Harley O. Staggers National Transportation Center
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ADVANCED PLANNING SURVEYS USING AUTOMATIC LICENSE PLATE READING EQUIPMENT

MAUTC Project #2

and

EVALUATION OF AUTOMATIC LICENSE PLATE READING EQUIPMENT FOR ADVANCED PLANNING

WV RP #115

by
Lloyd J. French III
David R. Martinelli
Ronald W. Eck

Final Report

May, 1998

Sponsored by
Division of Highways
West Virginia Department of Transportation

In Cooperation with
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16. Abstract Recent technological advances in computer hardware, software, and image processing have led to the development of automated license plate reading equipment. This equipment has primarily been developed for enforcement and security applications, such as monitoring parking garages or border crossings. Because license plate data are used in several transportation planning studies, automated license plate reading equipment has the potential to increase the quality and efficiency of many of the typical activities of transportation planning agencies.

The key performance attributes of license plate reading equipment with respect to the specific needs of transportation planning are determined. The following general needs are investigated:

- the specific license plate data requirements of transportation planning studies
- the effect of the equipment on traffic operations and safety
- special equipment characteristics required due to the temporary nature of transportation planning and the constraints of transportation planning agencies

Performance criteria for the equipment are established with respect to the unique needs of transportation planning. A methodology is developed to test license plate reading equipment with respect to the established performance criteria. An existing license plate reading model is then tested against these criteria to determine if it has applicability in the transportation planning field. In addition, understanding the limitations of the existing reader is an important step in developing a better system for the future. Finally, technical specifications for an automated license plate reader for transportation planning are developed. These specifications can be used to provide motivation and direction for the future development of automated license plate reading equipment for transportation planning.

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ABSTRACT

Recent technological advances in computer hardware, software, and image processing have led to the development of automated license plate reading equipment. This equipment has primarily been developed for enforcement and security applications, such as monitoring parking garages or border crossings. Because license plate data are used in several transportation planning studies, automated license plate reading equipment has the potential to increase the quality and efficiency of many of the typical activities of transportation planning agencies.

The existing applications of automated license plate reading equipment are signifiicantly different than transportation planning applications. First, in existing applications, traffic is highly channelized. Transportation planning studies will need to sample vehicles as they normally travel. Second, existing applications permit the equipment to be installed at a fixed site by the manufacturer. Due to the temporary nature of transportation planning studies, the equipment will need to be set up many times at temporary locations. In addition, persons other than the manufacturer will need to set up the equipment.

The key performance attributes of license plate reading equipment with respect to the specific needs of transportation planning are determined. The following general needs are investigated:

- the specific license plate data requirements of transportation planning studies
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CHAPTER 1 - INTRODUCTION AND PROBLEM STATEMENT

1.0 Introduction

Transportation planning agencies can use license plate data to support their planning activities. New advances in machine vision and image processing have led to the development of automated license plate reading equipment. License plate reading equipment for transportation planning applications is still in the development stage. When it is sufficiently developed, it is believed that this equipment will be useful in collecting data specifically for transportation planning studies.

The development of this equipment begins with a system that can interpret license plates correctly, however, that does not necessarily make it useful in collecting license plate data for transportation planning. There are other issues that dictate its applicability. These fall into three general categories: license plate data needs specific to transportation planning studies, traffic operations and safety, and the characteristics of the equipment. Each is discussed in detail below.

1.0.1 Transportation Planning Issues

Not all transportation planning activities have the same requirements for license plate data. Figure 1-1 provides an overview of the license plate data requirements associated with each transportation planning study. Using license plate matching as an example, it is not as critical that the equipment read the plates correctly as it is that it read them consistently. If the errors the equipment makes in reading plates are reproducible from one system setup to another, then the end result will be matching vehicle observations without necessarily reading the plate correctly. On the other hand, if the activity is conducting a travel survey by mail or telephone, then reading the plate correctly is critical. Misread plates may lead to erroneously placing persons at the survey site, with potentially disruptive results.

There are several types of planning studies that use license plate matching, consequently the requirements for the matching abilities of the equipment may be suitable for one activity and not another. If the intent is matching for cordon studies, then it is preferred to match like license plates at a rate of nearly 100 percent. However, if the intent is to determine travel time, then the requirements for matching are much more relaxed, as the planner is merely seeking a statistically valid sample size and is not concerned with capturing all potential matches.

1.0.2 Traffic Engineering and Safety Issues

License plate reading equipment must cause minimal intrusion to traffic. Traditional methods of collecting trip survey data include stopping motorists for several minutes while they answer the survey. Several states, including West Virginia, have adopted policies that prohibit stopping traffic for this purpose. In the same manner, it is a desirable attribute that the system be non-intrusive to traffic. If the equipment is intrusive to traffic, several negative safety and congestion impacts can be expected.

- A noticeable presence along the side of a freeway, such as a stalled vehicle, can reduce capacity by 15 to 30 percent (FHWA, 1994). License plate reading equipment has the potential to have a comparable impact on capacity. On freeways that operate within 15 to 30 percent of their capacity, intrusive equipment could cause freeway flow to break down, resulting in stop and go traffic.

License Plate Data Needs for Transportation Planning Studies

Need to Positively Identify a Vehicle

Mail-out or telephone surveys for
O-D Studies
-license plate data are used to access motor vehicle records yielding an address or locating a telephone number

*need the highest level of character and state recognition accuracy; do not want to incorrectly place a vehicle at the sampling location

*need autos/personal vehicles for most applications, may need heavy vehicles for some applications

*need plate data processed quickly so surveys go out before motorists forget

*do not necessarily need a high percentage of vehicles sampled (can miss a few)

Need to Find an Identifiable Marker on the Vehicle

License plate matching for
Travel Time and Speed Studies
-level of service, congestion, and travel times contours; license plates observed at 2 stations at known times, spacing between stations known; v=d/t

*need a statistically valid sample size of speeds; do not need a high percentage of vehicles sampled

*will need personal vehicles and/or heavy vehicles depending on the application

*do not need a high level of character and state recognition accuracy

*do need the number interpretation to be consistent from station to station

*time value of data is not critical

License plate matching for
Cordon Studies
-determining external-external trips; license plate observed as it crosses cordon lines; can match plates to determine movements & dwell time

*need a high percentage of vehicles sampled

*will need personal vehicles and/or heavy vehicles depending on the application

*do not necessarily need a high level of character and state recognition accuracy

*do need the number interpretation to be consistent from station to station

*time value of data is not critical

Important Characteristics of the Reader Regardless of the Application
-Mobility, data is collected for transportation planning on an as needed basis at temporary sites
-Intrusiveness, can not cause traffic backups or erratic driver behavior
-Safety, must not be a problem to drivers or workers
-Site Requirements, must be able to be set up at a suitable location (fit into roadside space with no cabling or other hazards across the road
-Data Processing Capacity, must be able to store images without overloading the system

Figure 1-1 - License Plate Data Needs for Transportation Planning Studies

- Drivers that notice an obstruction along the roadside tend to shy away from it. Intrusive equipment could induce a lateral shift in the motorists path. This shift may be into an adjacent lane on a multilane facility, or into the opposing lane on a two-lane two-way facility. The safety implications of such a phenomenon are increased potential for sideswipe and head-on collisions.
- Finally, if the equipment is large, bulky, and positioned near the roadside edge, it is considered a roadside hazard. Recommendations for treating it must be made if appropriate.

1.0.3 Equipment Issues

There are several attributes of the system that will influence its effectiveness in transportation planning. For example, transportation planners need to collect data at several temporary sites for short durations, as opposed to a single site for a long duration. Therefore, the equipment must be mobile, easily transportable, and relatively simple to set up. Other attributes that will influence its effectiveness are: reliability, cost, accuracy, data transportability and format, and processing time per vehicle. The time required to process one vehicle is very critical because it will determine the hourly vehicle capacity of the system. The vehicle processing capacity of the equipment may not correspond well with the capacity of the highway facility. Furthermore, certain vehicle arrival patterns, such as a dense platoon, may temporarily exceed the system capacity.

1.1 Problem Statement

Automated license plate reading equipment has been successfully employed in applications other than data collection for transportation planning. Furthermore, the technologies that comprise license plate reading equipment have advanced sufficiently to make development of the equipment for transportation planning feasible. Since license plate data are used for several types of transportation planning studies, there is immediate use for equipment if it is developed. The goal of this research is to evaluate the use of automated license plate reading equipment for transportation planning applications and to guide the further development of the equipment. This includes the following objectives:

1. Determine the key performance attributes of license plate reading equipment with respect to the specific needs of transportation planning.
2. Develop technical specifications for a general purpose automated license plate reader for transportation planning.
3. Develop a methodology for testing automated license plate readers for their applicability in transportation planning activities
4. Test an existing reader with respect to the requirements of transportation planning.
5. Make recommendations for practitioners considering transportation planning studies that require license plate data to be collected automatically.

Chapters 3 and 4 discuss the existing uses of license plate reading equipment and potential studies where license plate reading equipment can be used in transportation planning. Chapters 5 and 6 discuss the specific technological components of license plate reading equipment. Chapter 5 covers the components in a general fashion; Chapter 6 discusses the specific model of license plate reading equipment used and tested in this research. Chapters 7, 8, and 9 discuss the requirements of the automated license plate reader with respect to the needs of transportation planning. The requirements are developed with respect to (1) quality of the data produced, (2) traffic intrusion, (3) roadside safety, (4) transportability, and (5) equipment setup. In addition, the tests to which license plate readers should be subjected in order to determine their suitability for transportation planning are provided. The tests developed and presented include: accuracy, matching, and traffic intrusion. Finally, the performance of the reader used and tested in this research is presented. Chapters 10 and 11 present the recommended technical specifications and recommendations for practitioners, respectively.

CHAPTER 2 - METHODOLOGY

2.0 Introduction

This chapter provides a description of the general methodology and the work plan as it was executed for this research. The general methodology is contained in Section 2.1 and an overview of the work plan is presented in Section 2.2. Because the details of each task are provided with the results, only an overview of the work plan is provided in this chapter.

2.1 Research Goal and Objectives

The goal of this research is to evaluate the concept of using automated license plate reading equipment for transportation planning and to guide the further development of the equipment. This includes the following five objectives:

1 Determine the key performance attributes of license plate reading equipment with respect to the specific needs of transportation planning.

2. Develop technical specifications for a general purpose automated license plate reader for transportation planning.

3. Develop a methodology for testing automated license plate readers for their applicability in transportation planning activities

4. Test an existing reader with respect to the requirements of transportation planning.

5. Make recommendations for practitioners considering transportation planning studies that require license plate data to be collected automatically.

These five objectives were accomplished through the execution of the following work plan.

2.2 Work Plan

2.2.1 Task #1: Review Literature and Background

The literature relevant to license plate reading and transportation planning was reviewed. As will be described in Chapter 3, it was found that most applications using license plate reading equipment have been in the enforcement arena. These systems have been employed to recover stolen vehicles, monitor ingress and egress at parking garages, maintain inventories of vehicle fleets, and identify persons at border crossings. These applications were investigated because the use of license plate readers in these activities provides an indication of the feasibility of developing license plate reading equipment for transportation planning applications. Site visits were made to the leading vendors to further review the technical aspects and performance of each system.

In addition, the uses of license plate data in transportation planning are reviewed. Traditional transportation studies, such as cordon studies, trip surveys, and travel time studies, are reviewed in detail to determine the requirements of the license plate reader. Other less common or less established studies are briefly presented to demonstrate the broad range of activities in which the equipment might be employed.

Finally, the state of technology of the main components of license plate reading equipment were reviewed. For each component, the following items are investigated:

1. The role of the component in an automated license plate reader.
2. The possible technological alternatives that could be employed, (e.g., monochrome versus color cameras) along with some advantages and disadvantages of each alternative.
3. General recommendation for the alternative that would most suit the unique needs of transportation planning.

2.2.2 Task #2: Draft Specifications and Purchase Equipment

Technical specifications were developed for the procurement of two stand-alone LPR units capable of supporting transportation planning studies. Drafting the specifications involved synthesizing information acquired during Task #1 into a bidding document for interested vendors. A variety of items were considered and incorporated. From a traffic operations viewpoint, the traffic flow observed in the highway network could not exceed the capacity of the system. Average headways on a freeway can be less than two seconds. The system must be capable of processing and storing the image within this brief time frame. In addition, the system must be able to read plates from vehicles traveling at speeds that range from 15 mph on local streets to over 75 mph on freeways. From a safety perspective, no obstructions, such as cables, may be placed in the travel lane.

Other issues that entered into the drafting of the specifications are:

- State recognition. Is it necessary for the reader to recognize state origins? If so, how many states need to be recognized? only the home state? the home state and the neighboring states? all states?
- Lighting. Is it necessary to read plates after dark? If so, which method of lighting is likely to be the least disruptive to traffic?
- Accuracy. What percentage of plates need to be read correctly? Should accuracy be based on the percentage of characters read or should it be based on the percentage of the plates read correctly in their entirety?
- Training and Installation. Is the equipment difficult to set up, operate, or maintain?

At the conclusion of the research project, the experience of using and testing the equipment provided additional insight into the technical requirements of the equipment. The original specifications were rewritten based on these additional discoveries. These updated specifications can be used to motivate and guide the further development of the license plate reader for transportation planning.

2.2.3 Task #3: Test the Equipment Accuracy

Typical transportation planning studies were analyzed to determine the accuracy requirements for the equipment. The analysis included a detailed investigation of the products of each planning study. The mechanics of the studies were then investigated to determine the requirements of the input data needed to produce the desired output.

In the past, most applications of the equipment have been in controlled settings. The lanes were heavily channelized and the traffic flow was metered. Since intrusiveness to traffic must be kept to a minimum, transportation planning activities will not be sampling traffic of this nature. Therefore, it is critical to test the accuracy of the equipment on typical facilities of the highway system. The testing took place on the Pellissippi Parkway in Knoxville, Tennessee. It is typical of the high-speed, unchannelized facilities on which transportation planning applications will take place.

Two different configurations of the equipment were tested. The first configuration had one camera covering each lane and the other had two cameras covering each lane. There were two accuracy tests for each configuration. For each test, sample sizes of approximately 1900 vehicles were used for the single camera configuration and 2700 vehicles were sampled for the dual camera configurations. The test results were then compared to the accuracy requirements to determine which planning studies this model of license plate reading equipment can support.

Task 2.2.4 Task #4: Evaluate and Test the Equipment for Activities Based on License Plate Matching

The matching rate between two units was tested simultaneously with the accuracy test. For each configuration, two readers were setup in series so that each system sampled the exact same set of plates. The interpretations at the two readers were then compared to determine the percentage that matched.

Detailed analyses of cordon studies and travel time studies provided insight into a matching rate criteria for each of the studies. The matching test parameters were closely scrutinized to determine the proper interpretation of the results. The factors that caused the imperfect matching rate were identified. These factors were then analyzed to determine if they would be randomly distributed, or if they could be specific to one reader. For example, in a cordon study, would the problem be with all the readers, or is there a chance that one reader would be a "problem reader?" If the errors are particular to a specific reader, the results of the study would be influenced.

The matching rate was then compared to the requirements developed for cordon studies and travel time studies. For each type of study, it was determined whether the equipment is suitable for the particular application.

2.2.5 Task #5: Assess Equipment Intrusion

The presence of the equipment along the roadside can produce at least two driver reactions. First, the motorist may reduce speed. Second, the motorist may laterally shift the vehicle away from the roadside where the equipment is located. These phenomena were quantified for two different highway functional classifications: freeways and local streets. For both functional classifications, the distribution, mean, median, mode, and standard deviation of the data were collected. A comparison of these data were made between the case when the equipment was present and when it was not present. For each case, a sample size of 200 vehicles was used.

2.2.5.1 Task 5A: Measuring Speed

A doppler-based speed gun was used to perform a spot speed study of vehicles traveling through the sites. Under similar weather and traffic conditions, a spot speed study was performed at the same location, but without the equipment present on the roadside. Special events or incidents did not influence the speeds on any occasion when speed data were collected.

2.2.5.2 Task 5B: Measuring Lateral Shift

The lateral position of a vehicle was measured in the following way. Longitudinal lines were painted every foot transversely across the lane. In a 12-foot lane, this means there were 12 lines painted. As a vehicle passed through the site, the distance from the lane edge to the nearest wheel was determined visually using the lines as a guide. For the passing lane, if the driver-side wheel tracked over the third line from the lane edge, this indicated that the driver was three feet from the lane edge and approximately centered in the lane. If the vehicle tracked over the sixth line from the lane edge, this indicated that the vehicle was six feet from the lane edge and probably close to entering the traveling lane on the passenger-side.

Lateral position was measured first with the equipment present and then later for the same area without the equipment. As in the other measurements, no special events or incidents influenced the traffic on any occasion when data were collected.

Using cones to channelize traffic can be an effective way of providing the license plate reader with more consistent images to interpret, likely resulting in higher accuracy. The intrusiveness of the channelized setup was measured for the local street but not for the freeway, as it presented a safety hazard in the high speed environment.

2.2.6 Task #6: Evaluate The Equipment as a Roadside Hazard

In this task, a qualitative analysis of the roadside hazards posed by the equipment setup was performed. Consideration was then given to the options available for rectifying any hazards identified. The options fall into one of the following four categories, in order of desirability: (1) remove the hazard from the roadside, (2) relocate the hazard to a location outside the clear zone, (3) replace the hazard with a breakaway version, or (4) shield the hazard with a suitable barrier.

Task 2.2.7 Task #7: Evaluate Equipment Transportability and Set Up Time

Performance requirements were established for both transportability and set up time. These requirements were derived from the work force attributes and time constraints of typical transportation planning agencies. The performance of the existing license plate reader was then evaluated with respect to the requirements. Finally, these requirements were used in the development of improved technical specifications for the license plate reader.

2.2.8 Task #8: Evaluate Cost Effectiveness

The cost of the license plate reading equipment is in excess of $40,000 per unit. This cost might be prohibitive to some or most planning agencies. However, over its useful life, the equipment may prove to be more cost-effective than labor intensive means of collecting license plate data, i.e., pencil and paper or videotaping. A few case studies are presented along with some general guidelines for determining when the existing license plate reading equipment might be the most cost-effective alternative. These recommendations are based on the assumption that the reader is a viable alternative from a performance point of view. Currently this is not the case, but may be in the near future.

2.2.9 Task #9: Recommendations for the State-of-the-Practice in License Plate Data Collection Technologies

Recommendations that transportation planning agencies could use regarding the acquisition of license plate data are presented. These recommendations are made on the basis of what was found during this research to be the state of the practice in license plate reading.

2.2.10 Task #10: Recommendations to Future Developers and Users of Automated License Plate Reading Equipment

This task summarizes the findings of this research endeavor. New technical specifications are developed based on this research. These specifications will be a valuable resource for future system developers. In addition, some specific areas requiring more focused research are identified, both to develop the reader and to more effectively manage the data it produces.

CHAPTER 3 - LITERATURE AND PRIOR WORK REVIEW

3.0 Introduction

This review will investigate three items. First, the traditional methods of collecting license plate data are discussed. The different methods of manual collection and their limitations form the basis of discussion. Next, the applications of real-time automated license plate reading equipment (LPR) in applications other than transportation planning are reviewed. There have been many applications, mostly in enforcement activities, ranging from toll collection enforcement to identifying suspicious vehicles at international borders. It is important to review these applications because they demonstrate the abilities and shortcomings of the license plate readers. Third, travel time studies were performed in three cities using automated license plate reading equipment not having all of the capabilities of the equipment used in this research. This application will show how license plate readers interface with the current transportation planning field, and will highlight the experiences of the researchers.

3.1 Traditional Methods of Collecting License Plate Data

3.1.1 Manual Field Collection

A number of manual techniques exist for collecting license plate data. Conventional strategies that have been employed in the past include: using a pen and paper to record the data from passing vehicles; reading the plate data into an audio tape recorder as vehicles pass; and typing the plate data from passing vehicles into a laptop computer stationed at the roadside.

One basic problem with each of the manual methods is that at high volumes or high speeds the field technician has little chance to capture the needed data. In high speed situations, the plate may be out of the field technician's view before it is read in its entirety. In high volume environments, the person may only record a few plates in their entirety while missing the majority of them. In these situations, it may be appropriate to record only the first or last few characters on the plates. This would yield a larger sample size, but would preclude this sample from being used for studies where the driver must be contacted, such as in trip surveys. This scenario is acceptable in some planning applications, such as license plate matching. For example, if a field technician can record all characters but one, and the last character is known to be a number, then there are no more than 10 plates in the state that would match with what is recorded. In fact, the number of matching plates is likely to be less than ten. If the identical "partial" plate observation is recorded at two different stations, there is very little chance that they are different vehicles. However, at close vehicle headways, the vast majority of plates will still go by undetected and an insufficient number of characters may be recorded for those plates that are sampled. For each numerical character not recorded, the number of vehicles in a given state that would match with the recorded data increases by a factor of 10. For example, recording all but two numerical characters means that 100 vehicles in the state could match with the partial observation. For each alphabetical character not recorded, the number of potential matches increases by a factor of 26.

Another problem is that none of these methods provides the exact time of the plate observation. This is an important consideration in travel time studies. The time can be approximated using the laptop computer, which can record the time of the entry. The time can be deduced in the audio tape method if the exact starting time of the tape is known. However, even in these cases, error can be introduced while the technician reads, deciphers, and enters the data.

In summary, manual methods rely heavily on field personnel and will be subject to human error. The person may misread the plate, be affected by lighting or glare, or wrongly record what they correctly read. Of particular concern is the tedium inherent in the task of collecting such data. The tendency to miss vehicles or wrongly read or record data due to inattentiveness is a real concern. Some applications, such as the trip survey, need the highest level of plate data accuracy. Since there is no method of verifying manually collected license plate data after they have been collected, manual methods have little applicability in these studies.

3.1.2 Manual Collection from Video Tape

License plate data can be collected by videotaping the plates of passing vehicles and playing the tapes off-line to manually read the plates. Two problems emerge with this method. First, it can take in excess of 20 hours of manual reading for each hour of tape (Shuldiner and D'Agostino, 1993). Second, since the plate identification process is so time-consuming, the data may not be available until long after the trip was made. In cases where these data are used to determine motorists' addresses for mail-out travel surveys, that time may prohibit the surveyor from getting quality results because the motorist may forget the particulars of the trip being surveyed.

3.2 Applications of Real-Time Automated License Plate Reading Equipment in Fields other than Transportation Planning

There have been many applications of real-time automated license plate reading equipment worldwide. This review will deal mainly with applications in the United States because reading American license plates is different from reading plates in other countries. First, there are more than 1800 different types of license plates in the U.S., each having different colors, symbols, fonts, and borders (Gibson, 1995). Second, U.S. plates are smaller than those in most other countries. Finally, they tend to be dirtier since they are often mounted solely on the rear of the vehicle. This is a place of high air turbulence which picks-up dirt and other road surface debris and deposits it on the plate. These factors make reading license plates in the U.S. a more challenging task. For the project described herein, it was important that the equipment have a proven track record in reading U.S. plates in actual field applications. Although several vendors sell such equipment, two have emerged as superior in American applications: Perceptics Corporation and Imaging Systems of Alphatech Incorporated. Consequently, the license plate reading applications of Perceptics and Alphatech form the basis of this discussion.

The success of the following projects, since the majority involve enforcement activities, provides an indication of the accuracy of an LPR system. Enforcement applications require a high degree of accuracy. False alarms can lead to false accusations, wasted time and effort, and frustration on the part of the falsely accused. These applications demonstrate the comfort level that the users of the technology acquired after becoming acquainted with it.

3.2.1 Primary Automated Lookout System (PALS) - Canadian Ports of Entry

With thousands of people traveling between the US and Canada every day, Canadian officials believed that significant benefits could be accrued by automating the border crossing inspection process. In 1992, the Canadian Ministry of Revenue procured Perceptics' LPR equipment to use in this effort (Gibson, 1995).

The LPR is used in the following way. First, for each vehicle approaching the border, the LPR locates and reads the license plate number and state. The plate is then matched against a data base of vehicles either stolen or registered to suspicious persons. If the vehicle is listed in this database, the inspector is notified to inspect the vehicle further, otherwise the vehicle proceeds through the border crossing expeditiously (Gibson, 1995).

In this effort, Perceptics has installed many LPR units that have demonstrated accuracy in identifying each license plate number and state, province, and country of issue. The company claims that it can do this in all weather conditions, 24 hours a day and seven days a week. The project was so successful that Canada is in the process of equipping nearly 120 land-based ports of entry with this system (Gibson, 1995).

3.2.2 Electronic Toll Collection Enforcement

Toll booths can be a major headache to motorists, as they are often bottlenecks that result in congestion and backups. One method of eliminating the bottleneck is to collect tolls with special electronic tags that permit automatic vehicle identification and electronic charging of the appropriate toll (Jordan, 1995). This toll collection technology requires a special lane for "tag-equipped" vehicles only. One primary incentive for motorists to become equipped with these tags is that traffic in this lane flows faster than the conventional toll booths, thus saving the motorist time.

Vehicles that are not equipped with the electronic tags will always be tempted to use the exclusive lane for tag-equipped vehicles. Using the lane allows violators free access to the tolled facility, and a quicker trip through the toll collection area. In fact, a recent study on a toll road of this sort showed that 40 percent of the users of the "Tags only" lane were not equipped with tags (Jordan, 1995).

The enforcement of these lanes is critical to ensure that every user pays the appropriate toll. It also enhances traffic operations in the lane by prohibiting violators from congesting the lane. The following example demonstrates the effectiveness of LPR equipment in the enforcement of these "Tags only" lanes at toll booths.

Alphatech first set up such a system on the Verrazano Narrows Bridge in New York City. This was expanded to include 116 lanes of equipment throughout the Metropolitan Transportation Authority Bridges and Tunnels network. When the system detects a violation, the equipment captures up to four images of the rear of the vehicle. The images are compressed, stored, and later read by an operator. From the license plate information, the owner's name, address, and vehicle type can be found (Jordan, 1995).

Although Alphatech's equipment has the ability to read license plates in real time, it is not utilized on the Verrazano Narrows Bridge. However, the operator is assisted in the reading of license plates from the images through the use of optical character recognition (OCR) software. The OCR software achieved accuracies up to 90 percent. With the operator assisting the system, greater accuracies were achieved (Jordan, 1995).

3.2.3 Commercial Vehicle Operations

Law enforcement officials have set up a nationwide database of commercial vehicles called SafetyNet. SafetyNet assists in the identification of violators by providing an on-line record of "out of service" inspections and past driver violations. In addition, information pertaining to the driver, power unit, and secondary unit are also available on this database. The data contained in SafetyNet for a particular vehicle can be accessed via the vehicle's license plate number and state (Gibson, 1995).

Perceptics' LPR has successfully performed in the commercial vehicle inspection process in the following way. As a vehicle nears a weigh station, the license plate is read by the LPR. In less than one second, the truck is identified and its records are available to the enforcement personnel at the station. Using this technology allows officers to make better informed decisions during the inspection process so that unsafe or unauthorized commercial vehicles are kept off the highways. The drivers of safe commercial vehicles benefit from having inspections expedited, cutting down on their lost time and making them more productive. Wisconsin and Minnesota have implemented such systems. Sites expected to come on line in the near future sites include Iowa, Indiana, and Oregon (Gibson, 1995).

LPR equipment also shows potential for application in Weigh-In-Motion stations (WIM) and weigh and distance tax auditing. At WIM stations, trucks having no violations and falling within the weight restrictions are permitted to bypass the stations. Perceptics reported collaborating with IRD of Saskatoon, SK, Canada, to interface WIM and LPR technology.

3.2.4 Security and Access Management

Applications in security and access management are numerous. The accuracy of the equipment in these applications tends to be higher because frequently the equipment can be fine-tuned to a specific vehicle fleet. Applications include monitoring exclusive or permit-only parking lot violators; monitoring parking garages for frequent visitors who may be shopping for cars to steal; or monitoring rental car parking facilities as an integral part of a fleet management system (Jordan, 1996). In addition, the equipment has also been used to aid in the recovery of stolen vehicles (Jordan, 1995).

In 1989, Alphatech was employed by the Hertz car rental agency to set up a system that used LPR equipment in their parking garage in Manhattan (Jordan, 1996). The system is used for automatic inventory and control of the exit gate. When a vehicle drives up to the exit gate, the license plate is read. If the vehicle was rented within the prior 15 minutes, then the gate is opened automatically. If the vehicle wasn't rented, then a manager is silently paged. Since all license plates are read as they leave, an inventory of those vehicles still left in the garage can be kept automatically.

Alphatech has also used their equipment in parking lot access management applications (Jordan, 1996). Parking lot administrators report experiences with vehicles entering with one ticket and exiting with another. There are several motivations behind this practice. First, by using a ticket that has a more current entry time, the parking fee is reduced. Second, a patron may claim loss of their ticket and assert short term parking, even if the car was in the garage for several days. In addition, sometimes thieves enter with one vehicle, but leave with a stolen vehicle. Finally, if the cashier has access to unused tickets, they may switch high and low value tickets and pocket the difference.

Alphatech has applied their LPR equipment to dealing with the problem of parking garage ticket fraud (Jordan, 1996). When a patron enters the garage and receives a ticket, an image of the back of the vehicle is captured and sent to a central computer. The central computer reads the license plate and associates it with the image, the ticket number, and their time of entry. When the patron leaves, another image of the back of the vehicle is captured. The attendant can tell by visual inspection of the two back end photos whether or not that ticket matches the vehicle. The central computer can calculate how much the patron truly owes if they are using the wrong ticket, or if they claimed to have lost their ticket. In addition, if the patron's ticket doesn't match the vehicle, their identification is checked by the lot personnel. This system should deter thieves or at the very least provide additional evidence that will make them easier to locate or convict. Alphatech reports using this system in parking garages in Boston and Raleigh.

Finally in the area of security, LPR technology can be employed in the task of recovering stolen vehicles (Jordan, 1995). In the late 80's, the Massachusetts State Police provided Alphatech with a database of 40,000 license plates of stolen vehicles. Alphatech set up the LPR equipment on one side of the Sumner Tunnel in Boston. When a vehicle's plate was read, it was matched against the database of stolen vehicles. If it turned out to be a stolen vehicle, the LPR operator was alerted to notify a law enforcement officer on the other side of the tunnel. This application led to the first stolen vehicle recoveries in the U.S. using LPR equipment.

3.2.5 Vehicle Emissions Testing

LPR technology can also be used in conjunction with individual vehicle emissions testing. Perceptics reported integrating the LPR with two types of emission testing systems (Gibson, 1995).

One is a fixed site emissions testing center where the whole license plate is read, stored, and printed on the test sheet with time of entry. Second is a mobile system where the license plate is read at the entry to an interstate highway. If the vehicle meets the emission standards, the image is dumped. If the vehicle is not up to standards, the image is stored along with the number, time, date, location, and emission test results.

Hughes - Santa Barbara and Alphatech report of an emissions testing device dubbed the "Hughes Smog Dog." This device projects an infrared beam across the roadway to measure a vehicle's particulate emissions. If the emission level is not in compliance with standards, a license plate reader is employed to identify the vehicle so that the owner may be notified of their violation.

3.3 Prior Transportation Planning Studies using Automated License Plate Reading Equipment - Collection of Travel Time Data

One version of automated license plate reading equipment has been used in transportation planning studies (Shuldiner and D'Agostino, 1993). The LPR was used to perform travel time studies in three cities: Boston, Massachusetts; Seattle, Washington; and Lexington, Kentucky. It was the first published report of the equipment being used in the field of transportation planning. Shuldiner and D'Agostino collected more than 1500 hours of traffic on video tape. Video cameras were used to videotape the rears of passing vehicles. Taping typically ran from around 6:30 am to 10:30 am, and again in the afternoon from 2:30 pm to 6:30 pm. They only taped during daylight hours because they relied strictly on existing light. In most cases, the equipment was set up at four locations in series. The idea was to find vehicles that passed by more than one location and determine the times they passed each. Using this information in conjunction with the distance between the two locations enabled an average speed from location to location to be calculated.

The license plates were read off of the video tape with both the license plate reading equipment and manually for comparison purposes. The license plate reading equipment used optical character reading (OCR) to read the number off the image. A license plate matching program that utilized a "fuzzy matching algorithm" was used to find license plates that were detected at more than one location. Matching license plates were used to determine travel times for individual vehicles. These individual travel times were aggregated and statistics calculated. The following lessons were learned from the experiment.

First, it was learned that technicians can require up to 2000 percent longer than the LPR to process video tape. The reader goes through two hours of tape in two hours. The technician that must go through the tape frame by frame takes up to 40 hours.

Second, even at relatively low plate matching rates, a significant number of plates and accurate travel times can be obtained. The report contained a comparison of manually read plates, which had a higher matching rate, and the automatically read plates. The travel time resulting from the automatically read plates compared very favorably with the manual read plates.

There are three differences between the technology employed in this application, and technology being evaluated under this study. First, Shuldiner and D'Agostino's equipment did not read license plates in real time. There was no image processor in the field, as it resided in a laboratory area where the video tapes are transported to be read. The technology that Perceptics and Alphatech offer has an on-site image processor that reads the plate number and state while a host computer stores this data. Second, Shuldiner and D'Agostino's equipment did not use an external lighting source, as they relied strictly on ambient light. Perceptics utilizes an infrared strobe light and Alphatech uses a flood light. These allow the equipment to read plates when existing light is insufficient. Finally, Shuldiner and D'Agostino's equipment did not identify states. Even if the LPR is used to read the plate number, the state must be read and input manually. Both Perceptics and Alphatech offer the ability to identify the state while reading the number.

3.4 Concluding Remarks

In recent years, license plate reading has emerged as a viable tool in enforcement applications. Several activities and studies of transportation planning agencies use license plate data. As the literature demonstrates, there has been little research performed in the development of license plate reading equipment specifically for transportation planning. However, if such a system could be developed for transportation planning, it would be of significant benefit to the field. Transportation planning agencies need to make optimum use of the resources available to them. Automated license plate reading equipment could be a valuable tool to the agencies. There is a need to investigate the requirements of license plate data collection for transportation planning and relate these to the development of automated license plate reading equipment.

CHAPTER 4 - LICENSE PLATE DATA NEEDS FOR TRANSPORTATION PLANNING, ENGINEERING, AND RESEARCH ACTIVITIES

4.0 Introduction

State departments of transportation (DOT), metropolitan planning organizations (MPO), municipal planners, and other planning agencies use license plate data to perform their given functions. Automated license plate reading equipment (LPR) can benefit these agencies in two ways. First, it can automate the data collection in which they are currently engaged. This can lead to a time and cost savings for the agency, and most likely more accurate data. Second, it can open opportunities to conduct new types of studies. LPR's can have distinct advantages over the conventional methods of collecting license plate data. First, the LPR time stamps the data very precisely. As will be demonstrated, this added dimension of time makes the data useable in a variety of new ways. Second, the LPR collects the data and stores it in electronic format without direct human intervention. This makes it more useful in matching with other license plate data bases. Finally, the LPR provides the license plate and time data quickly, potentially in real-time. If the data can be matched or manipulated in real-time, the equipment adds yet another dimension of usefulness to the data.

This chapter is divided into two parts. First, the existing uses of license plate data are presented. These activities could be enhanced in terms of cost-effectiveness, accuracy, and accessibility if LPR technology is employed. Second, new uses of license plate data are presented. These applications would be possible due to the advantages that LPR's have over conventional methods.

It must be noted that the applications presented are not an exhaustive list of applications. They represent a sampling of the applications from the fields with which the author is familiar. It is expected that many other ideas could be generated from other individuals having different backgrounds.

4.1 Existing License Plate Data Uses

Existing license plate data uses are presented in this section because LPR technology may be able to enhance these activities. In general, LPR technology potentially has two advantages over conventional methods that will allow it to collect more data to use in the existing applications. First, the LPR will not likely be influenced by traffic speed. At high speeds, such as those found on freeways, it is very difficult to obtain accurate license plate data manually, even under the lightest of traffic conditions. Second, the LPR should not be sensitive to ambient light conditions. This makes data collection possible during night, dusk, and dawn conditions. The net effect of these two advantages is that more data is available.

LPR technology can also provide higher quality data to support these existing activities. This is because an image of each vehicle is saved electronically. If accuracy can not be sacrificed, then an image of each vehicle and its plate can be reviewed to ensure correctness.

Several activities are presented. In each of the activities, the emphasis will be placed on how license plate data is used to support these functions. Each of the activities could benefit from employment of LPR technology due to the advantages explained earlier.

4.1.1 Origin - Destination Studies

The purpose of origin-destination studies is to determine the travel patterns on a transportation network. A popular method employed in conducting origin-destination studies is the trip survey. In a trip survey, a particular facility in the transportation network is selected. A sample of users of this facility are asked to fill out a survey that includes information such as their trip origin, destination, and purpose. There are several methods of distributing the survey. Commonly, license plate data are used to match with the motor vehicle records of a state to determine the owners, their addresses, or their telephone numbers. Contact is then made with the owner as soon as possible. If there is too great a time lapse between the trip and the survey, the likelihood of the driver remembering the trip and all its characteristics is greatly reduced.

LPR technology can be particularly advantageous in trip surveys in two specific ways. First, the license plate data are captured in electronic format. Matching with the large motor vehicle records database can be performed without human intervention, making it a much quicker process. Second, accuracy should be a high priority so that someone is not erroneously sent a survey. Reviewing the saved images will ensure 100 percent accuracy.

4.1.2 Cordon Studies

A cordon study can be defined as a study of the trip pattern into, out of, and across a cordoned off area. There are several reasons for performing such studies. One may cordon off a residential area and measure the trips entering and exiting within a specified period of time. These will likely be "cut through" trips.

In addition, trips that begin or end outside of a transportation network are of particular interest to transportation planners. These data are specific inputs into traffic assignment models. To measure these trips, planners cordon off the transportation network and record the trips that cross the cordon lines. Those trips that both enter and exit the study area are also of interest, and must be matched to determine through trips.

Performing cordon studies requires license plate data. If the objective is to determine which vehicles both entered and exited the study area, then the license plate serves as an identifiable marker which will allow the vehicle to be identified as one which was observed doing so. If the objective is to determine the characteristics of the trip, then the license plate data serves essentially the same purpose as it does with origin-destination studies.

4.1.3 Travel Time

Travel time is a basic traffic flow parameter that is commonly measured and easily understood. Planners may use it, for example, to estimate the Level of Service of an arterial, or to determine distances that can be traveled from a point of interest, such as a CBD, in given units of time, such as 15 minutes or 30 minutes.

Travel time can be measured using license plate data. The license plate is used as an identifiable marker on the vehicle. If it observed at two different points, and the time of observation at each point is recorded, a travel time can be calculated. If the distance separating the two points is also known, then the space mean speed can be directly calculated by dividing the distance by the travel time. This space mean speed provides a truer measure of the prevailing speed on a facility than a spot speed study, or time mean speed. Time mean speed is always biased towards faster vehicles and always overestimates the true speed of traffic.

4.1.4 Trip Generation Studies

Trip generation studies are a specific case of the more general origin-destination study. In this study, the license plate data is collected at a specific land use, such as a shopping mall or a gas station. The destination of the particular trip is known --even though it may not be the primary destination. The origin of the trip can be assumed to be the home address of the owner of the vehicle, or the owner can be surveyed via mail or telephone as in the origin-destination study to determine such things as: origin, route choice, primary destination, or other destinations.

4.2 Potential License Plate Data Uses

4.2.1 Advanced Heavy Vehicle Classification

Currently, to perform heavy vehicle classifications automatically, a data collection device must infer from data the presence and classification of a heavy vehicle. These classifications are scientific guesses based on either the number of axles or some electronic fingerprint of the vehicle. License plate data could be used to positively identify and classify a heavy vehicle and take the guess work out of the process.

If there is a database of trucks and trailers that can be accessed via the license plate, then the truck classification procedure can be performed automatically and with much higher precision and accuracy than is currently achievable. As a heavy vehicle passes the license plate reading site, its plate is read and matched against this database to extract the classification data. If the data base contained real-time cargo and destination information, the study could be greatly enhanced.

4.2.2 Tracking Driver Behavior Over Time by Combining License Plate Data with Other Traffic Data Collectors

Currently, traffic data such as speeds and headways are collected for a given facility on a given day. If license plate data were integrated with this traffic data, then the data can be linked to a given vehicle. If the data collection takes place over a long period of time, a particular driver's behavior can be tracked. This could lead to new findings in the areas of human factors and driver behavior and reduce the need for driver simulation stations. The following examples illustrate how tracking traffic data by specific drivers over time can be beneficial.

4.2.2.1 Tracking Driver Behavior Towards Special Features in the Transportation System

When new work zones are placed in the transportation system, or a new traffic signal is installed, the safe and efficient operation of these elements depend heavily on driver behavior toward them. For example, the speed that drivers travel through work zones greatly influences the safety of the work zone.

If the LPR could be linked with other equipment such as wide area vehicle detection technologies or even a simple speed gun, the behavior of specific drivers toward the special feature over time can be measured. The data from each day of data collection can be matched against each other to determine which users are the frequent users. This data is then extracted by driver and plotted versus time. Trends can then be observed, models built, or better traffic control or policies adopted. For example, if driver respect toward the work zone degrades over time, appropriate engineering or law enforcement intervention can be applied.

4.2.2.2 Tracking Driver Facility Usage over Time

One of the basic factors influencing highway capacity is the proportion of drivers that are familiar with the facility, or as it is commonly called, the percentage of "commuters." Highway Capacity Manual procedures are somewhat vague on how to measure this parameter, and if it could actually be measured, its effect on highway capacity can truly be measured. License plate data can be used to precisely determine what proportion of traffic are familiar users. For a given facility, each day a comprehensive list of the license plates of vehicles using the facility can be captured. If the data for each day are matched against each other day's data, the number of common users will be found. The number can be compared to the overall traffic on the facility to find the proportion of traffic that are "commuters." Having a direct way to measure this parameter will allow research to be designed that can determine the relationship between capacity and "commuters."

4.2.3 Determining Movements to Progress in Traffic Signal Systems

License plate matching can also be used to determine which movements are most appropriate for progression in traffic signal systems. Plate data could be collected at key points in the signal system and matched with one another. If the plate data are available in electronic format and in real-time, plates could be matched in real-time. This would allow the major movements through the system to be determined at any given moment. With this data, traffic signal system algorithms could be designed to alter timing plans to respond to traffic demand in real time.

4.2.4 Determining Macroscopic Traffic Flow Characteristics

A system of two interconnected license plate readers can be used to directly measure the macroscopic traffic flow characteristics density (k), space mean speed (u) and flow (q). Assume two license plate reading units are set up in series at some distance of separation. When a vehicle passes the first unit, its license plate will be read and recorded along with the time. This data will then be transmitted to the central computer. When a vehicle passes the second unit, the same information is recorded and transmitted to the central computer. At the central computer, a matching program searches through the list of plates recorded at the first station for a match to this vehicle just observed at the second station.

If a match is found, then the central computer counts how many vehicles have passed the first station since the vehicle was first observed at that station. This represents how many vehicles are between the two stations at that instant (assuming no access points between the two stations). If this number of vehicles is divided by distance between the two points this will yield density.

In addition, if the central computer determines the time passage since the vehicle was observed at the first, the separation distance can be divided by this time to determine space mean speed. Multiplying the density by the space mean speed will yield the flow rate.

As will now be discussed, these three parameters can be used exclusively or in some combination to perform important functions not currently performed using license plate data.

4.2.4.1 Monitoring Freeways for Incident and Queue Detection

These data can be used to monitor freeways for incidents or queues. They can provide a more accurate account of prevailing traffic condition information than loops or other detectors that only give occupancy and flow because q, k, and u can be measured directly and compared to the q-k model for that facility to determine if a breakdown has actually occurred.

4.2.4.2 Determining the Relationship between Space Mean Speed and Density

The relationship between space mean speed (u), density (k), and flow (q) is fundamentally determined as flow equaling the density times the space mean speed. However, the relationship between any two of the variables cannot be theoretically determined and has been the subject of much research in the past. The relationship between space mean speed and density has been of particular interest since determining it will permit the remaining relationships to be determined theoretically. Using the macroscopic traffic flow data calculated from the license plate data will allow further research in this area or could allow the relationship for a particular facility to be measured. This would permit the actual flow-density model for the facility to be determined. If this model is known, the density and flow information provided in real-time will predict incidents with greater reliability. Furthermore, if this model is determined, attributes of the incident, such as capacity and speed through the incident site can be determined, further aiding traffic control center operators in the tasks of emergency vehicle deployment and alternate routing.

4.2.4.3 Calibrating Link Performance Functions

Finally, these data can be used to calibrate link performance functions. Link performance functions are models used in traffic assignment models. They are used to relate the traffic volume on a particular link with travel time. They are used so that appropriate volumes can be assigned to all links such that an equilibrium is achieved. This equilibrium is based directly on travel time, either by assigning volumes such that total network travel time is minimized or by assigning them such that no driver can change routes and achieve a lower travel time. More accurate link performance functions will lead to more accurate traffic forecasting models, which are central to the accuracy and effectiveness of long-range transportation plans.

Link performance functions can be calibrated by recording sets of travel times and flows, which are calculated as discussed earlier. These data can then be used to calibrate a model relating the two variables, such as a linear or logarithmic regression model. Flow is the independent variable and travel time is the dependent variable. This model is the link performance function.

4.2.5 Predicting Emissions Through Better Modeling Data

An important current issue is the air pollution caused by vehicle emissions. Modeling procedures have evolved that are aimed at predicting the emissions that will be produced by the traffic on a given facility. However, these models have come under great criticism because of the assumptions they make in the modeling due to the lack of data. One important assumption could be replaced with improved data via license plate data.

Not all vehicles pollute equally. A small minority of vehicles emit the majority of pollution caused by the automobile fleet. Currently, the traffic stream on a facility being modeled is assumed to have an average or some other arbitrarily chosen number of these polluters. However, through license plate data, it can be determined exactly how many of these vehicles are present in any given traffic stream.

The data base of the major polluting vehicles could be identified and listed by make, model and year. For example, new cars are much less polluting than those manufactured in the past; this would be indicated by the data base. When a plate number is captured on the facility in question, it can be matched against state motor vehicle files to determine its make, model, and age. This data can then be matched against the data base of polluting vehicles to classify it by pollution level emitted. This information will indicate precisely the level of high polluting vehicles present on a given facility and eliminate the need for assumptions.

4.3 Summary

In summary, state departments of transportation and other planning agencies can use license plate data in several ways. In some cases, the license plate data are already collected via some other method. Automating the collection of the data may increase its accuracy and accessibility. In other cases, automated license plate readers will open new opportunities for using the data. This is because automated license plate reading can have three advantages over conventional methods. First, the LPR should be capable of accurately time stamping the license plate data to within a second or two. The added dimension of time to the data makes it much more useful. Second, the data should be available quickly, potentially in real-time. Therefore, the license plate data can be manipulated to give meaningful data such as density, speed, and flow in real time. These variables have a vast range of real time applications that can now be explored. Finally, the license plate data can be matched against databases more easily, quickly, and more cost effectively because the data is already in electronic format.

CHAPTER 5 - AUTOMATED LICENSE PLATE READING EQUIPMENT COMPONENTS

5.0 Introduction

The state of the art in the key components of automated license plate readers has evolved to the level required to read license plates from moving vehicles. Automated license plate readers are comprised of four key components: a camera, light source, triggering mechanism, and image processing algorithm.

The triggering mechanism is used to detect when a vehicle is within the camera field of view. When the triggering mechanism is triggered, the image capturing components, the camera and light source, are activated. The camera and light source act in consonance to capture an electronic image of the plate. The light source is needed to ensure adequate and uniform lighting across the image. When the image is captured, it is transferred to an image processor. There an algorithm segregates the plate from the image and identifies the state origin and alpha-numeric code. The image and interpretation then need to be transferred to a permanent storage area, generally the hard drive of a personal computer.

For each of these components, a menu of technological options are available. For example, cameras can be either monochrome or color, digital or CCD, and can have a wide range of shutter speeds. The overall performance of the license plate reader will be dictated by the technology employed for each of the components.

The following discussion will provide an overview of each of the license plate reader components. The technical options available for each component are presented, along with the general advantages and disadvantages of these options with respect to license plate reading for transportation planning applications.

5.1 Camera

The most significant recent advancement in cameras with respect to developing license plate reading equipment is the digital camera. When an image is captured, the data need to be transferred from the camera to the computer for image processing. A color image that is 512 pixels by 512 pixels would have over one million bits of information to be transferred. This transfer process could be a bottleneck in the image capturing process.

The image capturing sequence requires that the current image be transferred to the computer before the camera can capture a new image. If an image is collected before the previous image is transferred, the resulting image will resemble a "double exposed" picture. As will be discussed later in the report, multiple images will be needed of each plate. This involves capturing several images within a fraction of a second.

CCD cameras transfer the image data in series, one bit of information at a time. This is a time-consuming process that could interfere with the capability of camera to capture all of the necessary images. Digital cameras have the potential to speed the transfer process so that the camera can be ready to capture another image sooner. Digital cameras can transfer multiple bits of image information simultaneously, cutting the transfer time to a fraction of what it might take with a CCD camera. In cases where multiple images are to be taken of a plate by a high speed camera, the time savings will be important.

Another important camera attribute is the capturing of color images. Color provides significantly more useful information for plate identification and interpretation than monochrome images. Unfortunately, using color images raises important issues. First, color images provide more data to search through and discard when locating the license plate. A monochrome image will have one bit of data for each pixel--a number corresponding to the shade of gray. A color image has four bits of data for each pixel-- the shade of red, green, blue, and the intensity. Typically, the majority of the image is the background around the license plate. Therefore, the use of color also introduces volumes of insignificant information. A real-time interpretation algorithm may not be able to process all of the information within the time headways between vehicles. Second, color image data will take four times as long to transfer from the camera to the computer than a monochrome image. This is an important issue regardless of whether the system performs real-time interpretations. It will be particularly important if multiple images are captured.

Shutter speed is the final critical camera attribute that will affect the performance of the license plate reader. Shutter speeds of 1/50000th of a second and 1/100000th of a second are employed in other applications and are rapid enough to capture license plate images from moving vehicles. An increase in shutter speed requires a more powerful light source to ensure that the image is properly exposed. In license plate reading applications, high shutter speeds will be necessary to "freeze" fast moving vehicles and capture multiple images of the plate before it travels out of the camera field of view.

In short, the state of the art in cameras has developed to the point that a camera can be purchased off-the-shelf for use in a license plate reader. In general, a color digital camera having a fast shutter speed will be required.

5.2 Light Source

Due to its ramifications for camera and trigger selection, the light source is a particularly critical component. All cameras need sufficient light exposure to capture an image. Cameras with high shutter speeds must capture the image in a short time frame, therefore requiring a high level burst of light.

Ambient light is not a viable light source for automated license plate reading equipment. Sunlight does not provide even lighting across the image and may cause shadows. Using this source of light would require the image processing algorithm to correct for the inconsistent light levels across the image. Since the camera is located on the roadside and not directly behind the vehicle, the image processing algorithm is already required to correct for slightly skewed plate images. In addition, it will probably be required to correct for less than optimum camera lens settings, which cause distortion in the plate characters and symbols. Requiring the image processing algorithm to also adjust for insufficient lighting further complicates the algorithm. Since it is technically feasible to provide uniform lighting, it is better to deal with the lighting problem by providing a sufficient light source rather than adjusting the image processing algorithm.

In addition, the use of sunlight as a light source would require a camera with a slower shutter speed. This limits the number of images that can be captured of each plate. Furthermore, data collection would limited to times with sufficient sunlight. Data collection at night, and possibly cloudy days, would be prohibited.

To achieve uniform lighting across the image and eliminate shadows, the light source needs to overpower the sunlight. This is not feasible in the visible light spectrum, as this powerful light source would temporarily blind drivers in the vicinity of the equipment setup, creating extremely hazardous driving conditions.

It is, however, feasible to overpower the sunlight in the infrared light spectrum. While humans do not detect infrared light, typical cameras are sensitive to it, enabling a quality image to be captured. The image would be devoid of some colors, and may appear nearly monochrome, but it would be free of shadows and uneven light as caused by the sun. Furthermore, the light would cause no visibility problems for traffic traveling into or away from the light source.

As will be discussed, the light source also has ramifications for the triggering device. An internal triggering license plate reader would need sufficient light at all times to search for plates in the image. A light source that can overpower ambient sunlight would consume significant energy, therefore it is desirable to activate it only when images are actually being captured. Realistically, if the internal trigger could not operate with a lesser light source, an external trigger would be necessary.

In summary, a powerful infrared light source that can overpower the ambient sunlight is needed. This light source should only be activated while images are being captured to conserve energy. Consequently, an external trigger is a likely recommendation because an internal trigger needs a constant light source to monitor the area for license plates.

5.3 Triggering Mechanism

The purpose of the trigger is to fire the image capturing components when a plate is within the camera field of view. In general, there are two types of triggers: external and internal.

With external triggers, a vehicle detector is placed across one lane. The image capturing components are then aimed at a field of view that is likely to contain the license plate at the moment in which the vehicle detector is triggered.

The main advantage of the external trigger is that it will fire predictably and consistently. A typical external trigger is the electronic eye. It uses an infrared beam of light running transversely across the lane. When the beam is broken, it means that a vehicle has been detected. When the beam is reconnected, the rear of the vehicle should be located precisely at the light beam. The image capturing devices are then fired. If the vehicle is traveling in a normal lane position and the plate is at bumper height and roughly centered on the vehicle, then the plate should be in the camera field of view.

The main disadvantage of external triggers is that the possibility exists that the plate will not be in the camera field of view when the image is captured, such as when the vehicle lane position is off-center. In these cases, the plate generally passes through the camera field of view at some point, but not at the moment when the external trigger fires. In addition, heavy vehicles have gaps, such as the gap between the tractor and the trailer, that can prematurely trigger the equipment, or cause it to trigger several times.

External triggers will generally be triggered at least once by each vehicle. The sensing technology is fairly simple and reliable. However, since the trigger is not dependent on the license plate, it will sometimes capture images that have no license plate in them.

Internal triggers rely on machine vision to determine when a plate is in the camera field of view. In this case, the camera field of view is monitored by an image processing algorithm that can recognize a license plate. When the algorithm detects a license plate, an image is captured.

The advantage of internal triggers is that the plate itself causes an image to be captured. If the plate is off-centered, or the vehicle is off-centered in the lane, an external trigger will miss the plate because the image is captured a fraction of a second too early or too late. The internal trigger should not have this problem since it will synchronize the capturing of the image with the presence of the plate in the field of view.

One disadvantage of internal triggers is that the technology is not simple. The image processing algorithm must be designed to filter out competing items such as bumper stickers or other writing on the vehicle. On the other hand, it must be flexible enough to accept license plates with a wide range of colors, formats, and fonts.

Another disadvantage of the internal trigger is that it will require a constant light source. As discussed earlier, the light source used for image capturing will require exorbitant levels of power when in use. It will not be feasible to employ the light source full-time to support the internal trigger.

Finally, the internal trigger may not provide enough advance notice to capture the required number of images when multiple images are needed. The light source will require a short rise time before images can be captured. By the time a plate is detected and the light source is ready, a very limited number of images may be captured.

The internal trigger appears to be most appropriate for transportation planning applications. In transportation planning, license plates need to be read on unchannelized, high speed facilities. There is too great a variation in vehicle and license plate position to rely on an external trigger. However, license plate readers that have successfully employed internal triggers did not have a light source other than sunlight and also did not capture multiple images. If these are important attributes of the license plate reader, then an external trigger will be required.

5.4 Image Processing Algorithm

The purpose of the image processing algorithm is to locate the plate within the captured image, identify its state of origin, and read its alpha-numeric code. Of the algorithms that accomplish both state and number interpretation, expert systems or decision trees, and neural networks have emerged as two leading technologies.

Decision trees are rule-based systems that use different components of the plate image to work through a decision tree and arrive at a state identification and number interpretation. Rules regarding font characteristics, character grouping and spacing, and the presence of borders and emblems are written into the decision tree logic. There are two distinct disadvantages to decision trees. First, a comprehensive decision tree capable of interpreting all U.S. plates would take an exorbitant amount of time to design. Since there are over 1800 different types of license plates in the U.S., determining the rules needed to identify all the symbols and all the fonts for over 1800 different types of license plates is nearly impossible. Accounting for imperfections in lighting, lens settings, or image skewing may not be possible. Equipment developed with a decision tree algorithm would be very sensitive to equipment setup, traffic conditions, and geometric features of the roadway. Furthermore, since the image processing algorithm must run during the time headways between vehicles, it would likely have a processing capacity that is below the highway capacity.

Neural networks are widely used in image processing applications. They are commercially available from a variety of sources. In fact, neural networks are available in hardware form, which makes the processing time extremely brief. The main effort in employing a neural network is in its training. Training a neural network to read license plates would involve showing the network the characters, numbers, symbols, and borders that comprise license plates, and indicating the proper response. The training effort is potentially a time-consuming process, especially if the image processing algorithm will need to interpret images that are skewed and slightly out of focus. However, the training process is easily automated, as training software packages are commercially available or can be custom written.

A properly trained neural network could potentially interpret all 1800 plus license plates in the United States. Furthermore, the system may be less influenced by imperfect equipment setups than decision trees. A tolerant system would be more user-friendly and less likely to commit equipment dependent errors.

In conclusion, neural networks are the most feasible option for the image processing algorithm. They make the equipment less sensitive to its operating environment and setup characteristics. Also, neural networks are the only algorithm with the potential to identify the 1800 plus variations of U.S. license plates.

CHAPTER 6 - DESCRIPTION OF THE AUTOMATED LICENSE PLATE READING EQUIPMENT STUDIED IN THIS RESEARCH

6.0 Introduction

This research involved evaluating an existing license plate reader to determine its appropriateness for transportation planning applications. Furthermore, the experience of using a sample license plate reader provided further insight into the needs of a reader for transportation planning. The equipment developer of the reader used in this study was Perceptics. This chapter first describes the typical field setup components that were used in the project. Second, the field setup constraints are listed and discussed.

The typical field setup includes all those components necessary to perform license plate reading using the equipment while it is located along the roadside. Generally, there are components of two types: components supplied by Perceptics and components supplied by the user. The components supplied by Perceptics are the strobe, camera, sensors, and image processor. The components supplied by the user are the host computer, cargo van, generator, and the advance warning signs. Figure 6-1 is a schematic drawing demonstrating how all these components are integrated to form a license plate reading system.

6.1 Site Components

Each component of the license plate reading setup used in the project will be presented. The discussion will not focus on the technical specifications of the components as some of the material is proprietary. The technical specifications are generally available from Perceptics' "License Plate Reader Master Operations and Technical Reference Manual" [1996]. This discussion will concentrate on the experiences of the research team with the different components.

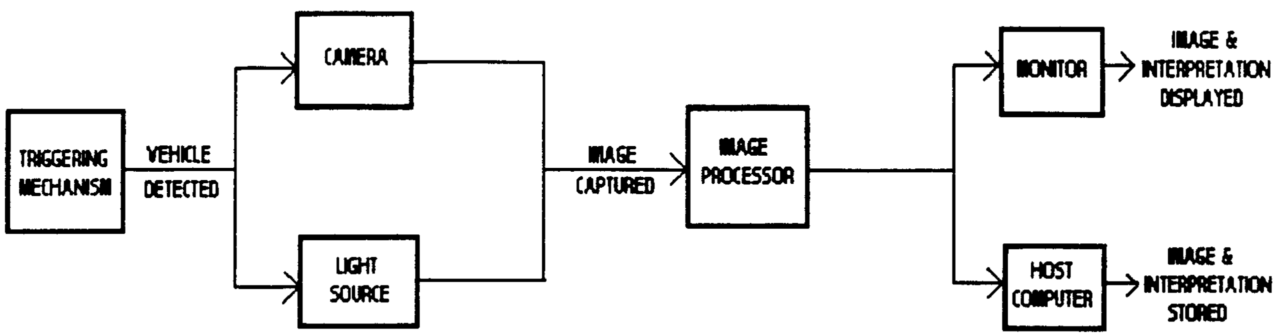


Figure 6-1 Schematic Drawing of the License Plate Reading System

6.1.1 Image Processor

The image processor used in the system is a hardware and software unit developed by Perceptics. Image processing algorithms in license plate readers are generally used to find the license plate in the image, segregate each of the characters, and interpret them. Unlike most other systems that are capable of only character interpretation, this image processor is also capable of state identification. In this case, the state is not directly read by interpreting each of the characters in the state name. Special features of the plate, such as borders, symbols, and lettering, are used to identify the state of origin.

The processor accepts video input from up to four cameras. This allows the user to employ up to two cameras to cover each lane of a two-lane (one direction) facility. The image processor accepts the 256 gray-scale images provided by the cameras via conventional coaxial cable, such as the kind used to connect a VCR to a television. The image processing unit connects to the host computer, which will be discussed next, and a monitor. The monitor displays the captured image and the interpretation. The host computer is used to store the images and interpretations.

The image processing algorithm running in the processor is an elaborate decision tree calibrated to the particular area in which the equipment is to operate. The decision tree contains information about the plate characteristics of those that are desired to be read. For example, in north-central West Virginia, the most common plates are those from West Virginia, Pennsylvania, Ohio, Virginia, Maryland, New York, and the province of Ontario. The researchers selected these to be included in the decision tree; Perceptics incorporated them into the algorithm. For the most part, only the standard issue of each state plate can be identified. In West Virginia, the standard issue, scenic plate, and some vanity plates can be correctly identified.

For West Virginia plates, the decision tree was calibrated by Perceptics using sample plates sent to them. For the remaining states, the decision tree was calibrated using images collected by the system during one of the initial field setups.

The decision tree has plate formats, font information, and other distinguishing characteristics programmed into it. For example, the "keystone" that is located in the middle of the Pennsylvania plate helps to identify that state. The plate formats programmed into the decision tree for West Virginia plates are as follows:

- [0-9,N, or D]a nnnn (standard issue and most likely to occur)
- [0-9,N, or D]S nnnn (scenic plate, very common due to its low cost)
- nnn nnn (uncommon version of the standard issue)
- nnnn (vanity plates, e.g. WVU alumni, Veterans, etc.)
- ann nnn (uncommon version of the standard issue)

Where n=number, a=alphanumeric, upper case or number = actual

The formats programmed into the decision tree are not an exhaustive list of all the plate formats available in the states, although they are the most likely to occur. Plates with formats that are not in the tree can be still be correctly identified, however, the probability of correctly identifying them decreases.

The speed of the image processor is another key attribute because it makes it possible for the time headways between traffic to overload the system, resulting in missed vehicles. The speed is dependent on whether or not the image file is being saved and on how many cameras are covering each lane.

For cases in which the image file is not being saved and only one camera is covering each lane, it takes less than one second for the system to process the image and transmit the interpretation to a host computer. This leads to a capacity of no less than 3600 vehicles per hour, which is approximately the hourly capacity of a typical two-lane freeway. However, if the arrivals are not uniform, and vehicles arrive at a rate faster than 3600 vehicles per hour, some vehicles can be missed. When two cameras cover each lane, the processing time is roughly 1.33 seconds. This leads to a processor capacity of approximately 2700 vehicles per hour.

When the image must be saved, the processing time increases significantly. The task which takes the most time is transferring the images to the hard drive for storage. The processor has eight buffers to store images when a queue of images that need to stored is formed. Assuming the eight buffers start out empty, a one-camera system can handle eight vehicles in ten seconds, and a two-camera system can only handle four vehicles in ten seconds. A four-camera system would be capable of handling only two vehicles in ten seconds. Bursts of traffic can overload the processor, as it was observed during field testing. Under traffic conditions on a test section of Interstate 79, which has an Average Daily Traffic (ADT) of approximately 20,000 vehicles per day, the processor performed without overload most of time, but was overloaded on occasion.

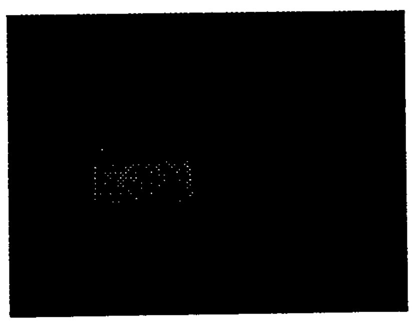
6.1.2 Host Computer

The image processor is connected to a host computer through the serial port of the host. Data are transmitted at a rate of 115.4 kilobaud. The connection occupies one of the host's COM ports, however no modem is required. The host computer serves two functions.

First, the host computer is used to control the processor. Through a terminal emulator program that comes with Windows 95 (Hyperterminal), the user is able to issue commands for tasks such as capturing and interpreting test images. A license plate reading session will usually begin in this mode, as the these commands assist the operator in tuning the lenses and aiming the equipment. This mode can also be used to change the internal settings of the decision tree, such as the characteristics about the plates that it will be identifying.

Second, the host computer is used to store the output of the processor. For each plate, the processor outputs two items: an image file and the interpretation. For each image captured by the processor, the processor stores a compressed image file on the hard drive of the computer. The saved image is in 256 scales of gray and measures 320 pixels by 480 pixels. A sample image is contained in Figure 6-2. The image file is saved under the name of its interpretation and the lane in which it was read. For example, if the survey were taking place on an interstate, and WV plate 5F 7900 was identified in the passing lane, the image file would be saved under the file name WV_5F7900.L1.300.jpg. "L1" indicates the passing lane (L0 is the travel lane). The "300" indicates that it was the 300th plate read since the beginning of that session. An individual file would use approximately five kilobytes of hard drive space.

Figure 6-2 - Typical Saved Image File



In addition to the image file, the processor also writes the plate interpretation, time and date of its observation, and the confidence in the interpretation to a text file. This file can later be imported into a spreadsheet for data manipulation such as license plate matching. Confidence ranges from 0.00 to 1.00, with 1.00 being the greatest confidence in the interpretation. This parameter was included in the output file so that in cases where the license plate data was being used in mail-out or telephone trip surveys, low confidence readings could be rejected to minimize the probability of incorrectly contacting a person. A typical entry in the output file is as follows:

Date	Time	State	Number	Lane	Confidence
1996-10-01	16:25:58	WV	5F7900	L1	0.93

The host computer does not have to be an expensive or sophisticated machine. The only real requirements are that it must have an open serial port and COM port, and it must be capable of operating Windows 95. A large hard disk is beneficial if large amounts of data will be collected. Finally, since the computer must be used in the field, a lap top computer will be simpler to transport.

6.1.3 Charged Coupled Device (CCD) Camera / Enclosure

The cameras used in the license plate reading unit were monochrome CCD cameras. They have an internal electronic shuttering capability of 1/10,000 second so that the image of the vehicle can be frozen. Perceptics' camera enclosure permits the use of either one or two cameras for one lane. This research experimented with both versions.

The enclosure is used to protect the cameras from weather exposure. It contains provisions for air circulation and filtering, rain shield, and heating of the glass face shield and the interior of the enclosure to prevent the shield or lenses from fogging.

The camera lenses are standard lenses that can be purchased at any camera shop. The aperture, zoom and focus had to be adjusted manually. This was usually done before the equipment was taken out to the field site. In the laboratory, an exact replication of the field setup was created. The lens settings were then optimized to the best of the technician's ability. When the cameras were taken out to the field, only a small adjustment if any was needed. This results in a significant time savings over trying to adjust the lenses in the field under traffic.

The zoom is set so that the height of the plate characters is 36 pixels. This is critical to the license plate recognition decision tree. It was noticed that characters that were too big were often misread. The aperture was set to provide a good contrast between the plate and its background. The processor provides the user with an indication of the contrast between light features and dark features in the image. This feedback from the processor is used to adjust the aperture. The focus is set to provide the clearest image possible.

The field of view at the rear of the vehicle measures 5.5 feet horizontally. When two cameras are used for each lane, the overlap between the two images is at least 12 inches. The total lane coverage for the two-camera system is 10 feet. An overlap of 12 inches is provided because the typical plate is 12 inches wide. An overlap of at least 12 inches means that the plate must be entirely within at least one of the images covering the lane. This saves processing time since only one of the two images will need to be processed. Furthermore, it eliminates the need to "stitch" adjoining images together before processing.

6.1.4 Stroboscopic Illuminator / Enclosure (Strobe)

A light source that flashes in sync with the camera shutter is used in acquiring the image. This light source provides a very powerful pulse of near infrared light only 100 microseconds in duration. This illumination is more powerful than sunlight, eliminating any shadows that may be caused by an overhanging trunk during the daytime, and making the system insensitive to day or night operations. In addition, since the light is so powerful, the plates do not need to be retroreflective.

A less powerful strobe than the one used in this research is available from Perceptics. This strobe can actually be placed in the same enclosure as the camera, simplifying the roadside setup. However, this less powerful strobe relies on the retroreflectivity of the plate. In West Virginia, the plates are retroreflective, so this strobe would work fine if only West Virginia plate data were needed. However, the more powerful strobe was selected since neighboring state Pennsylvania does not have retroreflective plates. The studies likely to be performed with the equipment will require out-of-state data.

An even more powerful strobe is capable of projecting light greater distances. However, while the strobe used here was two feet long, the even more powerful strobe is four feet in length. This larger strobe would reduce the transportability of the equipment, and might make positioning the strobe a two- or even three-person job. One person can setup the two-foot long strobe. The existing strobe projects enough light to be able to move the system 8.5 feet from the travel lane. As will be demonstrated, the system has little effect on traffic speed or lane position when it is located greater than six feet from the lane edge. The main benefit of the even more powerful strobe would be that the system could be moved from the roadside to an overpass.

6.1.5 Sensors

Vehicle sensing is performed using two standard infrared retro-reflective photo-detectors placed eight feet apart. The infrared beam is projected from the sensor head, which is on a tripod at a height of approximately six feet. The tripods and sensor heads are located on the shoulder of the road. A reflector is glued to the pavement at the opposite lane edge.

The two sensors work together in the following way. When a vehicle drives through the detection area, it blocks the first beam; then both beams are blocked; then the first becomes unblocked. At the instant the first sensor becomes unblocked, the rear of the vehicle, and consequently the plate, is located at the first sensor. This is when the camera captures an image. Thus, using two sensors makes it possible to positively sense the rear of the vehicle. Furthermore, placing them eight feet apart requires that an object has to be at least eight feet long to trigger the camera. Pedestrians, motorcycles, birds, or debris are not a threat to mistrigger the system.

Two problems were encountered in the vehicle sensing system. First, tractor-trailers often have gaps within their vehicle that falsely signal the end of the vehicle. For example, the gap between the tractor and the trailer will allow the sensor beam to reconnect. Consequently, the system usually acquires images of the sides of heavy vehicles. This was not a problem in this research since truck data were not of interest. Even if the sensing system did trigger on the rear of the truck, the plates on the back of trailers are usually not in a position that would be inside the field of view of the camera. If a user is interested in identifying trucks, there are plates centered on the front bumper of the tractor. In addition to being more consistently located on the vehicle, these plates are usually in better condition than those on the trailer. It should be possible to alter the vehicle sensing system so that it can detect the fronts of tractor-trailers rather than the rears of passenger vehicles. This was not tested in any detail during this research project. The main drawback to reading plates from the front is that most passenger cars in this geographic region do not have front-mounted plates. Thus, any system designed for tractor-trailers would read only tractor-trailer plates. Likewise, any system designed for passenger vehicles reads only passenger vehicle plates.

The second problem encountered with the sensors was that large trucks blew them over easily. The sensors weighed less than 10 pounds and were mounted rather high (six feet) on tripods. Even if the wind produced from a passing heavy vehicle did not blow them over, it sometimes moved them enough so that the reflector was not reflecting the beam back at them anymore. It was necessary to stabilize the tripod by hanging a 50-pound bucket of asphalt sealer from the base of the tripod. The bucket dangled in the air a few inches off the ground as shown in Figure 6-3. This completely eliminated the problem of the moving sensors.

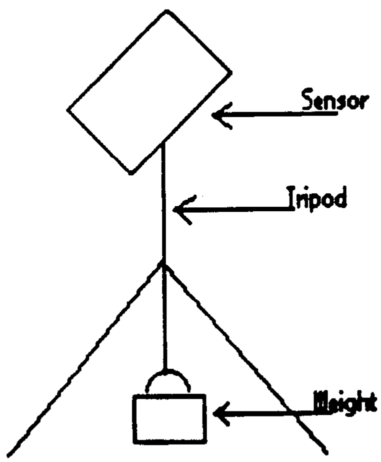


Figure 6-3 - Sensor Stabilizing

6.1.6 Generator

The license plate reading equipment is powered by electricity. The most likely power source for a field setup will be a gas-powered electric generator. At a minimum, the generator must be capable of producing 25 amps and three kilowatts of power. A special generator is not needed, as common, inexpensive generators are usually capable of producing the electricity to run the unit.

Five components need to be plugged in to an electrical source: the travel lane equipment, the passing lane equipment, the processor, the monitor, and the host computer. Since the computer, processor, and monitor are located in the van, these were plugged into a power strip that ran to the generator. Therefore, only three receptacles were needed on the generator.

6.1.7 Advance Warning Signs

A traffic control plan was needed that communicated the necessary information to the driver and complied with the Manual on Uniform Traffic Control Devices (MUTCD) [FHWA, 1988]- Part VI, which sets "Standards and Guides for Traffic Controls for Street and Highway Construction, Maintenance, Utility, and Incident Management Operations" and the West Virginia work zone traffic control manual. This traffic control plan is shown in Figure 6-4.

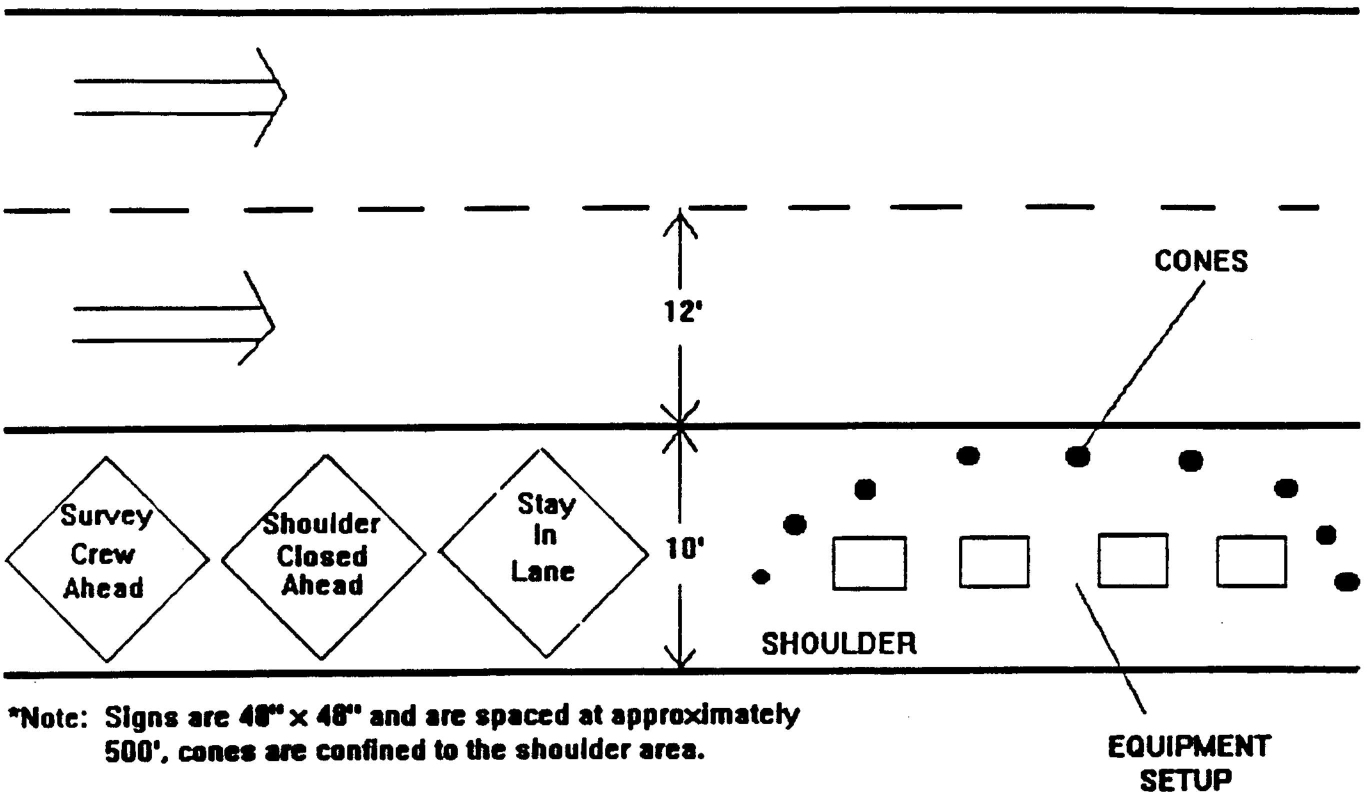


Figure 6-4 Traffic Control Plan for the License Plate Reading Field Setup

The signs are standard devices for work zones, i.e. they must be diamond shaped and have a black legend and border on an orange background. In this case, the devices were reflectorized for night time use.

The first sign says "SURVEY CREW AHEAD." This is a standard sign that notifies the driver of the presence of personnel along the road. A sign of this type is required by MUTCD. It should also convey the message that the setup does not involve the enforcement of motor vehicle laws, such as speeding.

The second sign drivers encounter indicates that the shoulders are closed. This is accompanied by cones that channelize the closed shoulder from the adjacent travel lanes. Both of these devices are required by the MUTCD.

The last sign the drivers encounter says "STAY IN LANE." This sign is not required by the MUTCD, but serves an important purpose whether cones are used in the center of the road or not. If the cones are present, this sign is critical because it indicates that no lane is closed and motorists should proceed through the site in the lane they currently occupy. Even if the cones are not present, the sign assists in keeping motorists from traveling through the site with part of their vehicle in each lane. Experience showed, however, that some motorists will shift laterally to the left through the site unless the cones are present.

Incidentally, using cones between the two adjacent freeway lanes is an acceptable use of cones. Part 6F-5 section b(2) of the MUTCD indicates that cones may be used to divide traffic lanes when two or more lanes are kept open in the same direction. For daytime operations, typical 18-inches cones can be used. However, for night time operations, the cones must be the 28-inches retroreflective types. There was no problem with cones placed on the centerline of low speed roadways, but problems were encountered on the high speed freeway.

6.2 Setup Geometry and Other Considerations

The typical field setup is shown in Figure 6-5. There are certain rules that must be followed in choosing the location for components involved in image acquisition. The other items are usually placed in convenient locations as far from the roadside as possible.

The constraints on the placement of the strobe, camera, and sensors are as follows:

- The strobe should be no more than 35 feet away from the plate. This is dictated by how far it can project the light.
- The camera and strobe should be separated by approximately six degrees. This is to prevent blooming in the image.
- The camera should be no more than 30 degrees from the line parallel to lane centerline / vehicle path. This is to prevent excessive tilting in the image.
- The sensors should be spaced approximately eight feet apart. This is to prevent false triggers by debris, animals, pedestrians, or motorcycles.

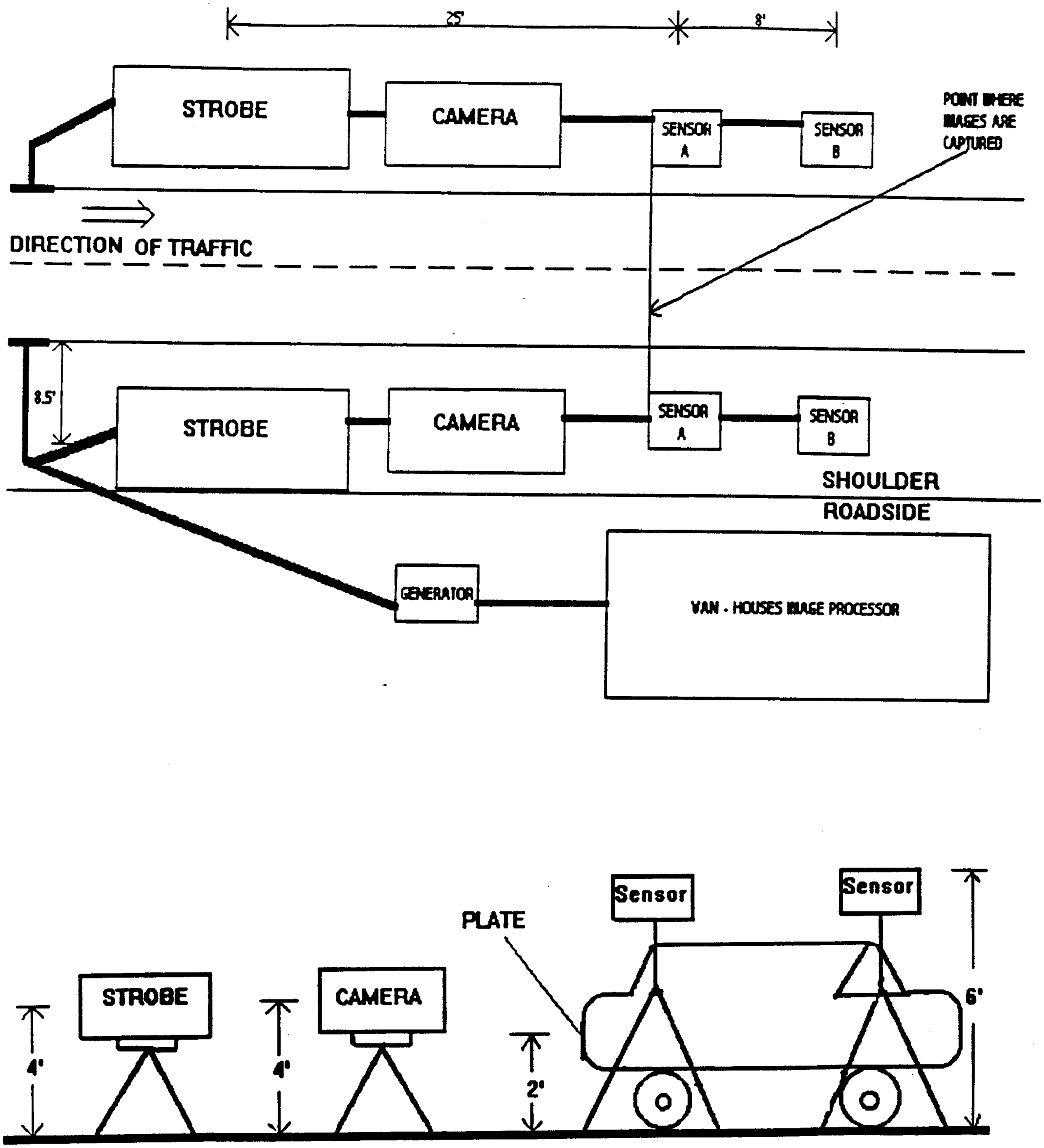


Figure 6-5 Typical Field Setup of the License Plate Reading Equipment (Two-Lane Coverage)

One of the more important constraints does not originate from the image acquisition process, it originates from the need to connect the systems that are monitoring two adjacent lanes of traffic, such as the case on a two-lane one direction facility. Cables must connect the image acquisition components with the image processor and the generator. Since the image processor and generator are generally only on one side of the road, cables need to be run either over or under the roadway. This usually can be performed only at an overpass or bridge, thus necessitating that the equipment setup is always near one of these structures.

There are two alternatives if the system can not be set up near a bridge or overpass. First, an image processor and generator can be placed on both sides of the road. Second, the cables may be placed in a conduit and attached to the road surface. This alternative is not recommended for two reasons: (1) it may damage the cables, and (2) it may become uncomfortable and unsafe for drivers to travel over it.

CHAPTER 7 - EVALUATION OF THE INTERPRETATION CAPABILITIES OF THE LICENSE PLATE READER

7.0 Introduction

This chapter evaluates the most important attribute of a license plate reader, its effectiveness at interpreting license plates. The license plate reader used in this study was designed to interpret in real-time both the state of registration and the number of license plates passing the unit. If it is highly effective at interpreting license plates, other drawbacks or disadvantages of the readers may be overlooked. However, if it is ineffective, the other attributes of the equipment become insignificant.

This chapter is presented in the following way. First, two key concepts, machine readability and accuracy are defined and discussed. Next, a description of the field testing of the equipment is presented. A discussion of the major results of the field test follow. A detailed examination of the usefulness of the license plate interpretation data follows. For each of the major types of transportation planning studies, it is determined whether the data produced by the reader will be appropriate based on the results of the field test.

7.1 Eye Readability versus Machine Readability

Nearly all license plates are readable to the human eye. License plates are designed for readability because they convey important information about the vehicle that must be interpreted by others, such as law enforcement officers. However, not all plates were readable by the license plate reading equipment chosen to perform this study. Plates having certain attributes can result in either a "No Read" or an incorrect interpretation virtually every time. These plates are not considered "machine readable."

The definition used for a machine readable plate in this study is a standard Tennessee plate that falls in the camera field of view without any obstructions. An example is shown in Figure 7-1. This definition permits many reasons why a plate would not be considered machine readable. They can be divided into three categories, plates not in the field of view, plates that are not standard Tennessee plates, and plates with obstructions. Each case will be discussed next.

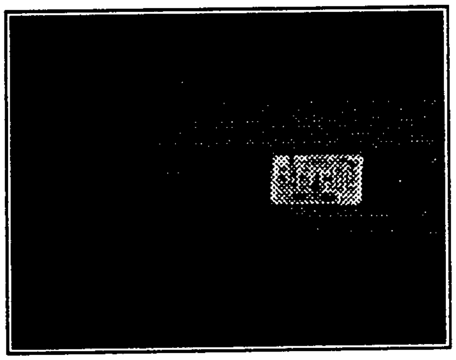


Figure 7-1 Typical Machine Readable Plate

7.1.1 Plates not in the field of view

The license plate reading equipment can be a somewhat noticeable presence on the highway shoulder and roadside. This presence may induce a lateral shift of vehicles away from the roadside towards the centerline. As shown in Figure 7-2, some vehicles shift so far that the plate is shifted partially or entirely out of the camera field of view.

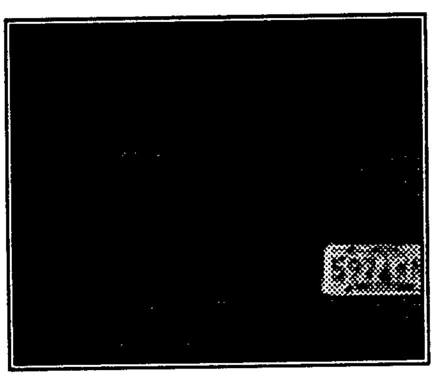


Figure 7-2 - Plate Falls Outside Camera Field of View

However, some plates will fall outside the field of view regardless of the driver behavior. When a heavy vehicle or large truck passes through the triggering mechanism of the equipment, the mechanism mistakes the space between the tractor and trailer for the end of the vehicle and prematurely fires the camera and strobe. In fact, often it will fire once or twice on the trailer, as the triggering mechanism detects the spaces between the tires. Even if the triggering mechanism were able to locate the back of trailer consistently, location of plates on the back of trailers is not consistent.

As shown in Figure 7-3, some full-size pickup trucks cause mistriggering and cause the plate to fall outside the field of view. The chassis is high enough off the ground that the electronic eye sees under it. It mistakes the space between the front and rear wheels as the end of the vehicle and captures an image of its side.

Figure 7-3 - **Full Size Pickup** Truck Prematurely Triggers Equipment

Other examples of plates that will be outside the field of view are those that are mounted in positions other than centered on the rear bumper. Some vans have the license plate mounted significantly higher than the bumper and off to one side. This is so the plate does not interfere with the operation of the rear doors. These plates often fall above the camera field of view.

7.1.2 Non-standard Tennessee plates

Tennessee was the only state in the decision tree when the test was performed. Consequently, the equipment automatically interpreted every plate as a Tennessee plate. Other states encountered included North Carolina, Michigan, Alabama, Indiana, Ohio, West Virginia, Pennsylvania, Georgia, South Carolina, Virginia, Maryland, and various county, city, state and U.S. governments, as well as a few plates of unidentifiable origin. Not only were these plates incorrectly identified as Tennessee plates, but their characters were often misread as well. The fonts, borders, and backgrounds are different for each type of plate. Since the system was trying to interpret out-of-state plates as Tennessee plates, it mistook borders and background decoration for characters and also demonstrated inconsistency in interpreting the different fonts.

Even within Tennessee, not every plate was considered machine readable. As shown in Figure 7-4, there are several non-standard versions that can lead to incorrect interpretation. Special or non-standard plates such as the Tennessee Alumni Plate or Handicap plate look different than the standard Tennessee plate. Plates with non-standard formats, such as "MUVEBUF" or "TN LADY" were not interpreted consistently well. However, since these characters were in standard Tennessee font and on a standard Tennessee plate they were considered machine readable.

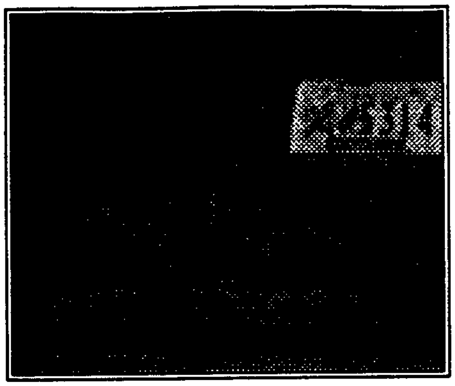


Figure 7-4 - Non-standard Tennessee Plate

7.1.3 Obstructed Plates

Plates can be obstructed for a number of reasons. The most common obstruction is a trailer hitch, as shown in Figure 7-5. A trailer hitch mounted in front of the plate causes some letters to be wholly or partially blocked rendering them unreadable to the equipment. Sometimes, the equipment correctly interprets a plate blocked by a hitch if the hitch looks like the letter it is partially blocking. The character “0" is an example of a character that might be correctly interpreted even if it is partially blocked by a hitch.

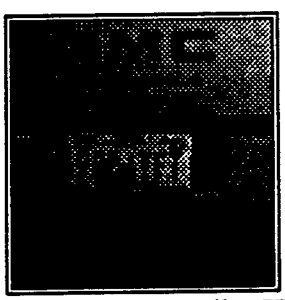


Figure 7-5 - Trailer Hitch Obstructing Plate

In addition, some plates, such as that shown in Figure 7-6, are situated in deep truck bumpers that partially block the last digit on the right side of the plate. Other obstructions include mud, dirt, rust, trailers, creases, and ladders (usually found on vans).

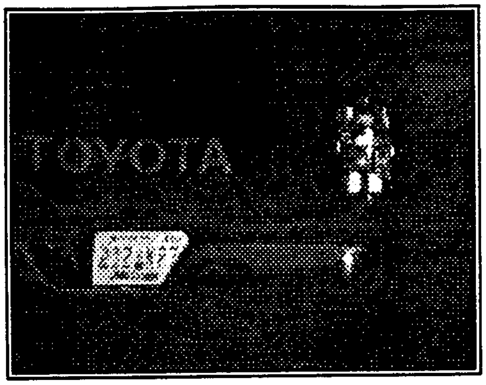


Figure 7-6- Deep Bumper Obstructing Plate

7.2 Accuracy

There are two basic ways to define an accurate license plate read. The first is to consider each part of the plate interpretation separately and treat each character independently. For example, if plate 1234 is interpreted as 1235, the license plate reader would have had three accurate reads out of four for an accuracy of 75 percent. This definition was not used in this study because transportation planning activities rely on the data provided by the whole plate, not the individual characters of it. However, calculating accuracy on a character by character basis may be beneficial to assist in the development of the image processing algorithm.

For this study, an accurate read was defined as a correct interpretation of both the state and the alpha-numeric legend. In the example above, the interpretation would count as one incorrect interpretation.

When calculating accuracy, the number of accurate reads is the numerator, but the denominator is not clearly defined. Potential denominators include total vehicles, total vehicles minus total trucks, total interpretations including "No Reads", total interpretations excluding "No Reads", and machine readable plates. For this study, total vehicles minus total trucks was chosen.

When total trucks are subtracted from total vehicles, total passenger cars are left. In transportation planning activities, sometimes only the passenger cars are of interest, as in trip surveys. In other cases, all vehicles are of interest, as in cordon studies. However, since it is already known that every truck will be missed, it is useful to determine how accurate the equipment will be on the remaining portion of traffic, that is, the passenger cars. In the general case of license plate reader evaluation, both total truck accuracy and passenger car accuracy will be of interest. Given these two pieces of data, the planner could determine the anticipated accuracy given a facility with a certain proportion of trucks.

7.3 Field Testing

The equipment was field tested in Knoxville, TN, on the Pellissippi Parkway at a location near the vendor's headquarters. The Pellissippi Parkway is a four-lane expressway connecting Interstate 40 just west of Knoxville with Oak Ridge, TN. The test location was less than two miles from the junction of the Parkway with I-40. In the test site area, the Parkway had 12-foot lanes, a wide median and roadside area, and level terrain. The traffic volume encountered was significantly higher than that encountered on I-79 in Morgantown, although the proportion of trucks was lower. The equipment was setup to read the curb side lane of the traffic traveling towards the interstate.

Two tests were conducted during daylight hours over the course of two days, March 17 and 18, 1997. A different equipment configuration was tested each day. On the first day, the "singlehead" configuration was tested. The "singlehead" configuration has one camera inside the camera enclosure. This means that for each vehicle, one image will be captured. The lateral lane coverage of this configuration is approximately 5.5-feet.

The "doublehead" configuration was tested on the second day. The "doublehead" configuration has two cameras inside the camera enclosure. The fields of view of these cameras overlap for one foot, giving them a combined lateral lane coverage of 10-feet. The primary advantage of the doublehead configuration over the singlehead configuration is the wider lane coverage. The main disadvantage of the doubleheaded configuration is that the processing time for two images is longer than that for only one image. This longer processing time causes the image processor to get overloaded at lower vehicular flows than for the singlehead configuration.

Each test involved setting up two independently-operating license plate reading units of the same configuration in series. These units were set up only a few feet apart, one directly downstream from the other. The goal was not only to conduct an accuracy test for each of the two independent machines, but also to determine how consistent the interpretations of an identical set of plates would be from machine to machine. Any inconsistencies between the interpretations of the two machines could be presumed to be caused by differences other than the characteristics of the plates. Since each unit had exactly the same weather conditions, external lighting conditions, highway geometrics, and traffic, only the equipment setups could be different. The primary differences in the equipment setups were the lens settings, component placement, sensitivity of the triggering mechanism, and aiming of the equipment.

The equipment was set up each day by a six-person team consisting of two employees having about nine months of familiarity and experience with the equipment, two vendor employees having expertise in the design and operation of the equipment, two other individuals, neither of whom had previous experience with the equipment. Since the lens settings and aiming of the camera and strobe are critical to the accuracy of the equipment, the vendor employees set and adjusted them.

Six workers were not needed to set up the test actually performed, but would have been needed to run the test that was planned. The planned test involved setting up both lanes for reading, the actual test only had one lane set up for reading.

As discussed earlier, Tennessee was the only state in the decision tree when these tests were conducted. Since the Pellissippi Parkway does not serve much interstate traffic, the overwhelming majority of plates were from Tennessee.

7.4 Overall Results

When a vehicle triggers a license plate reader, the light source and camera(s) capture an image of the rear of the vehicle. The image processor attempts to interpret the plate pictured in the image(s) and saves the image(s) The interpretation is the name of the file. It also writes the interpretation, along with the time, date, lane, and confidence to a text file where it keeps a record of all interpretations. Each interpretation was manually verified by the saved image of the plate. The interpretations of singlehead #1 and #2 were matched together by vehicle, the doublehead interpretations were likewise matched.

The overall results of the two tests are shown Tables 7-1 and 7-2. There were a total of 1953 vehicles sampled for the singlehead test, and 2714 sampled for the doublehead test. The percent of trucks stayed fairly consistent over the course of the two days at five percent and six percent of total traffic. Singlehead #1 had a high number of missing records because it experienced some equipment malfunctions during the middle of the test. The unit reset itself several times, causing it to miss some vehicles. Both tests began when the equipment was set up.

The singlehead test ended when it began to rain. The rain caused the triggering device to seriously malfunction. The doublehead test ended because the sample size was deemed large enough.

Table 7-1 - Summary of Performance Measures for Tennessee Test Site

Unit	Total Veh.	Total Trucks	Missing Records	Captured Images	Not Read	Read	Read Correct	Machine Readable
Singlehead #1	1953	106	302	1651	576	1075	595	1101
Singlehead #2	1953	106	90	1863	520	1343	520	1233
Doublehead #1	2714	176	139	2575	650	1925	650	1792
Doublehead #2	2714	176	58	2656	491	2165	491	1841

Table 7-2 - Summary of Performance Measures - Percentages

Unit	Total Veh	%Total Trucks	%Missing Records	%No Read*	%Read*	%Correct **	%Machine Readable
Singlehead #1	1953	5%	15%	35%	65%	32%	56%
Singlehead #2	1953	5%	5%	28%	72%	28%	63%
Doublehead #1	2714	6%	5%	25%	75%	26%	66%
Doublehead #2	2714	6%	2%	18%	82%	19%	68%

*Calculated as a percentage of "Captured Images"
**Calculated as a percentage of "Total Vehicles - Total Trucks"

The two most interesting points from this data are the proportion of correct interpretations and proportion of images considered machine readable. The percentage correct is calculated as the number of correct interpretations divided by the number of passenger vehicles. All units exhibited a low rate of correct interpretations. Singlehead #1 performed the best at 32 percent correct, but this is still very low.

The proportion of machine readable images was surprisingly low. In all cases, less than 70 percent of the images were machine readable. In the case of the singlehead #1, almost half of the images were not machine readable. Ideally, machine readability can be nearly 100 percent. Only in cases where the plate is covered with mud or seriously mutilated is the plate unreadable. A great many interpretations are lost because of the limitations of machine to interpret plates with special or nonstandard features.

For the remainder of the chapter, the data sample collected during these field tests will be evaluated in light of the requirements of studies typically performed by transportation planners. First, studies where a positive identification of the vehicle is made from the license plate data are investigated. An examination of studies where the license plate data is used only as an identifiable marker follow.

7.5 Studies where a Positive Identification of the Vehicle is Needed

Trip surveys are the most common type of study where the vehicle needs to be positively identified. In this type of study, the license plate data are used to determine either the telephone number or address of the person owning the vehicle. These data are available through the motor vehicle division of the state of origin. The owner is then contacted with a survey that indicates that they were observed on a particular highway facility at a certain time, and asks for some characteristics of that trip. These types of studies require the highest level of license plate data accuracy. It is not acceptable practice to incorrectly place a person at a location. These blunders often lead to complaints to the agency.

Besides trip surveys, there are other types of surveys where the data are used to contact the person. However, these usually do not require the high level of accuracy that the trip survey requires because a person's location is not identified on the survey. For example, a person could be contacted about seat belt usage or some other attribute of their driving habits. If there is no indication of where and when they had been observed, the consequences of contacting the wrong person are not as great.

In this section, the license plate reader interpretations will be investigated to see if they could be used in a study where the vehicle needs to be positively identified. First, they are investigated to see if the interpretations can be used without manual verification and interpretation via the saved images. Next, the concept of manual interpretation is explored and compared to other methods of collecting the data.

7.5.1 Determination of Whether the Machine Interpretations can be used Without Manual Verification

By accepting the interpretations without verification, errors of two types can be introduced:

Type I Error = rejecting a correct read, or missing the opportunity to survey a person
Type II Error = accepting an incorrect read as a correct read, or surveying an incorrect person

When performing a trip survey, the appropriate strategy is to minimize the occurrence of Type II Error at the expense of a higher rate of Type I Error. This strategy will minimize the number of persons that are incorrectly identified as traveling on the facility. Since there is a historically low rate of response on these surveys, missing the opportunity to send some surveys is not a problem. If it is planned for in advance, a high rate of Type I Error can be overcome by collecting a bigger sample size.

The exact level of acceptable Type II error is highly dependent on the agency in question. The agency has the option of manually reviewing all images to totally eliminate Type II error. The main drawback of manual interpretation is that it can be time-consuming. In trip surveys, the person must be contacted within a few days of the trip or they may forget the details of the trip that the survey is trying to capture. The final decision regarding an acceptable level of Type II error will involve a trade-off between devoting time and resources to manually interpret images, having the time available to interpret the images while trying to conduct a timely survey, and the agency's tolerance for complaints from persons contacted by mistake.

There will be instances in conducting trip surveys when a high level of Type I error is intolerable. This may be the case if the amount of data is limited and every correctly interpreted plate is needed. In these cases, manual review of the images will most likely be required. This not only eliminates all Type I and Type II error, but also adds additional plates to the database because plates that were incorrectly interpreted by the machine can be correctly interpreted by the human. As stated before, however, the manual interpretation must be performed quickly so the survey can be conducted in a timely fashion.

Other transportation planning surveys may not require a high level of confidence against committing a Type II Error. For example, a survey where seat belt usage is being surveyed, and the facility and time of observation are not being named, does not have the consequences of the trip survey where the place and time are named. The tolerable level of each type of error will vary depending on the type of planning study, any time or resource constraints, and the agency.

In this particular case, there was an overall accuracy of less than 40 percent. There is a significant chance of committing a Type II error if the interpretations are used without verification by manually checking the images. However, there may be a way to minimize the Type II error without checking the images. If low accuracy parts of the database can be eliminated, the accuracy rate of the remaining portion should be increased. If the accuracy rate of the remaining portion is high enough to provide an acceptable level of Type II error then the equipment interpretations may not need to be manually checked before conducting the survey. These cuts will cause a great deal of Type I error, but hopefully eliminate Type II error. In this case, the database was reduced according to two criteria: confidence and standard Tennessee format.

Confidence was selected as a criterion because there is a correlation between confidence and accuracy, and consequently the occurrence of Type I and Type II error. Unfortunately, with this equipment, a confidence of 95 does not imply an accuracy of 95 percent. As will be demonstrated, even at high confidence levels, the equipment performed with low accuracy, which leads to a high level of Type II error.

The format of the plate was selected as a criterion because it is the only other available cut that can be applied. If an incorrect machine interpretation is in standard format and is of high confidence, then there is no way of discriminating it from a correct interpretation.

The format accepted was the most common Tennessee format, a six character interpretation where the first three characters are numbers and the last three are letters. For example, 906HKW is an accepted format. All other formats were rejected. There are other standard Tennessee formats, but they are not nearly as common as the one that was used.

Tables 7-3 through 7-6 show the results of the applied criteria under different confidence levels. Tables 7-3 and 7-5 show the percentage of correct interpretations lost due to the cut. Tables 7-4 and 7-6 show the accuracy rate of the remaining images once the cuts are made. Tables 7-3 and 7-4 show these data after a confidence cut only. Tables 7-5 and 7-6 show these data after both cuts.

Table 7-3 Percentage of Correct Interpretations Rejected by Cutting at Various Confidence Levels

Confidence Cutoff	% of Correct Interpretations Rejected - Type I Error Rate			
	Singlehead #1	Singlehead #2	Doublehead #1	Doublehead #2
95	56%	45%	57%	58%
90	23%	20%	26%	20%
80	9%	10%	8%	8%

Table 7-4 Accuracy of Remaining Interpretations after Cutting at Various Confidence Levels

Confidence Cutoff	% Accuracy (1- Accuracy = Type II Error Rate)			
	Singlehead #1	Singlehead #2	Doublehead #1	Doublehead #2
95	78%	75%	82%	77%
90	71%	66%	79%	71%
80	68%	60%	73%	65%

Table 7-5 Percentage of Correct Interpretations Rejected after Non-Standard Formats are Eliminated - At Various Confidence Levels

Confidence Cutoff	% of Correct Interpretations Rejected - Type I Error Rate			
	Singlehead #1	Singlehead #2	Doublehead #1	Doublehead #2
95	57%	46%	59%	61%
90	25%	23%	30%	25%
80	12%	13%	14%	14%

Table 7-6 Accuracy after Non-Standard Formats are Eliminated - At Various Confidence Levels

Confidence Cutoff	% Accuracy (1-Accuracy=Type II Error Rate)			
	Singlehead #1	Singlehead #2	Doublehead #1	Doublehead #2
95	80%	76%	86%	81%
90	74%	68%	80%	74%
80	72%	62%	74%	68%

Neither applied criteria increases the accuracy rate, which would have consequently reduced the Type II error rate, sufficiently to justify using the interpretations without manual verification. The best performing reader was doublehead #1, which at 95 percent or greater confidence still carried a 14 percent chance of incorrectly contacting a person with a survey. This 14 percent Type II error rate is clearly too large for any organization conducting a trip survey. This may, however, be acceptable for other types of surveys.

The second cut did little to improve accuracy because the plate format and confidence are highly correlated. The algorithm that operates the image processor takes plate format into account when interpreting the image and assigning the confidence. Although eliminating non-standard formats did not prove to be a worthwhile endeavor in this case, it may be for subsequently developed equipment.

7.5.2 Investigation into Using the Equipment as an Image Capturing Device with Subsequent Manual Interpretation of the Images

In general, there is an advantage to gathering the needed license plate data by a system that automatically collects electronic images of the rears of vehicles, even if the plate interpretation needs to be performed manually. A group of electronic images can be interpreted manually very quickly. The triggering device used to capture the images gives it an advantage over video tape because the technician does not have time lapse between cars. Compared to the method of sending a technician out to the field to collect them with a paper and pencil or tape recorder, a larger sample size will be obtained from the identical population of vehicles, especially at high traffic volumes or speed. Furthermore, a permanent record of the plate is obtained when the electronic images are collected. These images could be used to verify the plate data either before the surveys are conducted or in response to a complaint. With manual observation, once the vehicle passes out of the technician's sight, there is no way to verify the data. Finally, the license plate reader should not be susceptible to external lighting conditions or weather, although in this case the triggering mechanism malfunctioned in the rain. A field technician is definitely influenced by lighting and would likely be influenced by weather. Videotape operation observed has only been successful in the daylight because it depends on the sun as its only light source

There are disadvantages to collecting electronic images, both in general and with this particular license plate reader. In general, this method is inferior compared to the video tape method in as far as the video recorder can capture 30 or more images per second of the rear of the vehicle. This translates into a much wider field of view than can be obtained from a single image. In addition, the multiple views may allow the interpreting technician to see around hitches and other obstructions. This will yield a larger plate data sample from a given vehicle population.

In this particular case, a few other problems can be anticipated. First, mistriggerings will occur, especially when the image processor capacity is exceeded or in the wake of heavy vehicles. Mistriggering rates ranged from two to fifteen percent with the norm being five percent or less. Mistriggerings result in vehicles passing the site without an image being captured. Second, the zoom and brightness settings for the lens are optimized for machine reading, not human reading. These settings need to be adjusted in advance or some image enhancements will be needed for human reading. Finally, mobility, setup time, and downtime can become prohibitive. By the time that significant labor and time are expended in transporting and setting up the equipment, the data may be able to be collected manually. Even video tape setups are significantly simpler than the license plate reader used in this study. Finally, due to the labor intensive nature of the equipment transportation and setup, and cost of the specialized license plate reading equipment, it may become hard to justify it economically compared to the other methods which use either common equipment, such as video or voice recorders, or no equipment at all, such as the pen and paper method.

7.6 Studies where Plate Data are Needed as an Identifying Mark

Unlike the previous application, where the license plate data were needed to make a contact with the owner of the vehicle, sometimes license plate data are used only as an identifying mark on a vehicle. These identifying marks are typically observed at two points in the highway network and matched together. Two results are usually extracted from the matching observations. One result can be the recognition that a motorist had traveled from one site to the other. The second result is the travel time. Usually, the time of observation is recorded along with the plate information. The difference between the times of observation is the travel time from one point to the other.

A study which concerns itself with the number of trips passing through, into, or out of an area is called a cordon study. The study that concerns itself with the travel time is called a travel time study. These two studies form the discussion of the remainder of this section. Each type of study is examined in detail to determine if the license plate reader interpretations are suitable for usage in the study.

7.6.1 Cordon Studies

In a cordon study, a domain of inbound and outbound stations are set up around an area of interest. The objective of the study is to determine how the incoming vehicles passing through the inbound stations distribute themselves among the internal zones and the outbound stations. To determine what type of license plate data are needed to achieve this objective, consider vehicles passing through a single inbound station with many possible destinations.

As close as possible to a 100% sample of vehicles passing the inbound station must be selected such that each is also identified at one of the outbound stations. To accomplish this task, the license plates are recorded at the inbound and outbound stations. These two data can be matched together to determine the vehicles present at both stations and therefore making the trip from one to the other.

An automated license plate reader will make errors. The sources of the errors can be classified into three categories:

- *plate dependent errors* - These are caused by some imperfection on the plate such as a crease or mud.
- *equipment setup dependent errors* - These are caused by the equipment component placement, adjustment of the camera lens, and highway geometrics. Although these errors will likely be present at all the stations, they will not be the same set of errors, nor will they have the same effect on the interpretations at each station.
- *traffic dependent errors* - These are primarily caused by individual driver behavior through the site. For example, a driver may travel outside the camera field of view, prohibiting the vehicle plate to be read. It can be assumed that these are randomly distributed at each site throughout the study duration, and that each site will experience a similar number of them.

If the license plate reader commits only plate dependent errors, the entire population of vehicles should be sampled. A correctly read plate at the inbound station should be read correctly at the outbound station. An incorrectly read plate at the inbound station should be incorrect at the outbound station. In addition, it should be the same interpretation as was recorded at the inbound station. In this case, all vehicles will be captured as part of the sample. Plates observed at an inbound station but not at any outbound station can be assumed to have dwelled in the study area until after the study or to have exited the area via unmonitored facilities.

If the license plate reader commits equipment setup dependent errors, sampling the entire vehicle population will not be possible, nor will it be possible to draw a random sample from the vehicle population. Some plates will be interpreted differently at each station. These will consequently be excluded from the sample. Since the sample is dependent on the interpretations at each station, the study will be biased towards the outbound station with attributes most similar to the inbound station. In addition, since these errors will cause some potential matches to be missed, making inferences about the non-matching plates will not be possible.

Traffic dependent errors are randomly distributed among the sites with each site experiencing the errors at approximately the same rate. These errors will reduce the sample size, but will not bias the sample toward any one outbound station. Traffic dependent errors would mainly be related to the drivers' actions, such as their lateral position in the lane while traveling through the site.

Some factors might bias the sample and need to be investigated on a case by case basis. Included are factors pertaining to weather or ambient lighting. If all the sites experience the same weather and ambient lighting, then the resulting errors will be equally distributed to each site and will not affect sampling. However, if the conditions are different at each site, these errors will not be equally distributed. In this case, the sample will be biased towards the outbound station with weather and light conditions most like the inbound station.

In short, for the license plate reader to be useful in cordon studies, equipment dependent errors must be eliminated. This is only possible if all inbound and outbound sites are exact replicas of one another. In practical terms, this can be accomplished with a system that can replicate the attributes of another site. In addition, the technician conducting the study will need to select sites with similar geometrics, lane widths, and roadside areas for set up.

7.6.1.1 Investigation of the Test Data to Determine if Errors are Equipment Dependent or Plate Dependent

In this section, the data collected from the tests are investigated to determine if equipment dependent errors did occur. Since the readers were set up in series only a few feet from one another, they sampled exactly the same plate population. In addition, they also had several site factors in common. The sites had the same highway geometrics, weather, external lighting, and traffic conditions. In fact, the only factors they did not have in common are those that dealt with the equipment setup, for example, lens settings, equipment component placement and aiming, and trigger sensitivity. The items which they do not have in common all fall into the category of equipment factors that would not be randomly distributed throughout the test.

In the context of this analysis, a match occurs when the identical state and number interpretation are recorded at both sites. As the test was conducted, if only plate and traffic dependent errors occurred, the two units should have had matching rate of 100 percent. The more equipment dependent errors that are introduced, the lower the matching rate. As shown in Table 7-7, there was in fact a low rate of matching. The singlehead test produced a matching rate of 20 percent and the doublehead test produced 30 percent matches. Further proving the point are the very low rate of plates interpreted incorrectly but consistently. These accounted for less than five percent of the total plates. These results indicate that the license plate interpretations are in fact very dependent upon the equipment setup characteristics.

Table 7-7 Results of matching exercise for Singlehead Units in Series and the Doublehead Units in Series

Test	% Correct - Correct	% Incorrect - Incorrect Match	% Matching
Singlehead	17%	3%	20%
Doublehead	25%	5%	30%

The low rate of matching demonstrated in Table 7-7 takes all factors into account for not having a match. This includes times when one or the other reader did not trigger and times when it captured an image but did not interpret it. Table 7-8 deals only with those plates that the readers interpreted at both stations. As shown, when the reader provides an interpretation of the vehicle at both stations, the matching rate is still less than 50 percent. Furthermore, this table also demonstrates that even if it interpreted exactly the same, there will still be a matching rate of only 47 percent or 66 percent. The lack of an interpretation can be attributed to failures in the triggering mechanism and failures to obtain good images of the plates.

Table 7-8 Evaluation of Those Vehicles Which Were Interpreted at Both Stations

System	C-C	I-I Match	I-I No Match	C-I	Total % Interpretations at both	% of these that match
Singlehead	17%	3%	10%	17%	47%	43%
Doublehead	25%	5%	14%	22%	66%	45%

Table 7-8 eliminated cases where no interpretation was given at one or both stations, but it did not eliminate the case where an unreadable or complex plate was interpreted. To isolate only good, readable plates, the plates that were read correctly at least one of the stations were examined. Even among plates that are readable, the matching rate is low. Table 7-9 demonstrates that when a plate is read correctly at one of the stations, there is less than a 50 percent chance that it will be read correctly at the other station.

Table 7-9 Analysis of Plates Interpreted Correct at Least Once

System	C-C	C-I	C-NR	C-MISS	Total Correct at Least Once	Accuracy at other station
Singlehead	340	335	111	110	896	38%
Doublehead	682	606	114	50	1452	47%

In conclusion, the interpretations are not useful in a cordon study because there is a great deal of equipment dependent error introduced by the readers. The equipment dependent errors that most influenced the results of this test are as follows:

- **Mistriggerings**, These are directly dependent on the differences in the sensitivity of the triggering mechanism, but are also dependent on site traffic characteristics such as volume and proportion of trucks. When a platoon of vehicles exceeds the capacity of the image processor, vehicles are missed. When a heavy vehicle travels through the triggering mechanism, not only is the truck missed every time, but the equipment may trigger three or more times. The heavy vehicle partially acts as a platoon reducing the image processor capacity to read the vehicles in its wake. The truck can also cause the triggering mechanism to go out of sync so that it does not trigger properly on the following vehicles.
- **Lens settings such as focus, brightness, and zoom**, These are difficult to set even in a controlled environment such as a laboratory. Setting and adjusting them in the field is very difficult. Setting them to capture images of plates with exactly the same character

height, clarity, and brightness, a requirement of the decision tree image processing algorithm, is nearly impossible.

- **Equipment component placement and aiming.** The relative positions of camera, strobe, and trigger must be set exactly the same. These are placed using a tape measure and are the same within a few inches. Aiming the camera is not as difficult as aiming the strobe. The camera aim can be verified by checking an image, however, the strobe aim does not have a definite method of judging its aim other than placing one's head where a plate is likely to travel and adjusting the strobe until the person sees their reflection. This is imperfect at best and dangerous if performed in live traffic.

7.6.1.2 Investigation of Data to Determine the Feasibility of an Intelligent Matching Program

The discussion in the 7.6.1.1 defined a match based on identical interpretations at both stations. However, a matching program could be written that matches together license plate interpretations when they are likely to be matches, even if their interpretations do not match. This section examines the feasibility of implementing such a program and provides guidance if one were to be written.

As demonstrated previously in Table 7-8, even if all interpretations could be matched together, the maximum matching rate that could be achieved with the test database would be 66 percent for the doublehead configuration and 47 percent for the singlehead configuration. This is still a relatively low matching rate considering it should be 100 percent. This is due to the fact that trucks and other non-machine readable plates cannot be matched if no interpretations are given for them. Furthermore, approximately five percent of the plates will be missed due to mistriggerings.

However, as stated before, the matching rate does not need to be 100 percent to be useful in transportation planning. In the cordon study, if the occurence of an interpretation is not equipment dependent, and these interpretations could be matched together to overcome the equipment dependent errors in the interpretations, then the equipment may be useful for conducting cordon studies.

Table 7-10 shows an analysis of plates interpreted at least one of the stations. For the doubleheaded unit, when an interpretation was given at one of the stations, one was given at the other station 80 percent of the time. The question is why did it not give interpretations 20 percent of the time. There are two reasons for this: failure to capture a readable image and mistriggering.

Sometimes the license plate reader captures an unreadable image of a readable plate. Some of these would be randomly distributed among the outbound stations, such as vehicles traveling out of the field of view. However, some are not randomly distributed among the outbound stations. As with the interpretations, the lens settings and equipment placement and aiming strongly influence the quality of the image and consequently the ability of the license plate reader to attempt an interpretation. Since the error in equipment setup is not randomly distributed throughout the sites, the ability to interpret an image is equipment dependent.

Mistriggerings can be caused by one of two reasons: the sensitivity of the triggering mechanism and image processor overload. Image processor overload is dependent on trucks and traffic flow. The occurrence of these mistriggerings could be presumed to be randomly distributed among the outbound stations. However, the sensitivity of the triggering mechanism will be specific to each site and therefore equipment dependent.

In summary, the ability to offer an interpretation is dependent on the errors that will not be randomly distributed among all the sites. This makes the selection of a sample based on the number of matches between the inbound station and the outbound stations biased. Even if a program could be developed that matched all the interpretations, which would be impossible from a practical viewpoint, it still would not make this license plate reading equipment useful for cordon studies.

Table 7-10 Analysis of Plates Interpreted at Least Once

System	c-c	c-i	c-nr	c-miss	i-i	i-nr	i-miss	Total Interpreted at Least Once	Interpretations at other station (%)
Singlehead	340	335	111	110	255	212	122	1485	63%
Doublehead	682	606	114	50	524	237	51	2264	80%

However, other applications, such as the travel time study, are not sensitive to equipment dependent errors. Therefore, it would be feasible to design such a matching program to boost the matching rate for application in that study. This matching program could be like most programs of its kind in that it matches identical sequences of four or five numbers. In addition, it could also be tailored to the errors the equipment is most likely to make. Based on the test database, these are the most common characters confused for one another by this license plate reader while interpreting Tennessee plates.

- 0, D, and Q
- A and R
- M, N, H, and W
- W and V

- 3 and 5
- 7 and 1
- TN Logo with 1
- I with the right edge of the plate

These errors will be plate type sensitive in that it will make a different set of mistakes for each state plate. For example, when the system interpreted WV plates, it did not confuse "3" and "5" but did still make "O" & "D" errors. A list of common errors and their frequency of occurrence could be extracted from any sample database for incorporation into a matching program. However, it would have to be done for each plate type, and there are over 1800 different types in the United States.

7.6.2 Travel Time Studies

Performing travel time studies does not have the same restrictions as cordon studies. Like a cordon study, for each inbound station there are one or more outbound stations. However, in a travel time study, as the name implies, the planner is determining the travel times of a randomly selected sample of vehicles. Since there are no comparisons to be made between the number of observations at each outbound site, equipment dependent errors are not an issue as in cordon studies. The only requirement for the travel time study is that the ability of the reader to interpret a plate must not be based on speed. If it is based on speed then the study would be biased towards either slow or fast vehicles.

Although it was not studied specifically, the license plate reader has been observed in operation for a significant period of time. During that observation period, at no time was there any indication that the ability of the license plate reader to interpret plates was dependent on vehicle speed. This observation can be traced back fundamentally to the high speed of the camera shutter. In 1/10,000 of a second, which is the speed of the shutter, a 65 mph vehicle moves only a little more than an inch. Faster camera speeds are now available so it is believed that speed is not likely to be an issue.

Therefore, for travel time studies, the equipment would be useful because it will match approximately 20 to 30 percent of the interpretations. However, before running the matching program, there is a need to eliminate "No Read" interpretations and impose some travel time "window" restrictions based on physics to reduce false matches.

7.7 Conclusion

In conclusion, this particular license plate reading equipment was not useful for cordon studies under any circumstances. It could be useful for trip surveys if the saved plate images can be manually interpreted in a timely fashion. It can be used for travel time studies under all circumstances.

Although the performance of this equipment was less than expected, it does not mean that license plate reading equipment has no future in transportation planning. The detailed investigations of the typical planning studies yielded some important specifications that the interpretations of license plate readers developed in the future will have to meet.

CHAPTER 8 - THE EFFECT OF PERCEPTICS' LICENSE PLATE READING EQUIPMENT ON TRAFFIC OPERATIONS AND ROADSIDE SAFETY

8.0 Introduction

In this chapter, the intrusiveness of the equipment is assessed. Intrusiveness is defined as the adverse effect of the equipment on traffic operations and safety. One of the basic requirements of the equipment, regardless of the specific application, is that it must not be intrusive to traffic. If the equipment is intrusive, it could increase the likelihood of an accident or decrease the vehicle carrying capacity of the facility.

8.1 The Effect of the License Plate Reading Equipment on Traffic Operations

Two performance criteria were measured to assess equipment intrusiveness with respect to traffic operations. First, the lateral shift induced by the equipment was measured. When vehicles are approaching the equipment setup, the presence of the equipment along the roadside may cause motorists to shift their position in the lane transversely away from the equipment. This is referred to as the induced lateral shift. Excessive lateral shifting could result in more frequent side swipe accidents.

Second, the speed reduction caused by the equipment was measured. The setup could cause a speed reduction for a number of reasons. The two most likely causes are (1) if drivers mistake the equipment as being speed enforcement related, and (2) if drivers slow because they perceive the equipment site as a roadside hazard.

Two types of facilities were analyzed: a two-lane directional freeway and a two-lane two-direction local street. For each facility, the lateral shift and speed reduction were measured for both passenger cars and heavy vehicles.

8.1.1 Measuring Lateral Shift

Lateral shift was measured by collecting samples of lateral positions under different equipment configurations, and comparing them to the case when no equipment was present. On both types of facilities, a minimum of 200 passenger car lateral positions and 100 heavy vehicles were collected for each configuration.

The lateral positions were collected manually using painted lines on the road surface spaced at one foot, beginning at the white lane edge line. The even foot lines were much longer than the odd foot lines to help differentiate between them. When a vehicle passed by the equipment setup, the observer recorded which mark the passenger side front tire traveled over. If the tire went between the marks, the last visible mark was recorded. For example, a record of "3" indicates that the vehicle was at least three feet from the shoulder side lane edge, but not more than four feet.

8.1.2 Measuring Speed Reduction

Speed reduction was measured in a manner similar to lateral shift in that samples were collected under different equipment configurations and compared to the case of no equipment present. Again, a minimum of 200 passenger cars were sampled at each facility and 100 heavy vehicles were sampled on the freeway.

Speeds were collected using a calibrated Doppler radar based speed gun in all cases but one. For one case, speeds were so low that the speed gun could not accurately and consistently detect speeds. In this case, marks were placed 40 feet apart longitudinally on the roadway, in accordance with the length of the typical equipment setup which is approximately 40 feet.

Vehicles were then timed with a stopwatch from one mark to the other. The speed was calculated by dividing 40-feet by the time it took to traverse it.

The lateral shift and speed reduction data are presented for each facility type. Two lane freeways are presented in Section 8.1.3, local streets are presented in Section 8.1.4.

8.1.3 Traffic Operations and Intrusiveness on Freeways

The lane position and speed data were collected on the southbound lanes of Interstate 79 at milepost 156. At this point, the approximate average daily traffic (ADT) was 20,000, with 20 percent truck traffic. Traffic was light during the times in which traffic data were collected. Most vehicles had their choice of speed and lane position. Very few vehicles went through the site side by side or following one another.

Two configurations were to be tested and compared to the null case. The first configuration had the equipment setup 8.5 feet from the edge of pavement with cones between the two travel lanes for channelization. The second configuration was like the first but omitted the cones.

The configuration that used the cones was eliminated due to safety considerations. The use of cones to channelize two adjacent open lanes of traffic is an acceptable form of traffic control according to the Manual on Uniform Traffic Control Devices (MUTCD). However, actual experience with the setup on I-79 indicates otherwise. During one such setup, the cones were hit by a heavy vehicle. The scattered cones were very hazardous to traffic in the area until they were removed from the traveled way.

Consequently, only one configuration was tested, i.e., the equipment setup 8.5 feet from the edge of pavement. The lane position and speed for this configuration are compared to the case of no equipment present to see if high speed interstate traffic is affected by the presence of the equipment at the roadside. The following sections detail these findings. Section 8.1.3.1 deals with effect of the equipment on passenger cars. Section 8.1.3.2 demonstrates the effect of the equipment on heavy vehicles. Note that traffic data were only taken from vehicles in the right-hand travel lane since it was by far the most heavily traveled. Since traffic volumes on I-79 were relatively low, vehicles infrequently needed to use the left-hand or passing lane.

8.1.3.1. Passenger Cars

In general, the data indicate that the equipment is not excessively intrusive to passenger cars on the freeway. Table 8-1 contains the lateral position frequency data; Table 8-2 shows the speed frequency data. Figure 8-1 shows these data pictorially.

Table 8-1 Passenger Car Lane Position Frequency Data - I-79

Distance from edge	No Equipment	Equip8.5' from edge	No Equipment	Equip8.5' from edge
0	2	0	0.8%	0.0%
1	8	5	3.4%	2.5%
2	48	30	20.3%	14.7%
3	100	89	42.4%	43.6%
4	63	53	26.7%	26.0%
5	14	18	5.9%	8.8%
6	1	8	0.4%	3.9%
7	0	1	0.0%	0.5%
sample size	**236**	**204**	---	---

Table 8-2 Passenger Car Speed Frequency Data - I-79

Speed	No Equipment	Equip 8.5 from edge	No Equipment	Equip 8.5 from edge
50-54	0	1	0.0%	0.5%
55-59	9	5	4.4%	2.4%
60-64	57	67	27.9%	32.4%
65-69	93	100	45.6%	48.3%
70-74	36	30	17.6%	14.5%
75-80	9	4	4.4%	1.9%
sample size	**204**	**207**	---	---
average	66.5 mph	66.0 mph	---	---
St. Dev	4.25 mph	3.70 mph	---	---

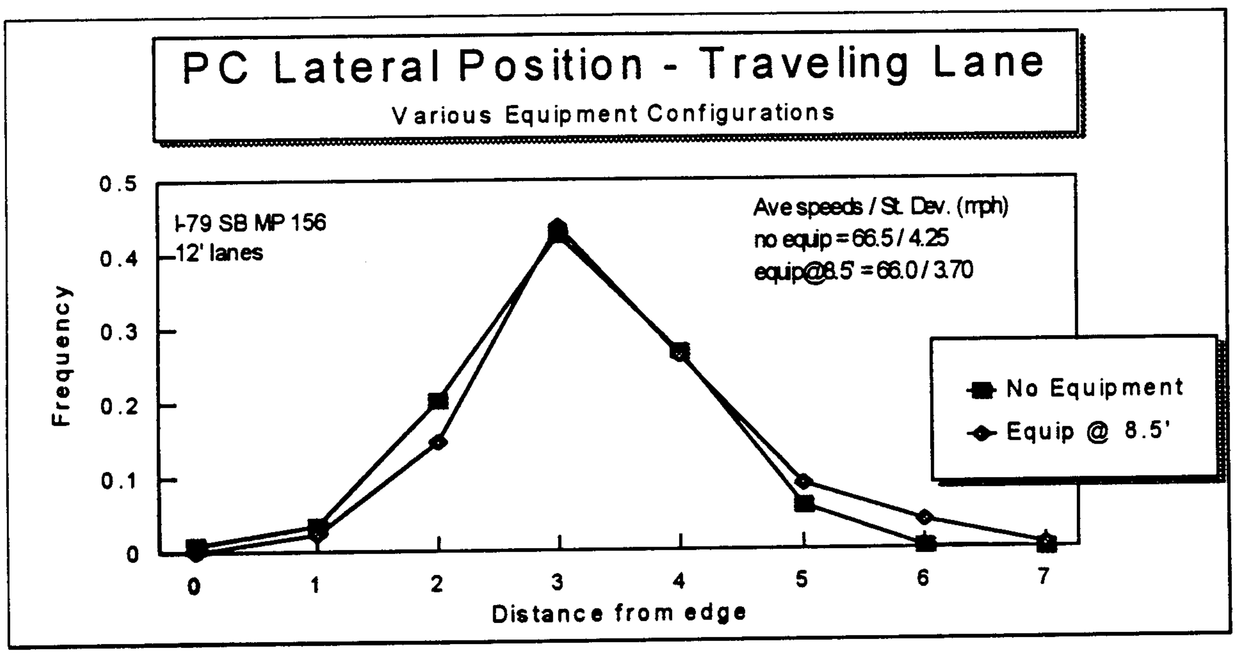


Figure 8-1 Lateral Shift and Speed Data - Passenger Cars on I-79

The data indicate a reduction in mean speed of only 0.5 mph when the equipment is present at the roadside. Both average speeds were above the legal speed limit, and the difference between the two was not statistically significant. This indicates that for freeways, no speed reduction should be expected due to the presence of the equipment. The ramifications of this are that no reduction in freeway capacity should be expected if the equipment is placed at the roadside.

The data indicated an induced lateral shift away from the lane edge and the equipment. Assume the typical passenger car vehicle is six feet in width. The lanes on I-79 are twelve feet wide. Therefore, a vehicle that is centered in the lane would have its passenger side tires track three feet from the lane edge. Any vehicle shifted towards that lane edge would have a lateral position reading of 0,1, or 2. Any vehicle shifted towards the center of the freeway would have a lateral position of 4 or greater. A reading of 6 or greater indicates that the vehicle may have been partially in the other lane or at least very close to the lane boundary. The data indicate that for both scenarios, nearly half of the vehicles are centered in the lane. However, with the equipment present, 30 percent fewer drivers chose a path that was off-centered towards the equipment.

Furthermore, 19 percent more drivers chose a path that was off-centered away from the equipment. The drivers that encroached on the adjacent lane increased nine-fold, from one without the equipment to nine with the equipment present. Of those nine vehicles encroaching on the adjacent lane, it is likely that only one of them actually entered the lane. In summary, although there is an induced lateral shift caused by the presence of the equipment at the roadside, it is not a serious enough problem to cause concern for driver safety.

8.1.3.2 Heavy Vehicles

In general, the data indicate that the equipment was not excessively intrusive to heavy vehicles on a freeway. Tables 8-3 and 8-4 show the lateral position frequency and speed frequency data for heavy vehicles on I-79. Figure 8-2 shows these results pictorially.

Table 8-3 Heavy Vehicle Lane Position Frequency Data - I-79

Distance from edge	No Equipment	Equip8.5' from edge	No Equipment	Equip. 8.5 from edge
0	4	3	3.7%	2.9%
1	34	15	31.8%	14.7%
2	55	57	51.4%	55.9%
3	13	22	12.1%	21.6%
4	1	4	0.9%	3.9%
5	0	0	0.0%	0.0%
6	0	1	0.0%	1.0%
7	0	0	0.0%	0.0%
sample size	**107**	**102**	---	---

Table 8-4 Heavy Vehicle Speed Frequency Data - I-79

Speed	No Equipment	Equip 8.5 from edge	No Equipment	Equip 8.5 from edge
50-54	0	2	0.0%	2.0
55-59	6	3	5.9%	3.0
60-64	53	31	52.5%	31.0
65-69	33	34	33.2%	34.0
70-74	6	25	5.9%	25.0%
75-80	0	5	0.0%	5.0%
sample size	**101**	**100**	---	---
average	63.0 mph	65.9 mph	---	---
St. Dev	7.14 mph	8.16 mph	---	---

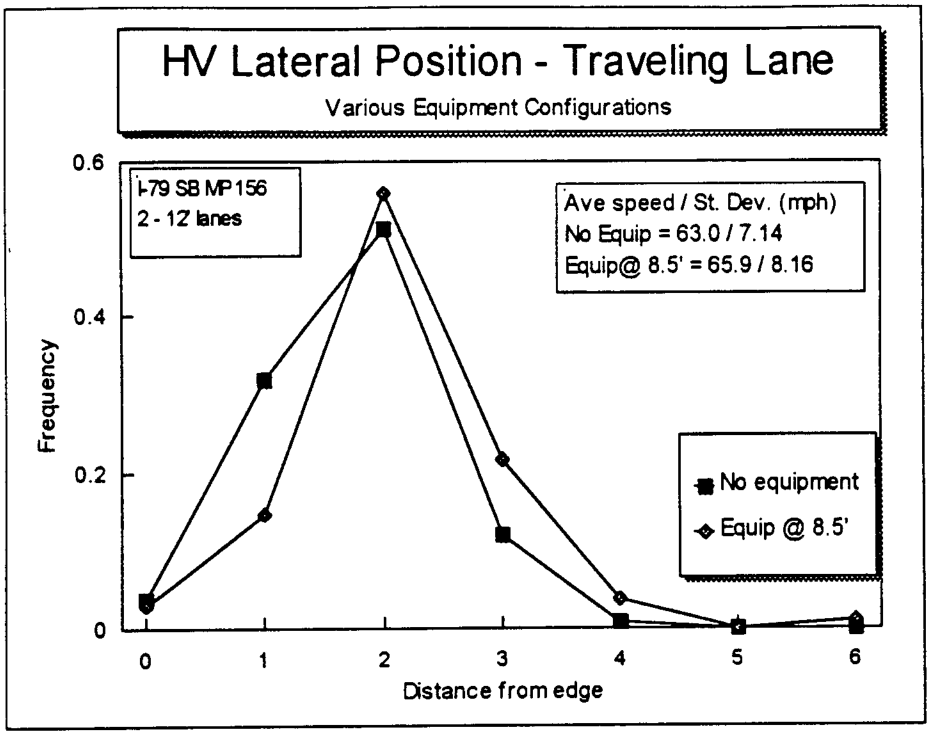


Figure 8-2 Lateral Shift and Speed Data - Heavy Vehicles on I-79

The average speed actually rose when the equipment was placed in position on I-79. This is counter-intuitive, as there is no logical reason why heavy vehicle drivers would increase their speed in response to the equipment. Furthermore, the increase in speed is not statistically significant. In actuality, the equipment has no significant effect on the selection of speeds for heavy vehicle drivers on freeways.

A lateral shift was induced with heavy vehicles, much like the one induced in passenger cars on this facility. If the average heavy vehicle is assumed to be 8.5-feet wide, a centered vehicle would have its passenger side tires track 1.75-feet from the lane edge. Readings of 0 would indicate the heavy vehicle was off-centered toward the shoulder. Readings of 2 or greater would indicate that it was off-centered toward the adjacent lane. In both cases, the most likely position for the vehicle was between two and three feet from the lane edge, indicating that the typical truck is not centered, but is instead slightly shifted away from the lane edge. The number of vehicles closer to the lane edge than is typically selected decreased by 50 percent with the equipment present. Concurrently, the number of vehicles shifted further from the lane edge increased by 104 percent. Any heavy vehicle with a lateral position reading of greater than 4 would likely enter in the adjacent lane. The indication of 4 means the passenger side tire is at least four feet from the lane edge. If the vehicle is 8.5-feet wide, this places the vehicle six inches into the adjacent lane. Occurrences of this situation increased from one to five when the equipment was present.

In summary, the induced lateral shift is more pronounced with heavy vehicles as opposed to passenger cars. However, the shift is not considered to be a serious safety problem. It is very likely that the shifts would not be as noticeable under heavier traffic conditions because more vehicles would have been present in the passing lanes. This is reinforced by the fact that during equipment operations, no accidents or problems were reported.

8.1.4 Traffic Operations and Intrusiveness on Local Streets

The traffic data for the local street were collected on Evansdale Drive on the Evansdale Campus of West Virginia University. This two-lane, two-way facility has 10.5-foot lanes and a posted speed limit of 25 mph. It serves as a collector street for the university parking facilities on the campus. It connects to three primary arterials, Monongahela Boulevard, Patteson Drive, and University Avenue.

Traffic is light most times of the day. Peak times for Evansdale Drive occur when faculty, staff, and students are entering and leaving the campus, mainly during the morning and evening peak hours and during lunch. Volumes seldom reached 150 vehicles per hour while the intrusion tests were being conducted. Heavy vehicles are scarce on this facility and consequently were not studied.

Three equipment configurations were tested on Evansdale Drive in addition to the "no equipment" condition.

- The equipment was set up six feet from the lane edge. This is the setup that will prevail when roadside space is not an issue and channelization is not provided.
- The equipment was set up at the roadside edge. On Evansdale Drive, there is a curb at the lane edge that separates the road from a grassy area. The equipment was positioned in the grass just behind the curb placing it approximately six inches from the lane edge. This configuration will be used when roadside space is limited and channelization is not used.
- The equipment was setup at the lane edge as described in the second configuration. In addition, cones were used to separate the two opposing lanes for channelization. This configuration is the most restrictive for traffic.

Using cones for channelization did not present the problem being struck like they did on I-79. However, drivers were confused on occasion, errantly interpreting the traffic control to indicate a closed lane. The driver would use the opposing lane to get around the site. Some did this in spite of signing indicating Stay In Lane. It was noted that drivers were more likely to mistake the traffic control for a closed lane if one of the research personnel was standing at the lane edge with the equipment.

Since only passenger cars were studied on this facility, Section 8.1.4.1 will present the lateral shift findings for passenger cars and 8.1.4.2 will present the speed reduction findings for passenger cars.

8.1.4.1 Lateral Shift Induced for Passenger Cars on Evansdale Drive.

In general, the lateral shifts induced were much more prevalent on Evansdale Drive than they were on I-79. Table 8-5 contains the lateral position frequency data. Figure 8-3 shows these data pictorially.

Table 8-5 Lateral Position Frequencies for Passenger Cars

Distance from roadside edge	No Equipment		Equip at edge of lane		At edge w/ cones		Equip 6' from edge	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%
0	0	0.0%	0	0.0%	0	0.0%	0	0.0%
1	20	9.9%	2	1.0%	18	9.0%	11	5.5%
2	101	50.0%	41	19.8%	160	79.6%	91	45.3%
3	53	26.2%	88	42.5%	23	11.4%	71	35.3%
4	26	12.9%	58	28.0%	0	0.0%	27	13.4%
5	1	0.5%	16	7.7%	0	0.0%	1	0.5%
6	1	0.5%	2	1.0%	0	0.0%	0	0.0%
Sample Size	202		207		201		201	

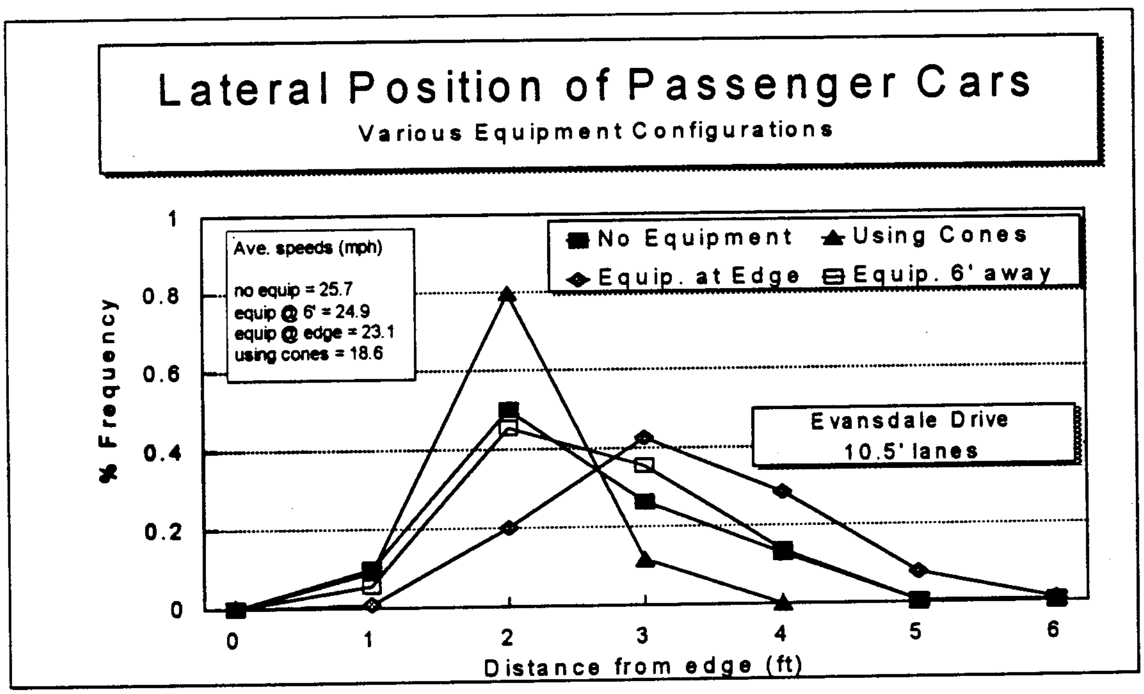


Figure 8-3 - Lateral Shift and Speed Data - Passenger Cars on Evansdale Drive

Clearly there was a significant effect on traffic due to two of the three configurations. The "no equipment" scenario and the "equipment at 6 feet" scenario look almost identical with a small shifting of vehicles away from the lane edge. This is very similar to that which was found on I-79 when the equipment was setup 8.5-feet from the lane edge.

More significant shifts were observed when the equipment was at the edge. In this case, traffic shifted between one and two feet away from the lane edge. Six-foot wide vehicles, perfectly centered in a 10.5-foot wide lane would have a reading of 2. A reading of 4, 5, or 6 represents encroachment on the adjacent lane. Over, 36 percent of the drivers encroached on the adjacent lane when the equipment was set up on the lane edge. In contrast, when there was no equipment or it was set up 6 feet from the lane edge, only 13.9 percent encroached on the adjacent lane.

When the cones were used for channelization, the result was a "single-file" like tracking of vehicles through the channelized site. Nearly, 80 percent of the vehicles tracked between two and three feet from the lane edge, in contrast to only 50 percent with no cones. Furthermore, no one drove closer to the lane edge than one foot or further away from it than four feet , which is not typical of the unconstrained traffic. Because the vehicle lateral positions are so uniform when channelization is used, the equipment can be aimed at an optimum position that will achieve quality images for a higher percentage of vehicles than is the case with other configurations. However, as will be demonstrated, this setup is very intrusive to traffic, particularly with respect to speed.

8.1.4.2 Speed Reduction Induced in Passenger Cars on Evansdale Drive

In general, there is a significant speed reduction caused by the presence of the equipment at the edge of pavement and the presence of cones channelizing the lane from opposing traffic. The speed frequency data are provided in Table 8-6.

There is no significant reduction in speed when the equipment is set up six feet from the lane edge. This is consistent with findings in the Highway Capacity Manual which conclude that objects six feet or further from the lane edge have no detrimental effect on capacity. Since this configuration is the standard setup for the equipment, intrusiveness should not be a problem in most cases.

Table 8-6 Speed Frequency Data for Passenger Cars on Evansdale Drive

Speed Range (mph)	No Equipment		Equipment @ 6'		Equip. @ EOP		Equip. @ EOP w/ Cones	
	Frequency	%	Frequency	%	Frequency	%	Frequency	%
5-9	0	0%	0	0%	0	0%	3	1.5%
10-14	1	0.7%	0	0%	0	0%	37	18.5%
15-19	1	0.7%	15	7.5%	17	8.5%	81	40.5%
20-24	52	34.9%	71	35.3%	120	60%	54	27%
25-29	78	52.3%	95	47.3%	56	28%	24	12%
30-34	14	9.4%	19	9.5%	6	3%	1	0.5%
35-39	3	2.0%	1	0.5%	1	0.5%	0	0%
Sample Size	**149**	---	**201**	---	**200**	---	**200**	---
Average	25.7	---	24.9	---	23.1	---	18.6	---
St. Dev.	3.37	---	3.81	---	3.32	---	4.38	---
Sig Diff. at 0.05	----		no		yes		yes	

There is a significant reduction in speed when the equipment is placed at the lane edge or when cones are placed in the roadway for channelization. The statistical significance was tested using a t-test for variables with assumed identical variances. The mean speed dropped by 11 percent when the equipment was placed on the roadside edge and by 28 percent when cones were used. In fact, a full 20 percent of the drivers were driving less than 10 miles under the speed limit when the cones were used. Although both configurations are intrusive, the use of cones makes the traffic excessively slow and could reduce capacity past the setup by as much as 28 percent.

8.1.5 Concluding Remarks

In general, when the equipment was setup six feet from the lane edge on Evansdale Drive, or 8.5 feet from the lane edge on I-79, a minimal amount of intrusion was detected. Traffic tended to shy away from the lane edge and the equipment, but not to any degree that would be considered dangerous. The only harmful effect of the shifting was the increased difficulty in aiming the equipment and the increased possibility of a vehicle driving outside the camera field of view.

The other configurations tested on Evansdale Drive were more intrusive. The more intrusive configurations could only be tested on a facility such as Evansdale Drive because speeds are so low. To test these configurations on a high speed facility such as I-79 would have created undue safety hazards. These configurations are only recommended on low-speed facilities, and then only when necessary due to roadside space limitations or the need to capture higher quality images through channelization.

8.2 Evaluation of the Equipment as a Roadside Hazard

This section investigates the potential hazards of locating the equipment along the roadside and provides some general methods of mitigating those hazards. The presence of the equipment at the roadside can create a hazard to drivers who leave the lanes for two reasons. First, the proximity of the equipment to the live traffic lanes gives high probability of impact by vehicles leaving the highway. Second, drivers face serious hazards if they strike some components of the field setup. The field setup includes the strobe, camera, sensors, van, and generator. Of these components, the field setup has only one rigid object, the van used to house the computer and image processor. However, the non-rigid objects are large enough and heavy enough to pose serious danger to motorists and equipment operators if struck.

This evaluation is separated into three parts. First, a discussion of the proximity of the field setup to live traffic is provided. Second, each component of the field setup is examined to predict the potential hazard of the equipment if it is struck by a vehicle. Finally, some conclusions and recommendations for minimizing the risk of an accident are provided.

8.2.1 Location of the Field Setup along the Roadside

To make highways safer, roadside recovery areas are provided on highways wherever possible. These areas provide a place for motorists to regain control of their vehicle once it leaves the travel lanes of the highway. The AASHTO Roadside Design Guide provides guidelines for the treatment of hazards located on the highway roadside. Because of the physical size of the equipment and its proximity to the road, these guidelines can be applied to the license plate reading equipment setup.

Research has shown that a clear roadside recovery area, or clear zone, of 30 feet will allow approximately 85 percent of vehicles leaving the roadside to recover [Wright and Zador, 1981]. Objects which must be located in the clear zone should either breakaway easily when struck or be shielded from traffic by an appropriate barrier. As an example, traffic signs must be located in the clear zone in order for them to be noticed by motorists. The sign posts should be designed to breakaway safely without causing an excessive amount of deceleration to the vehicle when struck. When hit, the posts breakaway close to the ground and send the sign and post safely over the vehicle and to the ground behind the vehicle.

The license plate reading equipment field setup is generally located well within the clear zone of the highway. In order to get an interpretable image, certain components of the setup need to be close to the traffic. Perhaps if zoom lenses and more powerful light sources are employed, the equipment could be moved to an overpass. However, this option was not available for testing during this research project.

For freeway operation, the light source, camera, and sensors were placed 8.5-feet from the lane edge. They were positioned there because they are directly involved with image acquisition. A vehicle leaving the travel lane has approximately 25 percent probability of recovering within the 8.5-feet [Wright and Zador, 1981].

It should be noted that it is possible to move the equipment further than 8.5-feet from the lane edge. For example, it is reasonable to expect the equipment to operate at a distance of 10-feet without sacrificing accuracy. This provides the opportunity to a roadside barrier to shield the equipment from traffic. Since the equipment is usually set up near a bridge, the bridge parapet can provide a safe area for equipment placement. However, the equipment was not placed there during this research work. In this particular instance, the approach to the bridge was a very high fill section. The space between the parapet and the top of slope for the embankment was inadequate for the equipment.

8.2.2 Components of the Site

Having established that the equipment must generally be placed in the clear zone, and that it will not always be possible to place it behind a barrier, it is necessary to investigate each of the components to determine the likely outcome of vehicle impact. It must be noted that the exact outcome will remain unknown, since it is beyond the scope of this project to test the crashworthiness of the equipment. A typical field setup is shown in Figure 6-5. Table 8-7 provides a summary of dimensions and weights of the components.

Table 8-7 - Summary of the Dimensions and Weights of the Components

Component	Length	Width	Height	Weight
Strobe / Enclosure	24"	12"	11" (placed on a 3' - 4.5' tripod)	45 lbs.
Camera / Enclosure	20"	12"	11" (placed on a 3' - 4.5' tripod)	30 lbs.
Sensor	6"	4"	(placed on a 5.5' - 6' tripod)	less than 10 lbs.
Weight for Sensor	5 gallon bucket of asphalt sealer tied the tripod base			48 lbs.
Van	15'	6'	7'	4500 lbs.
Generator	2.5'	1.5'	2'	150 lbs.

8.2.2.1 Stroboscopic Illuminator / Enclosure (strobe)

The strobe is the heaviest and largest of the equipment components mounted on tripods. It weighs approximately 45 pounds. When placed on the tripod, it is approximately four feet above the ground surface. It is 24-inches long, 12-inches wide, and 11-inches in height. If struck, the strobe could become a dangerous projectile. Because of its height, one of two scenarios are likely to occur when it is struck by a vehicle. If the vehicle strikes below the level of the strobe and hits the tripod legs, the strobe could fly towards at the vehicle and strike it in the windshield. The 45 pound mass could penetrate the windshield, striking the vehicle occupants at chest to face level. This could result in serious injury or even death. If the vehicle strikes the strobe, extensive damage to the hood and grill of the vehicle would result. In addition, the strobe could become airborne, endangering the equipment operators on the site.

8.2.2.2 Camera / Camera Enclosure

The camera and its enclosure, at a weight of 30 pounds, are not as heavy as the strobe. However, mounted on tripods that are roughly the same height, they cause essentially the same dangers. The camera can still penetrate the windshield or cause significant damage to the vehicle. The lighter weight could increase the projection distance over that of the strobe, posing even more danger to the equipment operators.

8.2.2.3 Sensors

The sensors, weighing less than 10 pounds, were often blown over in the wake of large vehicles. Consequently, five gallon buckets of asphalt sealer, weighing approximately 50-pounds, were tied to the tripods. These buckets dangle a few inches above the ground from a rope tied to the base of the tripod (See Figure 6-3). If the sensors were struck, the hazard would be the action of these heavy buckets. In close proximity to the ground, they are unlikely to become airborne or pose a threat to the occupants of the vehicle. They may ride under the vehicle or skid along the ground in front of the vehicle. The greatest danger in this scenario is not to equipment operators, but mainly to the vehicle grille and undercarriage.

8.2.2.4 Generator

Second to the van, the electric generator is the component most like a rigid object. An electric generator weighs between 125 and 200 lbs and sits very low to the ground. Depending on how it is struck and characteristics of the vehicle such as size and height off the ground, the vehicle could either ride over the generator or push it along the ground. It is likely the impact with the generator will cause significant damage to the vehicle, but would not result in serious injury or death to the occupant. The main concern with the generator is that it is a fire hazard. Impact with the generator could result in an explosion of generator and/or vehicle. Fortunately, the generator is not central to image acquisition and can be moved to a safer place. It is recommended that the generator be placed behind a barrier or as far from the lane edge as possible.

8.2.2.5 Van

The van is probably the biggest hazard among all the components. A collision with the van will result in serious damage to both vehicles, the probability of serious injury or death to the occupants, and the risk of fire or explosion. The equipment operators may or may not be in the van, but would be in great danger if in close proximity to the van during collision. Again, the van is not critical to image acquisition and should be placed in a safe area either behind a barrier or as far from the lane edge as possible.

8.2.3 Recommendations and Conclusions

The point of the discussion of the equipment as a roadside hazard is to heighten awareness of the potential dangers involved. Thoughtful site selection is crucial to minimizing damages. Run-off-the-road accidents are not an everyday occurrence and mitigation is possible. Avoiding areas with a history of accidents is one method. Another is to avoid areas where the circumstances are conducive to run-off-the-road accidents. Examples of sites to avoid include: the outsides of horizontal curves, areas with narrow lanes, large pavement drop-offs, and any area where traction and skid resistance is a problem. Using sites with long tangents, excellent sight distance and good road conditions are attributes that will minimize the risk. Finally, traffic control and site visibility are key contributors to site safety. The operators must set up a site that is clearly noticeable to traffic at a sufficient advance distance so that the driver can prepare themselves to travel through the site. Through site selection, traffic control, and careful placement of site components, the roadside setup can minimize the risk of an accident.

CHAPTER 9 - TRANSPORTABILITY, EASE OF SETUP, AND ECONOMICS

9.0 Introduction

In previous chapters, the quality of the plate interpretations and the equipment intrusiveness were investigated. This chapter investigates three important attributes of a license plate reader: transportability, ease of setup, and cost.

9.1 Transportability

Transportability is defined as the ability to move the license plate reader to and from a desired location along the roadside in a time- and cost-efficient manner. For transportation planning purposes, transportability is an important attribute of a license plate reader. In most cases, the transportation planning agency will perform short-term license plate data collection activities at various points, as opposed to long-term data collection efforts at a single point. Previous applications of this particular license plate reader involved long-term data collection at a permanent site. Therefore, transportability, and as will be discussed later, ease of setup, were new design requirements to the equipment vendor.

To be transportable, the equipment had to meet the following criteria:

1. The equipment must be capable of being moved by typical vehicles available to transportation planning agencies, such as standard-size pickup trucks or cargo vans. This involves both the space capacity and weight capacity of the vehicle.
2. The equipment must be capable of being packed into the vehicle by the equipment operators, which will be approximately two to three persons, with no special equipment such as a forklift or hydraulic lift.

3. The equipment components must not be damaged during typical transporting of the equipment.

The equipment evaluated in this study had a reasonable level of transportability. It required no special equipment to move or pack the equipment components. The equipment could be packed neatly into a standard-size cargo van or pickup truck, therefore a special vehicle was not needed.

In comparison, the manual methods of using audio tape or pen and paper, have the highest level of transportability as there is no equipment needed. The video camera method has approximately the same transportability as the equipment studied, which is to say that no problems are expected.

The only component of the equipment too heavy to be lifted by one person was the electric generator. This was not a component supplied by the vendor, but was instead a component supplied by the user. It took two people to lift the generator in and out of the vehicle used to transport the equipment. Since typically three to four workers were used to set up the equipment, the availability of two persons was not an issue.

There were no instances of visible physical damage to the equipment at any time during the experiments, but the equipment did have several computer hardware and electrical problems. It is unknown exactly what caused these problems, but there is a possibility that it may have been caused by the highway trip. During the highway trip, the components can be subjected to vibration and physical impact that can loosen the electrical connections. The equipment components were also subject to shipping and handling through the mail, which are also likely to be sources of the problems.

In conclusion, the equipment components are transportable from a physical size and dimension point of view. However, it is undetermined whether any damage is caused during the actual transportation. This is a serious consideration that must be addressed in designing future license plate readers.

9.2 Ease of Setup

The setup is defined as performing all necessary actions related to preparing the equipment components to collect plate data at the desired location. It does not include the transportation of the components to the site. The setup consists of three phases: locating and aiming the equipment components, connecting power and data transmission cables, and adjusting the focus, zoom, and brightness on the camera lenses.

Due to the temporary nature of transportation planning studies, the equipment will be subject to frequent setups. If the equipment setup is difficult and/or time-consuming, it can seriously limit the usefulness of the equipment to transportation planners. To be useful in transportation planning, the setup must meet the following criteria:

1. The equipment must be capable of being set up with the expertise typically possessed by technicians working in the transportation planning field. These technicians probably have a basic understanding of electrical and computer-based data collection tools, such as traffic counters, but would likely not have a deep understanding of imaging or the details of the license plate reading equipment. In short, it is likely that they could set up and operate the system, but it is unlikely that they could fix problems that arise in the software or hardware.

2. The equipment must be capable of being set up in a reasonable amount of time by a reasonable number of technicians. Ideally, the equipment should be set up early in the morning the day of the data collection, by no more than two technicians. However, a "reasonable amount of time" can actually vary from study to study. Take for example the case where the equipment takes an entire day to set up and an entire day to break down. If the data collection is planned for a single day, the entire effort will take three days: two days to set up and break down the equipment and one day to collect the data. Since the majority of the time is lost in dealing with the equipment, the set up time may prohibit its usefulness for use in that study. On the other hand, a study that collects data for a week does not have a high proportion of the total time devoted to handling the equipment. Travel time studies usually collect a sample size of 200 vehicles. Depending on volume, this may be accomplished in a few hours or at most a single day. Therefore, a long set up time would most likely result in a case where the majority of time is spent in equipment handling. Cordon studies and trip surveys usually involve data collection for a predetermined duration. The opportunity exists to adjust that duration based on the set up time, however, typical studies of this sort are of durations closer to a day or two than to a week.

   In addition to the study duration, other factors must be considered when determining a reasonable set up time. The time value of the data is an important consideration. If data availability is delayed until after the equipment is dismantled and transported to some office, trip surveys would be negatively effected by breakdown times exceeding a few hours. Finally, the data collection time using automated license plate reading equipment should not significantly exceed the time necessary to collect the data through conventional methods. These methods usually have very little time invested in set up and break down, but would likely have significantly more time invested in the actual data collection and reduction due to the inefficiencies in these methods.

In short, the set up time requirements will need to be determined on a case by case basis. However, because most transportation studies are of short duration, set up time of the equipment will be an important issue in most cases.

3. The equipment must be capable of being set up where the data collection is desired. The equipment should not dictate the location of the data collection.

4. The process of setting up the equipment should not require technicians to perform dangerous actions in live traffic.

As will be explained, the ease of set up for this particular equipment would become a barrier to its usefulness in most transportation planning agencies. In the following paragraphs, the three phases of the set up are explained in light of the criteria set forth.

Locating and aiming the equipment is a critical step in the set up because it has a direct effect on the quality of the captured images and consequently, interpretation accuracy. On standard sites where roadside space is not an issue, it is simple to locate the components in the proper position, within a few inches. However, where roadside space is not available to place components in their typical positions, improvising is necessary. Inexperienced operators will likely encounter accuracy problems due to improper placement of the components when the typical setup cannot be used.

In addition, locating and aiming the components involved two potentially dangerous acts if proper traffic control is not established. First, the only sure way of aiming the strobe was for the technician to kneel down in the center of the lane with his eyes at the typical plate height. The technician then looked into the strobe. When the technician saw his reflection, the strobe was properly aimed. The second dangerous act involved the placement of the reflectors used with the electronic eyes. The technician waited for a break in traffic, ran to the roadway centerline and placed the reflector in the proper position, then placed pressure on the reflector while the adhesive set.

The correct way of performing these actions involves setting up a proper lane closure for each lane that will be read. For the typical freeway, this would mean that at least two lane closures would need to be set up and removed during equipment setup. However, there is a great temptation not to set up the proper traffic control because it takes significantly longer to set up and remove the traffic control than it does to perform the actual work. The lane closures are also very intrusive to traffic, and require additional advanced warning signs that would not otherwise be needed.

Connecting the power and data transmission cables is a simple task. The ends of the cables were color coded and clearly labeled so that they could be connected properly with little expertise. However, the cables cause one of the biggest problems with the equipment setup. The camera, strobe, and sensors must be directly adjacent to the lane which they are to read. On multilane highways, where more than one lane of traffic will be read, it is necessary to have equipment components set up on both sides of the roadway. However, the image processor and electric generator are only on one side of the roadway. Therefore, it is necessary to connect the components on the opposite roadside with the image processor and generator. This connection is via cables that must run from one roadside to the other. It is not advisable to place the cables on the roadway. It would cause undue wear on the cables and may be a hazard to drivers due to the size of conduit that would be needed to contain the four cables that connect the two sides. Therefore, they are usually either run under the roadway at a bridge or over the roadway at an overhead structure. This seriously limits the location of the data collection activities to bridges and overpasses that are traversable by the technicians. One particular instance where this became an issue in this study was the testing in Tennessee. It was originally planned that both lanes of the Pellissippi Parkway would be read. However, the technicians were not able to walk safely under the bridges with the cables. Thus, only one lane could be read. One solution to this problem is to duplicate the generator and image processor on both sides of the roadway. However, this could add significant cost to the setup.

Adjusting the lens settings is a difficult and critical step in the setup. It is critical because the settings have a direct effect on the accuracy and type of errors made by the system. It is also the most difficult because there is no positive way to optimize the settings. More art than science, it requires a high level of imaging expertise and experience with the particular equipment to adjust the settings to get optimum performance. The adjustment process can be simplified in the field if the setup is replicated in the laboratory and the lens adjusted to approximately the correct position. This procedure sometimes minimized the amount of necessary field adjustment.

Typical setup times for reading two lanes ranged from two to four hours when the equipment worked properly. This involved having two to four technicians, which is the limit of useful labor for the task of equipment set up. With typical setup times of this magnitude, it is conceivable to set up the equipment in the early morning on the day in which the data will be collected. These setups would typically happen during the pre-dawn hours while it is still dark. This raises additional safety concerns and also the need for traffic control suitable for night-time operations. On the other hand, setting up equipment during this time is advantageous because traffic is lighter and the darkness allows certain items, such as the strobe and the electronic eyes, to be aimed more easily.

However, typical setup times are not frequently achieved, and cannot be relied upon. On several occasions, problems surfaced that caused the setup times to exceed six hours. Many times the data collection activities had to be canceled, due to hardware- and electronics-related problems, which were not decipherable to the inexperienced technician. Only an expert, knowledgeable about the inner workings of the license plate reader, could determine how to fix these problems. The license plate reader is a very complex system of computer hardware and software, cameras, and light sources. Unless the technician possesses the in-depth expertise that comes from the experience of building such a system from the ground up, or an equivalent amount of extensive training, he would be unlikely to be effective at diagnosing and fixing problems that arise.

It is unlikely that transportation planning agencies will have this type of expertise available in-house and will need to call upon the vendor frequently. Furthermore, unless these experts are actually on site to examine the equipment firsthand, their effectiveness is limited to only the simplest of tasks. Several times the technicians communicated with the vendor via telephone. The vendor gave instructions; the technician carried them out and relayed feedback to the vendor. These phone calls were very frustrating experiences that seldom worked unless the problem was simple. Complex problems were usually resolved by sending certain components back to the vendor for repair. This resulted in significant downtime.

In conclusion, the equipment used in this study failed most of the setup criteria set forth. First, it is not capable of being set up by technicians the morning of the data collection effort on a reliable and consistent basis. Secondly, the technicians will be unable to diagnose and fix problems most of the time. Consequently, significant downtime results when the equipment is sent back to the vendor to correct these problems. Thirdly, the equipment needs to be located near special features on the highway facility which may or may not be located at the point where the data need to be collected. Finally, certain aspects of the setup might have a tendency to cause the technicians to endanger themselves and the motoring public.

As was the case with transportability, the audio tape and pen and paper methods of collecting license plate data have no problems with ease of setup because there is no equipment to set up. The video camera method would be difficult to set up because it would require specialized training to aim the camera and adjust the lenses so that readable images can be obtained. As stated before, however, the firms that offer this service will eliminate the need for the agency to have that expertise in-house.

9.3 Economic Analysis

The motivation to develop the equipment will be dictated to a large extent by economics. The likely scenario for its development will be for the private sector to develop it for purchase by government agencies involved in transportation planning and engineering. The following discussion focuses on the benefits and costs of such a system if it is to be developed.

9.3.1 Benefits

The real benefit of the equipment is the improved license plate data base it produces. If the equipment performs properly, the data base should be (1) more complete, as more vehicles will be included in the sample, and (2) more reliable, as the interpretations should be correct more frequently. Possibly the most important benefit is that the data base will be in electronic format. In some cases, such as in video tape collection, the most expensive and time-consuming task is processing the data and converting it to electronic format. Once it is in electronic format, it can be used in matching programs, or to access motor vehicle registration files, quickly and inexpensively.

From an analytical viewpoint, determining a dollar value for the benefit of an improved data base is nearly an impossible endeavor. Furthermore, the value would vary depending on the type of study performed and the individual circumstances at the time of the study. For example, a high value would be placed on the data in the case of a trip survey where license plate data are limited and there is little tolerance for incorrectly sent surveys. On the other hand, a travel time survey on a highway having 4000 vehicles per hour, where the planner is only seeking to find 200 matching plate interpretations between an upstream and downstream station, places a lesser value on the data.

A surrogate measure of the benefits might be to determine the market for automated license plate readers in United States transportation planning agencies. In the U.S., there are 50 state departments of transportation, 340 metropolitan planning organizations, a Federal Highway Administration, and transportation authorities in Washington D.C. and Puerto Rico.

While the Federal Highway Adminstration (FHWA) has the most financial resources to commit to license plate readers, they are unlikely to need many license plate readers. FHWA has sole jurisdiction over highways in national parks and indian reservations, which amount to a very small fraction of the nation's highway system.

Transportation planning traditionally takes place at the state and local level. Recent transportation spending legislation has further strengthened the role of local and regional governments in transportation planning through the empowerment of the metropolitan planning organization (MPO). However, local agencies are the least likely to be able to afford expensive equipment. Furthermore, it is unlikely that an individual MPO would perform enough license plate data collection in a given year to justify the high capital cost of license plate readers. The MPO in Pittsburgh, Pennsylvania, one of the nation's larger and more progressive MPO's, indicated that they would need the license plate reader approximately once per year, but would not be willing to purchase their own.

State deparments of transportation seem to be the most likely purchasers of the equipment. They have sufficient financial resources to purchase the equipment, and are well-positioned to coordinate the usage of the equipment between their own needs and those of MPO's and other units of local government. The West Virginia DOT was prepared to purchase at least one and possibly two units of the equipment. West Virginia has seven MPO's. WVDOT planning personnel indicated that the units would have been used ten or less times per year. This correlates well with Pittsburgh's estimate of one usage per MPO.

If each state were to purchase one or two units, there is an initial market for 50 to 100 units. Of course, this does not take into account latent demand that is not realized due to current difficulties in collecting license plate data. It is reasonable to expect that if a quality license plate reader could be offered at a competitive price, more units would be demanded.

A minimum of two license plate reading units are required to perform a matching study. Some matching studies could make use of 25 or more readers. Currently, studies requiring several license plate reading stations are performed by private contractors capable of maintaining a larger fleet of reading equipment, due to the larger number of surveys they perform per year. Inexpensive license plate readers could potentially tap into this market.

9.3.2 Costs

Each of the several methods of collecting license plate data has different costs and benefits associated with it. The automated license plate reader used in this study is only one version of automated license plate reading equipment. As discussed in previous chapters, there are other vendors available, as well as firms that offer the service of automated license plate reading but do not sell equipment. In addition, there are always the manual methods of using audio tapes, video tapes, or simply pen and paper. This section will present the costs associated with different methods. First, some typical costs are estimated, then some case studies are given. The case studies are not necessarily typical or average or an indicator of what a particular project might cost. If an agency is considering a study which requires license plate data, a detailed investigation of that particular case will be needed to determine the most cost-effective option of collecting the data.

The license plate reader used in this study interprets the plates and provides the data in real-time. Seconds after a vehicle travels through the site, the interpretation is available in electronic format. It was originally thought that this would be a significant benefit in studies such as trip surveys, where the data are time-critical. The project team envisioned a post card survey being printed out with the driver's address seconds after that driver passed the site. However, the accuracy of the interpretations is so low that all the images would need to be manually verified. This eliminates the "real-time" benefit this equipment might have been perceived to offer over license plate reading technology that takes place off-line. However, there are other potential advantages that automated equipment can have over traditional methods, as discussed in the benefits section.

The cost of the license plate reading equipment used in this research was $37,875 for the hardware, software, cameras, electronic eyes, and strobes to read two lanes of traffic. Other costs not included in this figure are the cargo van or pickup truck, generator, labor, tripods, reflectors for the electronic eyes, and training and repair costs. Since minimal further technological development is required to develop a license plate reader for transportation planning, it is expected that the price of a new reader will be on the same order of magnitude as this license plate reader.

In contrast, the manual methods of collecting license plate data only involve the labor and some small costs, such as the cost of a tape recorder. Unlike the license plate reading equipment, the labor costs only accrue during transportation to and from the site and while the data are being collected, as there is no lengthy equipment set up process. Depending on the flow rate and speed of traffic, several technicians may be needed to collect data at a single site, but probably not more than would be needed to set up the license plate reading equipment.

Recording plates with video cameras method requires an electric source, which is commonly a rechargeable battery, and a tripod. Unlike the license plate reader, it does not require any of the devices associated with the triggering mechanism or the extensive cabling. However, it does require a new video tape every two hours. The labor requirements are relatively low with this method as two technicians can set up and operate a four lane (two lanes per direction) station. Estimated cost data for all methods are shown in Table 9-1. The costs presented represent direct costs only, and do not include overhead, employee benefits, or taxes.

Table 9-1 - Approximate Cost Data for Reading License Plates from Two Lanes of Traffic

Method	Capital Costs	Data Collection Labor Costs	Data Reduction to Electronic Format
Pen & Paper or Audio Recorder	less than $100 (paper supplies or tape recorder and tapes)	$6/hr per tech per hour of data collection + less than one hour of set up/ breakdown time Up to 4 techs per lane	Process appx 400 entries per hour at $6/hr
Video Tape	$3000 (2 camcorders, VCR, and tapes)	$20/hr for one operator, $6/hr for one tech + less than two hours of set up/breakdown time	Up to 20 hours per hour of tape at $6/hr
LPR	$40,000 + generator, van, and tripods	$20/hr for two operators + less than five hours of set up/breakdown time	0 - Data are provided in electronic format

In Raleigh County, West Virginia, a private firm conducted a cordon study on the major routes entering and leaving the county. There was one major route in each direction; US 19 in the north, I-77/64 in the west, I-64 in the east and I-77 in the south. This study involved reading sixteen lanes of traffic over the four sites as each route has two lanes in each direction. In addition, the group performed another day of license plate reading via video and pen and paper for mail out surveys on several state and county roads. The cost of conducting these studies and producing the final report was approximately $70,000.

In Knoxville, Tennessee, the vendor of the equipment used in this study collected data for a cordon study that required six stations to be set up for two weekends. Each station was set up to read two lanes. The cordon study was performed to determine the need for a bypass around the northwest of Knoxville. The cost of collecting the data for the Tennessee DOT was approximately $40,000.

A group of university students conducted a small study using license plate matching to determine the proportion of vehicles currently on I-68 and I-79 in Monongalia County, West Virginia, that would use a proposed northern bypass of Morgantown. It involved reading eight lanes of relatively lightly traveled interstate traffic. Eight student technicians were used. They teamed up into four groups of two that worked together; one student read plates aloud to the other student who wrote down the last four digits. They did encounter some difficulties because they relied on ambient light. However, they were able to capture nearly all of the plate data for which they were responsible. The cost of this study was approximately $1,000. A study of this type would not be feasible, however, if the traffic volumes were much greater. The approximate average daily traffic of the facilities involved was 20,000.

As demonstrated, there are three different methods of collected license plate data, all having different costs and different levels of effectivness. In the following section, these two concepts are analyzed together, as the cost-effectiveness of the different methods are determined and compared.

9.3.3 Economic Efficiency

From the point of view of a state department of transportation, the purchase of automated license plate reading equipment could be economically justifiable. In the case of the Knoxville Bypass, the Tennessee DOT was willing to pay $40,000 for the data to support one study and conduct research on the license plate reader. It was estimated earlier that a state could use the equipment approximately one time per year per urban area. In Tennessee, there are four large urban areas: Knoxville, Memphis, Nashville, and Chattanooga, that would likely have at least one application per year. In addition, there are several smaller urban areas, such as Johnson City, Kingsport, Oak Ridge, Jackson, Columbia, and Clarksville, which would average one use per year. The state of Tennessee may perform up to 10 studies per year using the equipment. If they are willing to pay $40,000 for the data each time, their willingness to pay for data for one year is $400,000. In contrast, the equipment needed to perform studies such as that conducted in Knoxville would only cost $60,000. The equipment could pay for itself within one year, and would have a service life that extended well beyond that one year time frame.

This indicates that the benefits of collecting license plate data using automated license plate reading equipment outweigh the costs. Thus, it needs to be determined if the automated license plate reader is economically efficient with respect to the other methods of collecting license plate data. In Table 9-1, the approximate cost data for collecting license plate data by different means were provided. These data can be used to determine the productivity efficiency of each method.

The productivity of collecting license plate data is a function of three variables:

- Traffic volume

- Number of studies performed
- Sample size per study

The traffic volume effects the productivity because the video tape method and the automated license plate reader will be more efficient than the manual method at higher volumes. There is a limit to the number of license plates that can be manually recorded in one hour. Considering the time required to read and record the number on paper, and factoring in breaks for the technician, it is unlikely that more than 400 plates can be captured in one hour. In contrast, a highway can carry upwards of 2000 vehicles per hour per lane. This equipment and the video tape methods can take advantage of high traffic flow rates because their hourly plate capturing capacity is closer to that of the highway.

The number of studies performed is an important consideration because the video tape method and the automated license plate reader are capital intensive. The initial investment for an automated license plate reader will be approximately $40,000. This cost needs to be spread over many studies if it is to compete with manual methods which require little capital investment.

Finally, the sample size of the study is important. The manual and video tape methods are labor intensive and have a higher marginal cost than the automated license plate reader. For each additional plate that needs to be captured, the automated license plate reader becomes more cost-effective with respect to the other methods.

The three cost components of collecting a license plate data base are:

- Capital Cost
- Field Data Collection Cost
- Data Reduction to Electronic Format Cost

These are summed to determine the cost of acquiring an electronic data base of a specified number of plates at a given traffic volume and equipment usage.

In the analysis, the productivity variables were varied as follows

- Traffic volume: Varied from 1,000 to 4,000 vehicles per hour, stepping 1,000 vehicles per hour (i.e, 1,000, 2,000, 3,000, 4,000 vph)
- Equipment usage: Varied from 1 study performed to 100 studies performed, stepping 10 studies performed. (i.e., 1, 10, 20, 30...90, 100 studies performed)
- Number of plates needed per study (sample size): Varied from 2,000 to 100,000 plates, stepping 2,000 plates. (i.e., 2,000, 4,000....98,000, 100,000)

For each combination of productivity variables, the lowest cost alternative is presented. The costs were calculated subject to the following assumptions:

- The cost data in Table 9-1 were used.
- Each method will achieve a 100% accuracy rate
- The time value of the data is negligible
- All plates do not have to be captured

The results are contained in Table 9-2. For each combination of traffic volume and number of studies, the sample size at which the automated license plate reader becomes most cost-effective is reported.

The manual method is most cost-effective when low amounts of data are collected because of the low cost of capital. The automated license plate reader becomes the most cost-effective as larger amounts of data are collected because it relies little on manual labor. The video tape method is not the most cost-effective at any level because it is too capital intensive to compete with the manual method when low volumes of data are collected, and too labor intensive to compete with the automated license plate reader when high volumes of data are collected.

Table 9-2 The Most Cost-Effective License Plate Data Collection Method at Varying Levels of Volume, Studies Performed, and Plates Needed per Study

Note: The table entries represent the sample size at which the Automated License Plate Reader becomes more cost-effective than Manual or Video Tape Methods. For example, if 30 studies will be performed on facilities having volumes of 4000 vph, and if a sample size of at least 72,000 plates are to be collected each time, then automated license plate reading equipment should be used. [In some cases, Manual Methods are the most cost-effective at all sample sizes. This is denoted by "Manual*".]

# of studies performed	Volume			
	1000 vph	2000 vph	3000 vph	4000 vph
1	Manual*	Manual*	Manual*	Manual*
10	Manual*	Manual*	Manual*	Manual*
20	Manual*	Manual*	Manual*	Manual*
30	Manual*	Manual*	86,000	72,000
40	Manual*	Manual*	66,000	56,000
50	Manual*	88,000	54,000	46,000
60	Manual*	74,000	46,000	40,000
70	Manual*	68,000	40,000	34,000
80	Manual*	66,000	36,000	30,000
90	Manual*	54,000	34,000	28,000
100	Manual*	50,000	30,000	26,000

*Manual methods were optimum at all levels of sample size

In some cases, manual methods are not acceptable. Examples include cases where a permanent record of every plate must be captured. Table 9-3 shows the most cost-effective method between the video recorder and the automated license plate reader. At each combination of traffic volume and number of studies, the sample size at which the automated license plate reader becomes most cost-effective is reported. In cases where that sample size is greater than 100,000 plates, the video recorder is assumed most cost-effective at all levels.

Table 9-3 Comparison of the Video Recorder and Automated License Plate Reader at Varying Levels of Traffic Volume, Sample Size, and Number of Studies

Note: The table entries represent the sample size at which the Automated License Plate Reader becomes more cost-effective than the Video Tape Method. For example, if 10 studies will be performed on facilities having volumes of 1000 vph, and if a sample size of at least 86,000 plates are to be collected each time, then automated license plate reading equipment should be used. [In some cases, the Video Tape Method is the most cost-effective at all sample sizes. This is denoted by "Video*".]

# of studies performed	Volume			
	1000 vph	2000 vph	3000 vph	4000 vph
1	Video*	Video*	Video*	Video*
10	86,000	76,000	72,000	70,000
20	46,000	40,000	38,000	38,000
30	32,000	28,000	26,000	26,000
40	24,000	22,000	20,000	20,000
50	20,000	18,000	18,000	18,000
60	18,000	16,000	16,000	16,000
70	16,000	14,000	14,000	14,000
80	14,000	12,000	12,000	12,000
90	14,000	12,000	12,000	12,000
100	12,000	10,000	10,000	10,000

*Video methods were optimum at all levels of sample size

The results of this analysis show that in most cases, the most economical choice is the automated license plate reader. The marginal cost of the video recorder method is higher than the automated license plate reader because a technician is required to manually review each tape to record the license plate data. This is time-consuming and expensive if a technician is required to sift through the tape frame by frame to record the license plate data. In this case, the only justifiable applications for the video tape method are either when every plate must be captured, or when a permanent record of each plate is needed and the number of plates to be collected is small.

There are methods of automating the video tape review process to increase its efficiency. The license plate reading equipment that operates off-line can significantly reduce the data reduction time. Since it has an image processing algorithm that searches the video for license plates, the technician is able to view plate images quickly without the need for searching through the tape for them. Furthermore, the license plate reader provides an interpretation that can either be confirmed or quickly corrected. This has the potential to reduce the time to review one hour to tape from twenty hours to two hours or less. If this productivity increase is factored into the analysis presented above, the results are significantly different. A comparison of the improved video tape method with respect to both the manual method and automated license plate reader is provided in Table 9-4.

The improved video tape method is the most cost-effective method in most cases, with the exception of a few cases when only a small amount of plate data are being collected. An analysis was also performed to determine whether the improved video tape method or license plate reader was most cost-effective. This is useful when manual methods are not technically feasible. In every case the improved video tape method was the more cost-effective than the automated license plate reader.

Table 9-4 Comparison of the Manual Method, the Improved Video Recorder and the Automated License Plate Reader at Varying Levels of Traffic Volume, Sample Size, and Number of Studies

Note: Table entries represent the thresholds at which one method becomes more cost-effective than another. For example, consider a case where 10 studies will be performed on facilities having volumes of 2000 vph. If the sample size to be collected each time is less than 12,000 plates, then manual methods are the most cost-effective. If the sample size is greater than 12,000, then the improved video tape method is the most cost-effective.

# of studies performed	Volume			
	1000 vph	2000 vph	3000 vph	4000 vph
1	Manual at all	Manual at all	Manual at all	Manual <=94,000 Video at others
10	Manual at all	Manual <=12,000, Video at others	Manual <=10,000, Video at others	Manual <=6,000 Video at others
20	Manual at all	Manual <=4,000, Video at others	Manual at 2,000, Video at others	Manual at 2,000, Video at others
30	Manual at all	Video at all	Video at all	Video at all
40	Manual at all	Video at all	Video at all	Video at all
50	Manual at all	Video at all	Video at all	Video at all
60	Video at 2000, Manual at others	Video at all	Video at all	Video at all
70	Video at 2000, Manual at others	Video at all	Video at all	Video at all
80	Video at 2000, Manual at others	Video at all	Video at all	Video at all
90	Video at 2000, Manual at others	Video at all	Video at all	Video at all
100	Video <= 4000 Manual at others	Video at all	Video at all	Video at all

9.3.4 Summary

Based upon the economic and productivity analysis performed, the following can be concluded:

- The benefits of collecting license plate data with an automated license plate reader outweigh the costs. However, there are methods of collecting the data, and the automated license plate reader is not always the most cost-effective of the methods.
- Manually collecting the license plate data is only technically feasible when small amounts of data are needed, every plate is not needed, and a permanent record of the plate is not needed. In these cases, manually collecting the data is usually the most cost-effective method
- Collecting license plate data via video tape is technically the only method that ensures that a permanent record will be captured of every license plate. In cordon studies, this method is likely to be the only technically feasible method.
- If the video tape must be reviewed manually without any automation, the video tape method is never the most cost-effective method of collecting license plate data. When larger amounts of data are needed, or the manual method is not technically feasible, the automated license plate reader is the most cost-effective alternative.
- If the video tape reviewing process can be automated, the video tape method is the most cost-effective method of collecting license plate data when larger amounts of license plate data are needed or the manual method is not technically feasible.
- If data are to be collected at night-time, or is required in near real-time, the automated license plate reader is the only technically feasible alternative.

CHAPTER 10 - RECOMMENDATIONS FOR A TRANSPORTATION PLANNING ORIENTED AUTOMATED LICENSE PLATE READER

10.0 Introduction

In earlier chapters, the performance of an existing license plate reader was evaluated with respect to standards that were derived from the characteristics of transportation planning studies and the agencies conducting them. In this chapter, these standards are synthesized to describe a license plate reader that would be appropriate for transportation planning.

First, the advantages of the existing system are documented. These are items which a newly- developed system would want to incorporate. In addition, some enhancements that might be incorporated to improve these items are provided. Next, the disadvantages of the existing reader are presented. These are challenges that a new system would need to overcome. Suggestions for overcoming these disadvantages are discussed. Finally, these ideas are translated into a set of technical specifications for a license plate reading system for transportation planning. These specifications can be used by a private vendor wishing to develop such a system or by a planning agency interested in procuring the system.

10.1 Advantages of the Equipment Tested

The tested system had a few elements that must be preserved in any system developed for transportation planning purposes. First, the license plate reader transferred the captured electronic images to the hard drive of a host computer. As discussed earlier, some transportation planning activities require the highest level of assurance that an interpretation is correct. The only way to achieve this is to manually check the interpretations via the electronic images.

One improvement that could be made to the existing system with respect to viewing the images is to develop an improved image viewing software package. Once the image is on the screen, it can be manually verified very quickly. However, at least half the time spent verifying images in this experiment was wasted in finding the images and waiting for the viewer to load them up on to the screen. A viewer that is developed specifically for this application would load many or all the images into memory, then display each in chronological order, changing between each image with only a keystroke. If that keystroke is a "C" for correct or an "I" for incorrect, with the program automatically logging the results, it would be another significant enhancement that would make the verification job easier.

Providing the confidence level of each interpretation is also an item which needs to be preserved in future systems. However, the algorithm which produces the confidence needs to be more closely related to the percentage of time that the interpretation will be correct. For example, if the reader indicates a 95 percent confidence, then 95 percent of the time the interpretation should be correct. In this case the accuracy did improve with increasing confidence, but the accuracy lagged behind the confidence significantly. Even at 100 percent confidence, accuracies of 75 percent were noted.

Another advantage of this system was transportability. The system could be broken down into components small enough to be loaded onto standard size pickup trucks or vans by only a few people. A system that does not require special vehicles or equipment for loading will be less expensive and ultimately more versatile than those that do. The main concern with this system is that it may have developed loose electrical connections or other damage during the transport. A new system must be built to withstand frequent transportation and handling by technicians.

10.2 Disadvantages of the Equipment Tested

The reader tested in this research did not meet the needs of transportation planning and is not recommended for use by planning agencies. This section will explore the reasons why the reader was deemed insufficient.

10.2.1 Manual Focus, Zoom, and Brightness Adjustment

The adjustment of the lenses was one of the most critical parts of the setup procedure because the accuracy of the reader was highly dependent upon it. At any individual reader, imperfect settings led to lower accuracy. Also, when a system of readers are setup, such as in a cordon study, inconsistencies in the lens settings between machines led to low matching rates, and more importantly, equipment dependent errors. In addition, field adjustment of lenses was difficult because the images were displayed at the image processor, but the adjustments were made at the camera. These two points could be spatially separated by as much as 15 feet or more. Thus, in order to adjust the lenses, one technician looked at the image and directed the person at the camera who adjusted the lenses. Since it was very noisy due to traffic and the motor on the electric generator, a relay person was often required to transmit the verbal messages between the two technicians. This could have been overcome with hand-held two way radios if planned for in advance, however, the ideal method of dealing with this problem is to make the lenses adjust automatically. If this is not feasible, at the very least there should be some method to allow the technician to remotely adjust the lenses from the image processor, where the camera images are actually being displayed.

10.2.2 Cabling Across the Roadway

On multilane highways, where more than one lane will be read by a single image processor, there will be a need for the components on both sides of the roadway to be connected to one another via electric and data transmission cables. Consequently, the equipment setups need to be located next to a bridge or overpass with traversable slopes. This may not always coincide with the desired data collection point. In some cases, there may not be any suitable place to set up the equipment, which would render the equipment useless.

Wireless data transmission must be incorporated to eliminate the need for data transmitting cabling across the roadway. A generator will need to be present on both sides of the roadway because it is not feasible to send electricity via wireless transmission.

10.2.3 System Complexity

Technicians that would be operating a license plate reader for a typical transportation planning agency would probably not be able to diagnose and fix problems if the reader is too complex. The reader evaluated in this research involved many complex sub-systems and components. In order to fix most problems, an in-depth understanding of the system that would only be possessed by the designers was required. Since the system frequently encountered problems, the resulting downtime and canceled work days were significant. Complex systems can also lead to long setup times, which was an additional concern with this system.

There are actions that both the vendor and the user can take to deal with system complexity. From the vendor point of view, a system that is more durable and designed with the non-expert user in mind will minimize the occasions in which the user will need expertise beyond their abilities. The vendor will also need to be prepared to provide extensive after the sale service.

The user will also need more training than was provided in this experiment. The agency may also want to consider exclusively assigning the license plate reading equipment to one or two specially trained technicians.

10.2.4 Truck Plate Interpretation

Truck traffic characteristics are important considerations in transportation planning. A license plate reader must be capable of reading plate data from heavy vehicles to be truly effective in transportation planning. The main problem with this reader was that the triggering system fired prematurely, resulting in images of the sides of these vehicles. However, another problem that will need to be overcome once the triggering problem is solved is locating the plate on the back of trailer. The plates can be located just about anywhere on the rear of the trailer. For the reader evaluated in this study, they would have been out of the field of view much if not most of the time. In addition, there is usually other writing on the trailers, making distinguishing the plates a more difficult task than is the case with passenger vehicles, where only the occasional bumper sticker competes with the plate.

10.2.5 Decision Tree Plate and Character Recognition

This reader used a decision tree algorithm to perform state recognition. There were only seven states in the decision tree and only the standard issue plates of each state were recognizable. In the U.S., there are over 1800 different types of license plates and that number continues to grow. An improved algorithm needs to be developed that can deal with this diverse and expanding population of plate types. It is anticipated that a decision tree will not suffice. Perhaps a neural network based recognition algorithm will be better able to deal with the numerous existing plate types. It would also be better equipped to add new plate types as they are developed.

10.2.6 Capacity of Image Processor Lower than that of the Highway

Several vehicles were missed because the flow rate on the highway was greater than that of the image processor. The image processor needed approximately two seconds to process the images and save them to the hard drive. The system had temporary storage buffers to deal with small platoons of vehicles, but larger platoons and high steady flow rates overloaded the processor. During field testing on the Pellissippi Parkway, where the reader was setup only on one lane of the two-lane facility, the processor was overloaded several times per hour. If both lanes of traffic were being read, the processor would have been overloaded even more often.

More modern electronics, such as processors and circuit boards, may have decreased the processing time and increased the processor capacity. A newly developed license plate reader should be capable of processing 2300 vehicles per hour per lane, the approximate ideal capacity of a freeway lane.

Another idea is to capture the images in real-time, but interpret them later off-line. Although there may be some specialized cases that require real-time interpretations, the most time-sensitive standard transportation planning study is the trip survey. The data would be just as useful if received within 24 hours, as it would be if received in real-time. This will reduce the processing time per vehicle to the time needed to capture and save the image. This approach may become essential if the recognition algorithm is to discriminate between nearly 2000 different types of plates.

10.2.7 Intrusive to Traffic

As demonstrated in Chapter 8, the equipment is a noticeable roadside presence and will have an effect on traffic. It had the effect of slowing traffic and moving them laterally away from the side of the road. On high traffic facilities, this phenomenon may cause the roadway through the set up to become a bottleneck. This would result because the vehicular capacity there is lower than the upstream roadway. Congestion and stop and go traffic might form just upstream of the system setup. Queues that form on otherwise high speed facilities not only cause frustration and delay, but also are safety hazards due to the increased likelihood of rear-end collisions.

A non-intrusive system must be developed. The key to developing such a system will be to move the system as far from the lane edge as possible. More powerful light sources and camera lenses will allow the components to operate at a greater distance from the license plate, and consequently the lane edge.

10.2.8 One Monochrome Image per Vehicle

One of the main problems with the system was that obstructions such as trailer hitches and bumpers partially blocked the plate in the captured image. However, if a technician were trying to interpret the plate as it passed them, the hitch or bumper would not be a problem because humans can "see around" the obstruction. Humans "see around" obstructions because as they move their head, their eyes take multiple images of the plate. A license plate reader could emulate this action by taking multiple images as the vehicle passes by. Capturing multiple images should reveal what might be obstructed in single image.

The singlehead system captured a single black and white image each time it was triggered. Although, the doublehead captured two images simultaneously, the interpretation algorithm only used the better of the two images, thus the processor did not accrue the true benefits of multiple images. Cameras with faster shutter speeds are available. In the same time that a 1/10000 second shutter speed camera captures one image, a camera that has a shutter speed of 1/50000 second can capture four images. The multiple images do not need to be spaced temporally at one every 1/50000th of a second, but the faster camera does make it more feasible to capture multiple images of a high-speed vehicle. If the multiple images are used properly by the interpretation algorithm, the reader could simulate the action of "looking around" obstructions. One method of accomplishing this might be to employ one neural network plate interpretation algorithm per image and one additional neural network to synthesize results and resolve conflicts among them.

Color cameras may also be needed for license plate reading in the future. With the numerous and diverse population of plates that the reader will need to discriminate between, the additional information that color can provide may be useful.

10.3 Technical Specifications for an Automated License Plate Reader for Transportation Planning

In this section, the technical specifications for an automated license plate reader for transportation planning are developed. First, the original specifications used to procure the reader used for this study will be presented. Next, an improved set of specifications that are based on this research are developed. These specifications are recommended for use by public sector planning agencies and private sector companies to develop such a system.

10.3.1 Original Technical Specifications

These are the original specifications developed after review of the license plate reading field and visits to some of the vendors.

Part I: Base Configuration and Requirements

- The LPR is an automatic and real-time device with one image processor.
- The LPR shall have two video cameras and lenses. Each camera shall have its own illuminator.
- There shall be environmental enclosures for both lighting devices and camera lenses.
- Each camera shall have an independent vehicle sensor to trigger the camera.
- The LPR shall include a set of complete documentation.
- The LPR shall include all software necessary to perform license plate recognition with the equipment.
- The LPR shall include all accessories, including but not limited to cables, to make the system operational.
- The data formats for the license image and interpreted alphanumeric must be explained, and documented if any format is proprietary.
- The vendor shall deliver the LPR and all accessories within 45 days after written notification that he or she is the successful bidder.
- The vendor shall provide installation and training for the system as per Part Two of these specifications.

Part II: Installation and Training

1. The vendor shall provide on-site (on-site meaning I-79 or I-68 near Morgantown, WV) setup and training of all equipment and accessories necessary to successfully operate the LPR within the four-week period after delivery of the LPR. The set-up will be performed to train West Virginia University personnel, West Virginia DOT personnel, and other personnel as per West Virginia University's request.
2. Training shall include the following:
   a. Overview of the steps performed by personnel operating the equipment.
   b. Written description of the setup, operation, and dismantling processes.
   c. Interactive, hands-on exercise for trainees to setup and operate the equipment.
   d. Supervised trial run to test trainees competence in the set-up, operation, and dismantling of the equipment
3. Installation and Training should last 40 working hours, spread over five working days.
4. The University will pay a maximum of $100 per working hour, plus travel expenses, for additional on-site technical assistance.

Part III: Performance Specifications

1. The LPR shall be able to automatically display the actual license image and interpreted plate number and state, side-by-side on the computer monitor in real-time (real-time meaning within a few seconds).
2. The LPR shall be able to transmit captured license image with the interpreted state and number to the host computer in real-time without separate communication hardware, at or

less than a rate of one second per vehicle for aggregated two-lane traffic flow in the same direction.

3. The actual performance of the equipment will be tested in the following way: The LPR will be stationed on southbound I-79 near the West Virginia / Pennsylvania State Line to simultaneously read traffic in both southbound lanes without interruption to traffic. Equipment will read license plates for a continuous three-hour period encompassing periods of daylight, dusk, and darkness. Same plates will be read manually. Based on a comparison of the equipment read plates with the manually read plates, the equipment shall conform to the following specifications:
   a. 85% average accuracy over the three-hour period, accuracy is defined as reading the entire plate number and correctly identifying the state. The plate shall be read correct in its entirety to be considered correct. If any of the plate is read wrong then the entire plate is deemed to be read incorrectly.
   b. 80% average accuracy over all 15-minute periods, accuracy as defined in 3(a). A 15-minute period may begin at any time and need not be limited to :00, :15, :30, and :45 minutes past the hour.
4. If the test results do not meet the performance specifications set forth in Part Three, there may be one re-test at a different location as determined by West Virginia University. The University will not accept the equipment for payment unless the equipment can demonstrate conformance to the specifications in 3(a) and 3(b) during one test.

Part IV: Warranty and On-Going Assistance

1. The vendor shall provide a one year warranty from the date of purchase and technical support via phone, fax, and mail to the University and State DOT personnel within 24-hour response time at no additional cost for a period of one year.

West Virginia University reserves the right to reject any and all bids.
The date of purchase will not be established until the equipment has successfully demonstrated that it meets the above specifications.

After the research effort, it was apparent that "Part I: Base Configuration and Requirements" was not tied strongly enough to the performance characteristics required by transportation planning. These requirements would need to be rewritten to reflect the license plate reading needs particular to transportation planning.

The concept of training put forth in "Part II: Installation and Training" was an excellent idea. In fact, more training was needed. In retrospect, more in-depth training was needed due to the complexity of the system. An additional week or two of training, possibly at the home office of the vendor, would have been beneficial.

"Part III: Performance Specifications" had two elements: performance specifications and a performance test. The performance specifications more properly belong in Part I with the requirements of the system. The performance test could be retained in its own section.

"Part IV: Warranty and On-Going Assistance" is critical and must be reinforced due to the multitude and complexity of problems that are likely to be encountered in a complex system such as a license plate reader.

10.3.2 Recommended Technical Specifications

In review, Table 10-1 provides the automated license plate reader requirements for three typical transportation planning studies: origin-destination studies, cordon studies, and travel time studies.

Based on the lessons learned during the research effort, the particular needs of transportation planning, and a retrospective investigation of the original technical specifications, the following specifications are recommended. These specifications are also provided in Appendix A.

Table 10-1 - Requirements for the Reader by Study

Attribute	Cordon Study	O-D/ Trip Survey	Travel Time Study
Accuracy Level	Marginal	High	Marginal
Site Dependent Errors Tolerated?	No	Yes	Yes
Confidence Level Of Interpretation Needed?	Yes	Yes	No
Missed Vehicles Important?	Yes	No	No
Need Heavy Vehicles?	Yes	Case Particular	Case Particular
Need Plate Data in Real-Time	No	No	No
Ease of Set up	Yes	Yes	Yes
Transportable	Yes		
Roadside Hazard Minimized	Yes		
Intrusiveness on Traffic Operations Minimized	Yes		

Part I: Base Configuration and Performance Specifications

1. The license plate reader (LPR) shall be an automatic device capable of producing state and alphanumeric interpretations of license plates within 24 hours of their observation. The format of these interpretations must be in an electronic ASCII text format. The LPR shall operate at an acceptable level regardless of ambient lighting or weather conditions.

2. The LPR shall be capable of processing 2300 vehicles per hour per lane of traffic covered.

3. The LPR shall be fully operational without the need for hardwire connectivity across roadways.

4. The LPR shall have provisions for automatic adjustment of camera lenses to either (a) optimize accuracy for that particular reader or (b) replicate the settings at another camera.

5. The LPR shall obtain multiple images per vehicle.

6. The LPR shall have no component greater than 50 pounds.

7. The LPR components shall be capable of being packed into a 60 cubic foot volume.

8. The LPR components should be constructed in a durable manner such that damage will not occur from frequent handling and transporting.

9. The LPR shall be capable of being set up within 5 person-hours by trained technicians.

10. The LPR shall be have the capability of ultimately identifying all the different plate types in the United States. It should be updatable to accommodate new designs; the provisions for adding new plate designs shall be clearly defined. It need not be capable of identifying all different plate types at the time of delivery, however it must ultimately be capable of identifying at least 3000 plate types.

11. For each LPR interpretation, the LPR shall indicate the confidence of the interpretation. The confidence shall be defined as the percentage of time that an interpretation of that confidence will be correct. For example, an interpretation with a confidence of 95 percent should be correct 95 percent of the time.

12. The LPR shall provide a permanent record of all interpretations and captured images.

13. The LPR shall be enclosed in an environmental enclosure capable of protecting the system against adverse weather conditions. The LPR shall be capable of operation during typical rain and snow events.

14. The vendor shall provide a complete set of documentation for the LPR. The documentation shall provide all technical details on the LPR components and detailed instructions for equipment set up and operation.

15. The vendor shall provide an image viewing system for retrieving and manually verifying saved plate images. This system shall display captured images in chronological order at a rate of up to 45 images per minute as determined by the user. The user should be able to directly input whether the interpretation is correct while viewing the image. The system must keep a record of these user inputs.

Part II: Installation and Training

1. The vendor shall provide training and orientation for LPR set up, operation, and troubleshooting at the vendor office for a period of time not to exceed two working weeks.

2. The vendor shall ship the LPR to the customer, travel to the customer office for original set up of the LPR and additional training. The set up and training shall take place over a period of no less than one working week.

3. At the completion of all training, trained technicians shall:
   (a) be familiar with and capable of using the provided documentation
   (b) set up and dismantle the LPR without assistance from the vendor
   (c) diagnose common problems without assistance from the vendor

4. The vendor shall provide onsite assistance, as directed by the agency, for a period of six months after the training completion if the system becomes non-operational. The vendor shall provide this assistance at no additional charge.

Part III: Performance Test

1. The performance of the LPR shall be tested over two 3-hour periods. Period one shall encompass only full daylight conditions. Period two shall encompass periods of dusk and night.

2. A correct interpretation shall be defined as interpreting a plate completely correct. Both the state and all alphanumeric characters must be interpreted correctly.

3. Accuracy will be defined as the number of correct interpretations divided by the number of vehicles.

4. A heavy vehicle is defined as any vehicle with more than four tires in contact with the pavement.

5. For each period, the LPR accuracy for heavy vehicles will be calculated. For each period, the LPR accuracy for all other vehicles will be calculated. The accuracy in each period for each vehicle class must be at least 85 percent. The accuracy for any fifteen minute period must be at least 80 percent.

6. The test site will be chosen by the agency one month prior to the delivery of the LPR.

7. If the LPR fails any portion of the performance test, the agency reserves the right to either reject the LPR or retest it at a site to be chosen by the agency.

Part IV: Warranty and On-going Assistance

1. Upon passing the performance test and providing the six months of free onsite assistance, the vendor shall guarantee the performance of the LPR an additional two years. During this time, any repairs and assistance will be performed free of charge.

CHAPTER 11 - CONCLUSIONS

11.0 Existing Automatic License Plate Reading Equipment

It is the conclusion of this research that the existing real-time automated license plate reader is not suitable for use in transportation planning. This equipment does not meet the specifications recommended in this report based on the needs of transportation planning agencies. Apparently, the reader was designed to a set of specifications that are too different from those needed for transportation planning. The system was designed to be set up once by a team of experts over the course of several days. Consequently, the system was not designed to be mobile, shipped and handled frequently, or setup by persons other than the vendor. The original system was also used where traffic was more confined than is experienced in the typical freeway environment. As a result, several specific problems arose that make the equipment inappropriate for transportation planning.

Primarily, the evaluated system is inappropriate because the quality of the interpretations is not acceptable for use in a wide variety of transportation planning studies. Although the system is acceptable for trip surveys, each interpretation must be manually verified. Manual verification is a time-consuming endeavor without special software designed specifically for the task. The reader could also be used in travel time studies, but the data needs associated with this task are not high and any data collection method, including pen and paper, could be used. Conversely, the system was deemed insufficient for use in cordon matching studies because of systematic errors that bias the study results. Cordon studies are common and any new license plate reader would need to accommodate this application to be of use to transportation planning agencies.

Even if the interpretation abilities of the reader were satisfactory, there are other problems that would render it unacceptable. The system effectiveness would be severely restricted due to the significant downtime, inconsistent set up time, and the need for highly specialized personnel due to the complexity of the system. These problems created frustration for the research team. Other problems include intrusiveness to traffic and the need to locate next to a bridge or overpass to read multiple lanes. Use of the equipment for multi-setup studies, such as cordon studies, would be cost prohibitive. Depending on the frequency at which an agency conducts studies that require only one reader, use of the equipment in these studies might also be cost prohibitive.

As an alternative, there are a few firms that conduct automated license plate reading studies. Since these companies have the equipment and trained personnel to set up numerous license plate reading stations simultaneously, their services are recommended for cordon studies and other studies where multiple stations are required. These companies might also be recommended for studies where a high degree of accuracy is required, such as trip surveys. The recommendation largely depends on the selection of a firm with dedication to quality. These firms tape record a lane of traffic using high resolution video cameras. This method allows them to capture plate images for nearly every vehicle. Consequently, assuring the correct interpretation is simple if they are willing to manually verify and correct the machine readings.

Traditional methods, such as pen and paper or audio tape, are still useful for low-volume or low-speed roadways. However, as traffic continues to grow, fewer facilities will fall into this category.

11.1 Recommendations for Testing New Automated License Plate Readers

Through this research, much was learned about the specifications required of license plate reading equipment for transportation planning applications. Appropriate tests must be conducted on new license plate readers as they are developed to determine if they meet those specifications. The specifications are presented throughout this report and synthesized in Chapter 10. Some basic recommendations for testing a new license plate reader are presented here.

11.1.1 Accuracy test

The accuracy test is the most critical test of license plate reading equipment. The primary task of the license plate reader is to interpret license plates. This test will determine how well it performs that task.

In general, the accuracy test should be conducted on many different classifications of roadway. Traffic conditions on a freeway are very different from those on a local street. The speed of traffic, lane width, shoulder width, and plate mix are significant factors that may influence the accuracy of the equipment. If this is the case, it will lead to equipment dependent errors that will render the equipment useless in cordon studies where different types of facilities are sampled.

In addition, the equipment should be tested several times for each single facility type. The exact number of times will be determined by the consistency of the interpretation accuracy. Several hundred plates should be collected when conducting a test. For the data collected in this study, the accuracy was calculated for the first 300 vehicles and the first 500 vehicles. In both cases, these accuracies were within a few percent of the accuracy that included the entire sample. This indicates that the reader was stable and a significantly smaller sample size could have been used. The project proposal called for two tests of 600 plates for each configuration. Unfortunately, due to problems with the equipment set up, single tests of approximately 1900 vehicles and 2700 vehicles were collected for the singlehead and doublehead configurations respectively. If matching tests are being conducted, the accuracies of the two individual readers can be calculated. Therefore, getting a sample of six or eight accuracy tests should not be a difficult task.

It is also recommended that the test include several different traffic control and component configurations. Traffic will react to each configuration differently, possibly leading to different accuracies. For example, this experiment was intended to test accuracy under two conditions: (1) when the traffic lanes were highly channelized and (2) when the equipment was 8.5-feet from the lane edge and no channelization was used. The experiment did not take place because the channelized setup was considered unsafe. However, the highly channelized setup probably would have resulted in a higher accuracy, since it more closely replicated the environment for which the reader was originally designed.

In addition to calculating the accuracy rate, it must be determined whether the interpretative abilities are dependent on the facility type, traffic control, or component placement. As stated before, these dependencies lead to equipment dependent errors. This eliminates the reader from use in cordon studies when all setups cannot be made identical.

The framework of a complete battery of accuracy tests is given in Table 11-1. Each block corresponds to one test sampling several hundred plates. The variables that influence the accuracy of the system will be those that exhibit different accuracies when the variable is changed.

Table 11-1 - Accuracy Test Framework

Equipment Configuration	Freeway				Local Street			
	Channelized		Unchannelized		Channelized		Unchannelized	
Configuration #1	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
Configuration #2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2

11.1.2 Matching Test

Matching tests are performed to determine the consistency of the license plate reader interpretative abilities across multiple machines. For this test, two readers were set up directly adjacent to one another in series. Each reader had the exact same population of plates to interpret. Both readers were also subject to exactly the same weather conditions, highway geometrics, and traffic conditions. This test methodology is highly recommended because it eliminates factors external to the equipment from causing an imperfect matching rate. The only possible cause of an imperfect matching rate in this test would then be related to the equipment itself. For example, it might be caused by differing lens settings from one reader to the other. These variations will definitely lead to site dependent errors and restrict the usefulness of the equipment in cordon studies.

Matching tests should be performed on different types of facilities and with different levels of channelization. If the machine accuracy is dependent on these variables then the matching rate will also vary some with facility type. Since the accuracy tests and matching tests can be conducted simultaneously, varying these parameters should not require any additional work.

11.1.3 Traffic Intrusion Test

Two characteristics of traffic intrusion were tested: lateral shift and speed. Both traffic characteristics were measured without equipment present and then compared with the results measured under different equipment and traffic control configurations. The methodology for testing traffic intrusion could be improved in two ways. First, the lateral shift needs to be measured automatically using instruments that can indicate the lateral position of the vehicle. In this project, lines were painted at every foot from the lane edge and a technician determined which line the vehicle tracked over. This method can be subjective and susceptible to human error. The second idea for test improvement is to determine machine accuracy while the intrusion tests are being conducted. During this study, the machines were not set up for reading, so a direct relationship between intrusiveness and accuracy could not be established. Considering that the equipment was designed for channelized traffic, the more intrusive system probably would have had a higher accuracy. A test for that hypothesis would have been useful.

In addition to speed and lateral shift, another characteristic of traffic intrusion should be tested: vehicular capacity through the equipment setup. If the equipment is intrusive, the vehicular capacity through the setup will likely be less than that of the unrestricted upstream roadway. It would be beneficial to determine the capacity reduction as the equipment could become a bottleneck on facilities with traffic flows near capacity. If the reader causes congested, stop-and-go traffic, it is less likely to be acceptable to transportation planning agencies. As with any measurement device, the less the reader influences traffic characteristics, the less likely it is to influence the results of the study.

11.1.4 Transportability

The easiest way to determine if the equipment is transportable is to pack the equipment components into a van or pickup truck and transport them to the highway roadside. If this can be accomplished without the use of special equipment, then the only remaining issue will be equipment durability. A more scientific method of checking these items is to weigh and measure each component.

To ensure durability, the purchasing agency may want to specify a service life, such as five years, with a manufacturer's guarantee. The durability could theoretically be tested by simulating the shipping and handling abuse that the equipment will endure over the service life. However, this will likely damage the equipment. Furthermore, the validity of such a test would be questionable. Variables such as technician care in handling the equipment and quality of the road surface and vehicle shock absorbing system are difficult to predict.

11.1.5 Set up Time

The set up time should be measured in trained technician-hours. It should be measured several times to determine if it is consistent. One of the main problems encountered with set up time in the existing reader is not the duration of the typical setup time, but the variation in set up times. It was virtually impossible to plan a day of data collection that would have the equipment set up in the morning because there was such a great risk of the set up time running significantly longer than expected.

11.1.6 Image Processor Vehicular Capacity

The vehicular flow must not exceed the capacity of the image processor, otherwise vehicles will be missed. Two items are of interest with respect to the processing capacity of the license plate reader. First, the largest vehicular volume that can be sustained without overloading the system must be determined. This will correspond to the processing time per vehicle. Second, the volume and flow rate that can be sustained in a small platoon must be determined. The size of the platoon will correspond to the number of storage buffers plus one. The flow rate will correspond to the platoon size divided by the processing time per vehicle. Since these are inherent, non-varying characteristics of the equipment, they need only to be determined once.

11.2 Recommendations for Further Research

The development of automated license plate reading equipment for transportation planning is a viable endeavor. For the most part, the technologies that are needed already exist. Based on the research performed, a number of items have been identified as areas where further research is needed. These areas can be classified into one of two categories: short term research needed to develop the license plate reader and long term research to automate license plate data reduction and application.

11.2.1 Research to Develop the License Plate Reader

Several shortcomings in the existing license plate reader were identified in Chapter 10. At that time, several ideas for solutions to overcome the shortcomings were presented. While some of the ideas were not technical engineering solutions, such as the need for more training, most of the ideas were technical in nature. Most of these technical ideas are not very well developed with respect to their application for license plate reading and will need to be further researched to determine how the technologies might be applied. These ideas are presented in Table 11-2, which lists the shortcomings of the existing reader and the technical ideas that were proposed as solutions.

Table 11-2 - Existing Reader Shortcomings and Solution Ideas

Shortcoming	Solution Idea
Decision tree interpretation algorithm limits the number of recognizable plate types	Neural network interpretation algorithm + use of color cameras
Processing capacity less than vehicular capacity	Use of more advanced computer hardware + off-line interpretation of images
Unable to capture images of truck plates	An improved triggering system that could locate the rear of the trailer
Need for cabling across the roadway in multilane setups	Wireless data transmission
Site dependent, systematic errors in cordon studies	Develop methods of replicating sites, particularly lens settings and component placement / aim
Intrusive to traffic	More powerful light sources will enable the components to be placed further away from traffic
Obstructions, such as trailer hitches	Multiple images taken over time
System downtime	Increased durability to withstand shipping and handling + less complex system

Bringing these ideas to fruition will involve a team having diverse technical expertise areas such as: mechanics and instrumentation, computer science and engineering, optics and photography, electrical engineering, image processing, and artificial intelligence. In addition to conquering the individual technical challenges, some significant effort will be needed to make all the sub-systems operate in consonance to construct automated license plate reading equipment acceptable for transportation planning applications.

In addition, other technologies are developing that can enhance or supplement license plate data. Global Positioning Satellite (G.P.S.) technology can be installed in vehicles to track the location and path of individual vehicles. Advanced image processing algorithms may be developed to locate additional identifying markers besides the license plate, such as the vehicle make or color, or additional writing on the vehicle, such as stickers. These additional data have the potential to improve matching based studies such as cordon studies or travel time studies. Finally, bar codes are receiving attention in motor vehicle registration. Some states have added bar codes to drivers licenses and vehicle registration cards. The next logical step would be to add a bar code to the license plate. This bar code has the potential to provide all the information currently provided by reading the plate without the need for imaging.

To support the development and operation of automated license plate readers, some guidelines for the structure and location of license plates must be developed. Certain color combinations of letters and backgrounds currently in use make license plates unreadable even to the human eye. Modeling the European style of license plates, where plates are standardized and clearly readable, would be ideal, but is not likely to occur in this country. However, requiring a minimum level of readability so that all plates are at least readable to enforcement personnel should be adequate for automated license plate reading.

Finally, license plate readers may need to develop beyond the four basic components of cameras, light sources, triggering mechanisms, and image processors, to include new technologies that can improve image capturing and processing. Cameras that move to track the vehicle along its path can provide higher quality images and more numerous images for each plate. A vehicle detector that can classify the vehicle and measure some of its basic traffic characteristics, such as speed or lateral position, at some upstream position may provide the equipment with the opportunity to optimize its configuration for each vehicle.

11.2.2 Research to Automate License Plate Data Reduction and Application

License plate data collection is only one task in transportation planning studies. Generally, the reduction and analysis of the license plate data is the most costly and time-consuming portion of the study. Once the acceptable license plate reader is developed, expertise in database management will be needed to develop methods of effectively dealing with the massive amount of data that will be generated. In cases such as the trip survey, the planning agency will also impose very strict time restrictions on the data application. There are a multitude of database management type applications to address questions that arise from management of the license plate reader output. A few of these questions are posed below:

- How can the license plate data be combined with the outputs of other data collectors, such as traffic counters, lateral position indicators and speed measuring devices? These individual collectors could be combined to create a data collection station encompassing more comprehensive traffic characteristics for each vehicle.
- How can the license plate data be used to automatically retrieve address and phone number data? This will involve developing a system that automatically accesses a highly restricted, remote database. For some states, this will be very large database.
- What is the best method of performing real-time matching of license plate data collected at multiple stations?
- How can license plate data be incorporated into databases that states or metropolitan planning organizations maintain to support infrastructure management systems?
- What is the best storage mechanism for the massive number of interpreted images that will be produced?

- What kind of image viewing system could be developed to accelerate the rate at which the interpretations are manually reviewed and corrected?

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