlighted.

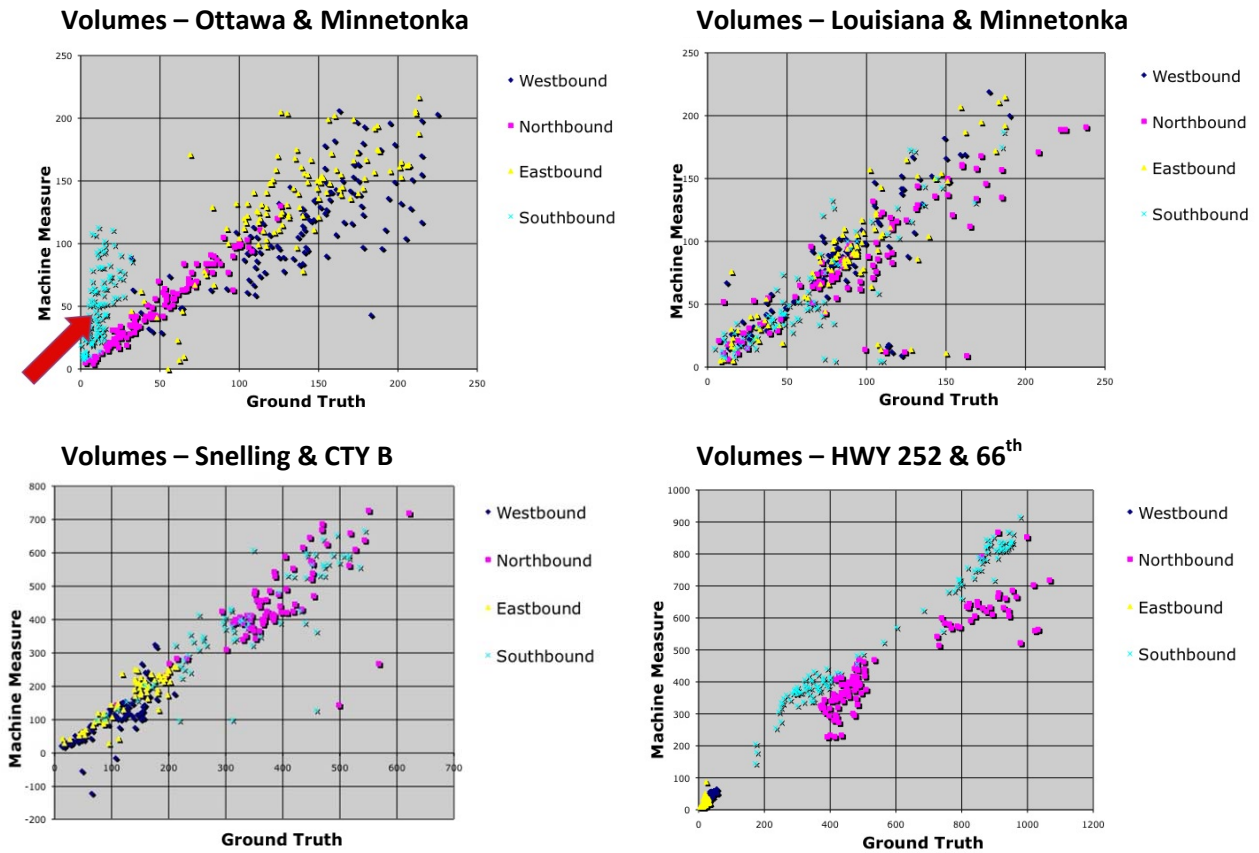


Figure 31: Extracted volume counts of each intersection

The approach volumes extracted from the machine vision system are generally well correlated with the ground truth measurements described previously. As shown in Figure 31, the exception was the southbound (SB) approach at the first site, Ottawa and Minnetonka. If this single approach is removed, the MPE falls under 10% (Table 6). While it can be seen that errors occur on all approaches, the overall accuracy was acceptable and in accordance with the previously described functional specifications.

Table 7: Aggregated Results for the Four Intersection Sites

	R²	Pearson R	MAPE	MPE
SB site 1 approach included	0.7096	0.8105	47.47	34.85
**SB site 1 approach removed	0.7320	0.8258	23.32	9.97

Table 6 indicates the aggregate error for all sites and approaches for any 15-minute count was slightly less than 10% while the average error was less than 25%. Note that the MPE and MAPE statistics are very sensitive to outlier errors. For example, the large over counting errors experienced for the single southbound approach created an MPE which was over three times larger than excluding this approach (34.85%) and a MAPE which was essentially twice as large.

In this chapter automated extraction of volume counts was developed and analyzed. The results demonstrate that a combination of presence and directional detectors can accurately detect and collect volume counts. Directional detectors occasionally gave spurious results that contributed significantly to the measurement error. In principle, directional detectors can be used to extract turning movements as well [12]. It seems reasonable that the anomalous behavior of this type of detector may be due to inherent design issues, as they have not been tested in the manner presented herein. We surmise that even modest improvements in direction detector accuracy will significantly improve counting accuracy.

Measuring directional movements from thru and turning vehicles is feasible once a panoramic view of the intersection with minimal occlusion is established, using special detectors available in Autoscope, a kinematic algorithm was designed to detect through and turning movements at all approaches. Using a combination of directional and logic detectors found in Autoscope, vehicle movements were tracked correctly. When access to the controller cabinet is feasible, Autoscope can extract phasing states. Knowing the current phase allows decisions to be made about where cars are coming from and where they are going to in combination with the kinematical algorithms even more accurately. The standalone requirement during deployment at these intersections prevented us from obtaining phase information from the intersection control cabinet. Without the phase information it became extremely difficult to utilize our previously described Autoscope kinematic algorithms to determine turning movements. As a result a phase detector was created based on a second kinematic algorithm for detecting the active phase; however, it was found that even minimal errors on the part of the kinematics phase detector lead to large error on the part of the turning movement identification and counting technique. As a result, even though most of the data collected was visually accurate upon observing the algorithms run, the few random algorithm errors lead to large data errors and thus the majority of the data counts were inaccurate. For example, during congested periods (which represents the majority of video collected) it was found that the volume of straight movements during a single cycle was equal to or greater than the volume of a turning movement for an entire 15-minute period; thus a single phase detection error during a cycle would cause a turning movement count to nearly double in size. This can be corrected if the directional detectors in Autoscope are

adjusted to apply to non-through vehicles or if access to the controller becomes available. A request for this modification has already been requested to the sensor developers and is currently planned for future modification. Access to the controller on the other hand is feasible through wired communication but due to our standalone requirement it is not currently planned.

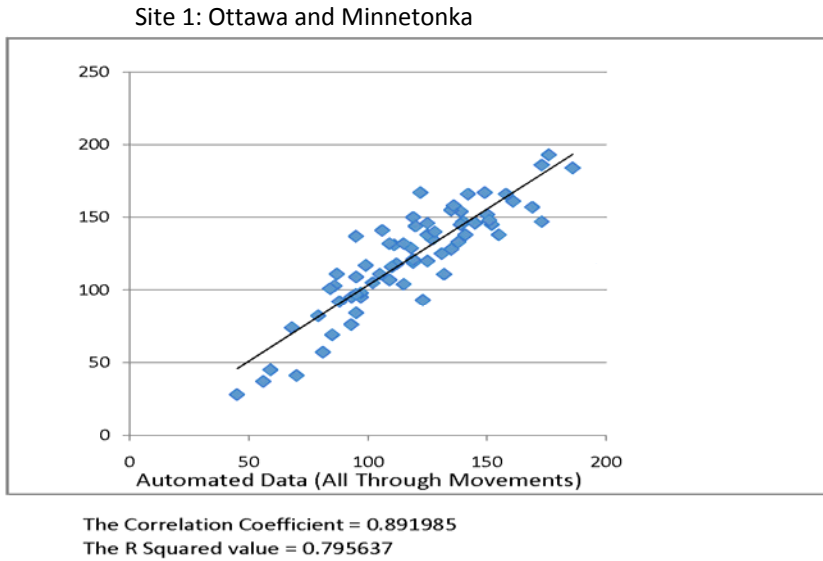


Figure 32: Ground truth vs. measured thru and turning volumes at all approaches of Site 1

It should be pointed out that as Figure 32 (above) demonstrates, straight movements were not seriously affected by the occasional error in the detection of the phase because of their magnitude as explained earlier and thus vehicle movements could be accurately measured. The next section will describe a mid-block arterial deployment experiment to analyze extracting speeds and vehicle classifications.

I. Arterial Mid-Block Data Acquisition

In order to test the ability of the prototype to extract speed and vehicle classifications, a mid-block experiment was performed. In this experiment volume, speed and classification were tested in one direction covering three lanes. Calibration was performed and speed detectors were placed on each lane. Straight-line distance measurements were done on-site at down lane and cross lane locations, which could be seen through the camera's view seen below. Each position is displaced at a relative distance of 25 feet. The known displacements were used to directly measure space mean speed as previously described.



Figure 33: SE University Ave. and SE 17th Ave. with labeled distance markers indicated

Arterial Mid-Block Data Results and Analysis

The speed data collected for all three lanes plotted against the ground truth measurements is shown in Figure 34. The far lane is most likely to have occlusion issues and one would expect that the far lane would also have the worst accuracy as it is farthest from the camera. The results below break from such a hypothesis and instead paint a picture of fallibility of the speed detector.

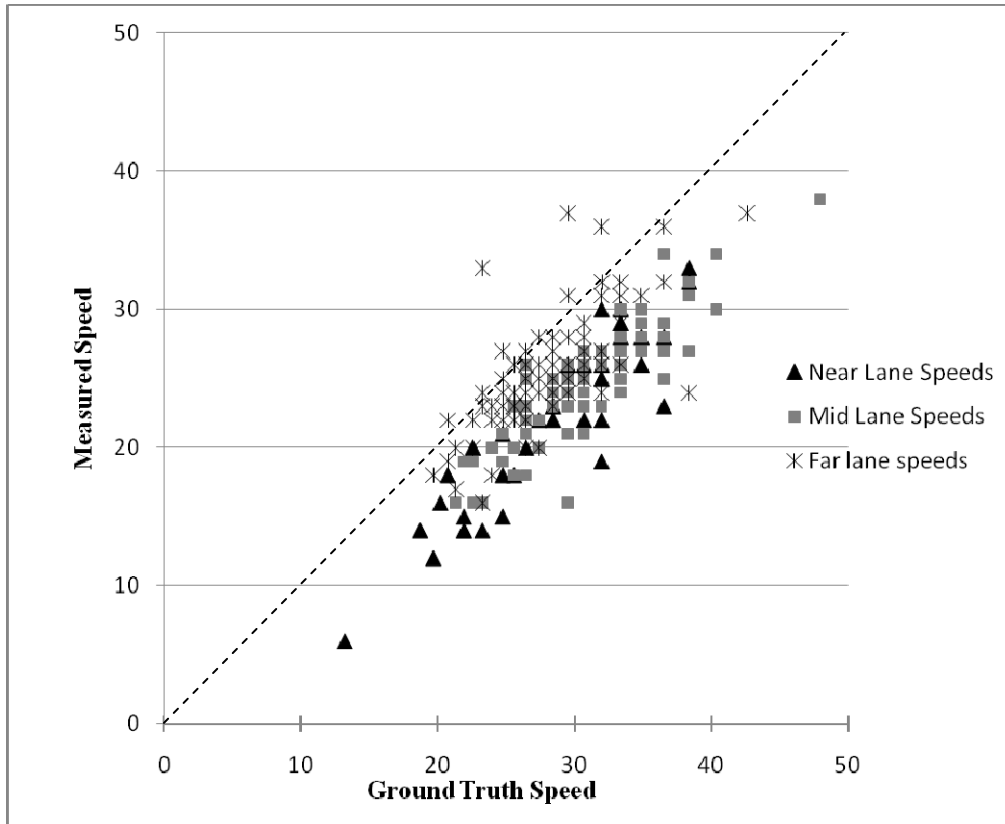


Figure 34: Measured speed data vs. ground truth measurements for the near, middle and far lanes of traffic

The consistency of underestimate of measured speed, which would suggest the issue, lies in the calibration on the speed detectors. Autoscope speed testing results demonstrated a wide range of inaccuracy. For example, MPE ranged from about 9 to 24 percent and Pearson’s R ranged from 0.74 to 0.91. This inconsistency can be attributed to calibration error, which can be fixed by improving the calibration algorithms. In turn, this calibration issue also affected the classification as shown in Table 7.

Table 8: Mid-Block Speed Data (per lane)

	Far lane	Middle Lane	Near Lane
Pearson R	0.7358	0.8554	0.9107
R ²	0.5414	0.7317	0.8294
MPE	-8.80	-19.23	-24.24
MAPE	11.04	19.23	24.24

Table 7 reveals two trends. The Pearson’s correlation coefficient shows us that actual and measured data correlated better when the vehicles were closer to the camera. This result is consistent with the occlusion analysis presented earlier. The second pattern shows that the MPE error decreases as distance from the camera increases. This is the opposite of what we expected,

as from our previous experiences, distance and error increase with a direct proportion, given the farther from the camera the object the harder details are to capture. Over-estimating speed was commonly seen in the near lane detections but not as frequently seen in the middle and far lane detections. This demonstrates a trend in the machine vision, which is not consistent with calibration errors but rather a trend, which is inherent in the machine vision detection algorithm.

Table 9: Mid-Block Classification Data

	Class A	Class B	Class C
Ground Truth	94.1%	4.64%	4.64%
Measured	96.86%	1.81%	3.63%
Samples	223	11	11

The Autoscope machine vision system separates vehicle types by estimates of vehicle length and not axle distance. The results from categorizing three vehicle classes (A=private vehicles, B=trucks/RVs, C=heavy trucks) determined that the tested machine vision system was accurate at normal vehicle classification (A) but much less accurate at uncommon classification such as trucks and buses. The inaccuracies seen in the classification of vehicle types B and C are likely the result of vehicle occlusion, insufficient calibration and small sample size.

Certain environmental and unavoidable conditions hindered data collection to such an extent that they were removed from the data pool altogether. When these conditions, which are listed below in detail were present, the data was logged and visually analyzed but not used in the experiments.

- 1) Extremely low lighting conditions. These were found during day to night transitions (dawn and dusk).
- 2) Rain and extreme fog. All of these hinder accuracy on detection, most notably rain and extreme fog. Of these, none occur during normal data counts as such data is irregular and has no utility to traffic engineers.
 - a. Snow – both standing and falling snow hinder accurate background recognition.
 - b. Sleet – Similar to rain, it caused false headlight recognition
 - c. Rain – Caused ‘doubling’ of headlights and glare, rain is a primary source of detection error
 - d. Extreme fog
 - e. High winds – caused occasional ‘Phantom’ detections due to moving background image triggering the detectors.
- 3) Incidents. (Stalled vehicles or accidents). Normal traffic conditions do not exist and normal vehicle movements are altered thus rendering sensor locations ineffective.

- 4) Initialization Periods. The beginning of each video clip requires ample time for the background to render and thus accurately detect.

The data collected during these conditions was initially analyzed and compared with the ground truth data but it was evident that such data was simply random and without utility to our experiments or transportation practitioners. It should be understood that these conditions help define the limitations of Autoscope for this application.

J. Conclusions

To conclude, a system for easily deployable, non-intrusive, portable, low-cost device designed for traffic data collection and video recording was designed, developed, and field deployed for over 106 hours under all weather conditions. Traffic information was extracted from our hardware by incorporating and deploying machine vision sensors to work in conjunction with our apparatus. With topology analysis, and video medium, intersection design has been represented. Taking into account factors such as vehicle occlusion, environmental lighting and peak hour scheduling, sensors for extracting traffic data were tested along with vehicle tracking techniques.

The hardware design meets all functional specifications including cost, reliability and deployment according to transportation practitioners consulted during this project. The automatic data extraction component is not as accurate as envisioned as of yet, however, as video and other advanced non-intrusive sensors such as radar technologies mature, data will become more accurate. To be sure, such technologies have improved dramatically over the last several years and are increasingly being used in practice. More importantly, these sensors are being enhanced with vehicle tracking technology, which should dramatically improve turning movement, speed and classification measurements.

The automated extraction of thru and turning movements was tested with a commercial ‘trip-wire’ based machine vision system, and an available “blob-based” tracking algorithm developed at the University of Minnesota [17]. In order to evaluate the performance, video data was ground truthed by logging approach counts with a Jamar field data collection counter. Volume data was collected and analyzed using the 106 hours of video collected at the four unique intersections. Though calibration of the machine detection systems and if necessary, detector placement, volume counts were collected at intervals of 15 minutes. The results of the volume data collection were found most accurate on manual counting through the video files, however, manual counting required more collection time (real time data collection plus some intersections required two passes to collect the entire intersection) than any other testing, needed the most man-power and thus had the highest residual cost. For the camera positions that are feasible to obtain with the device prototype, accuracy of the tracking algorithm was far below the recommended 90 percent threshold for accuracy set by practitioners; however, the tracking algorithm had only a small residual cost. Machine vision was accurate enough to meet the 90 percent threshold where errors ranged from occlusion, to lighting conditions to detector error and additionally machine vision had a low residual cost as compared to manual counting, thus showing the most potential out of the systems tested in this study.

Classification was tested in a similar fashion as traffic volume counts at a mid-block location approximately 250 feet upstream of a signalized intersection. Given limitations in the tracking algorithm used in our study, the classification testing was only performed for machine vision using Autoscope. Such testing was performed on a per-vehicle basis after calibrating and placing speed detectors as described in the Autoscope user manual and then attaching detector stations for acquisition of classification information. While the accuracy of small vehicles (A) was good (above 95 percent), the larger two classifications (B and C) had significantly larger errors with results showing accuracy below 50 percent. It should be further noted that the mid-

block testing met the conditions of Autoscope's normal use, however, classification was not also tested with the stop bar installation type.

Speed testing, similar to classification testing, was also performed at a mid-block location and was only tested with the Autoscope machine vision system, as the tracking algorithm output did not provide speeds at the time of testing. Speed testing was carried out after calibrating and placing speed detectors as described in the Autoscope user manual. Autoscope speed testing results were, as expected, more accurate in the nearer lanes. As the distance from the camera increased error increased as well. The near lane returned a Pearson's R-value above 0.9. The middle and far lane errors resulted in reduced R-values of 0.85 and 0.73 respectively.

Currently a new proprietary tracking algorithm is being considered for testing in an effort to increase accuracy. Furthermore, wireless transmission of streaming video from the box will be developed to allow for streaming video and traffic data. Such advances are ideal for use in conjunction with existing deployments of machine vision sensors at arterials.

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