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## **Demonstration of a Mobile Application of CVO Weight Enforcement Screening**

TTI/ITS RCE-99/03

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**DEMONSTRATION OF A MOBILE APPLICATION OF  
CVO WEIGHT ENFORCEMENT SCREENING**

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Research Report 99/03  
Research Project TM-04: CVO Weight Enforcement Screening

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16. Abstract This research explored the innovative use of Intelligent Transportation System technologies to enhance the capabilities of police vehicles and enforcement personnel in identifying and apprehending commercial vehicles that violate size and weight or other laws. The research complemented ongoing research involving other applications of smart police vehicles to improve a wide variety of enforcement activities. This research developed a prototype system using weigh-in-motion (WIM) equipment and video capture techniques to monitor commercial vehicle weights at a site in College Station, Texas. It demonstrated that weight enforcement screening can be done in a mobile environment as opposed to the typical fixed site application. The concept allows a roving or stationary license and weight enforcement trooper to monitor WIM equipment remotely by wireless transmission of WIM output along with information to identify the vehicle downstream. This demonstration project utilized video image capture for the subsequent identification and Cellular Digital Packet Data modems for image transfer.					
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## SUMMARY

Resources to effectively enforce truck size and weight regulations are extremely limited, so new methods are needed to stretch these resources. One means of stretching resources is the use of technology to assist enforcement personnel in identifying trucks that may be operating illegally. This research study developed a prototype system involving weigh-in-motion (WIM) and video image capture to assist an enforcement officer in identifying overweight vehicles. The system can perform this function while the officer performs other duties or is on roving patrol in the vicinity of the WIM system and within range of the communication system used to transmit truck data. This new system sends WIM data and an image of the suspect vehicle to a properly equipped “smart police” vehicle. Traditional weight enforcement methods used in Texas typically rely on an officer’s judgement based upon a passing visual inspection to determine if a vehicle may be overweight. The current verification process is slow, requiring trucks to stop and be weighed one at a time on portable or semi-portable scales. Most trucks weighed statically today are legally loaded, so a system is needed to screen trucks in the traffic stream and identify those that have a high likelihood of being overweight. Then, only the ones that appear to be overweight would need to be weighed statically.

The research considered two other vehicle identification options, transponders and license plate recognition (LPR) systems, but equipment availability was a problem. The video capture system transmitted a color image of the suspect vehicle and axle weight information to a stationary or roving patrol vehicle using cellular digital packet data (CDPD) transmission. The time delay between a suspect vehicle passing the sensors and image delivery into a patrol vehicle is approximately 35 seconds. This delay equates to the enforcement vehicle being located one to two miles downstream. The use of video frame grab with the WIM system extends the usefulness of a WIM system beyond its typical use at ports-of-entry. It is conceivable that a system of multiple and widespread WIM systems, the necessary communications network, and a fleet of properly equipped patrol cars could be quite effective in deterring overweight violators. Close scrutiny of the image data would likely reveal repeat violators and determine times when overweight vehicles are more prevalent.

To accomplish project objectives, two complete hardware/software products were built that operate in unison—a field component to gather and forward data and a client-side application which receives and displays the information for the end user. The field data gathering equipment must provide the following services:

- The unit must interact with a weigh-in-motion sensor to extract the weight, length, and speed data from passing trucks.
- The data must be processed to determine if the vehicle is in violation.
- An image capture system must be controlled to precisely snap a picture of the passing vehicle if in violation.
- The WIM data and vehicle picture must be transferred to a remote client.
- The field system must support image snap time adjustment and violation criteria input from a remote user.

The client system must provide the following functionality:

- The client must receive and store the WIM data and vehicle picture.
- It must present the information via a graphical user interface.
- The system must alert the user that new information has arrived.
- It must provide the ability to update violation criteria in the field system.
- The client hardware must be capable of residing in an enforcement vehicle.

The system hardware architecture consists of a medium-speed central computer interfaced to a WIM system and an image capture system, and providing a connection to a data network. The field system's primary processor is an Intel Pentium-based single board computer (SBC) running the Microsoft Windows95 operating system. The SBC receives a serial data stream from the WIM, hosts the video imaging system hardware/software, controls the dialup modem, and provides the platform for the overall system control software application. Windows95, while not the most respected real time operating system for field applications, is attractive due to the wealth of low cost hardware and software tools available to accomplish this demonstration project.

An image capture system is the second field component; it is comprised of a video camera unit, a camera frame grabber, and image rendering software/hardware. The video camera must be ruggedized and able to withstand the outdoor environment. The camera chosen for this research was a Phillips Communication Security Systems, Inc. (formerly Burle) camera model TC 391 with a 2.8 mm wide-angle lens. Image capture hardware inputs the video signal and delivers a digital representation. It is of paramount importance that the equipment capture a useable image of a vehicle traveling at the prevailing highway speed of 70 mph. Many products are sold to grab frames from a video stream, but using low-cost hardware to stop high-speed movement usually produces marginal or undesirable results.

The client side architecture is comprised of a computer running Windows95, a custom software application, a touchscreen display, and a network link to the Internet. The networking function can be provided by a LAN or telephone modem for an office environment or a radio modem for mobile clients. Windows95 networking is invisible to the application software; therefore, several different connection methods and associated speeds are available with no change to the application software. Specifically for this project, the client system must support installation in a motor vehicle. Since user interaction with the computer will be through the LCD touchscreen display, the computer can mount outside the cockpit area of the vehicle, thus freeing up valuable space. All user input and program control must be introduced via the touch screen and channeled to the computer, so the display must be easily readable in sunlight. This requirement is the driving force behind the external LCD touchscreen display specification.

On two different occasions during the summer of 1998, researchers tested the WIM and image transfer system with a mobile client. It was determined that the minimum distance downstream for the enforcement vehicle to receive and process information, then be able to apprehend a truck, was 0.6 to 0.7 miles at highway speeds.

At this distance, most WIM records and pictures were delivered to the mobile client with sufficient time available to review the image and begin searching the roadway for the indicated truck. The maximum distance that images and data can be transmitted using CDPD vary significantly when multiple packets are relayed. Sometimes, the user had to intervene in an image download and stop the transfer due to excessive delays between packets or even completely stop data transfer. Also, on occasion the CDPD modem would not stay registered with the service provider, requiring user intervention to reestablish a connection with the provider. The client software was also tested on a computer connected directly into the Internet. Performance was very good, with the only limitation being the upload speed of the dialup modem in the field.

Image capture quality of the onboard system was within an acceptable range for stationary or slowly moving objects but became progressively worse as the movement of the subject increased. A better system was needed, but cost was an obstacle in moving to a faster image capture board in the computer. Also, an image can only be acquired approximately every 3 seconds, allowing only a single frame grab per vehicle passage. This feature alone was not deemed to be a fatal limitation since the slow data transfer nature of the CDPD modem would not support multiple image transfer to the enforcement personnel.

The CDPD radio system is the limiting item in the entire system design. The radio only provides a data transfer rate of approximately 800 bytes per second on a good connection. In addition to the problem of throughput, there is an issue of registration stability. The CDPD system requires users to register on the network in a fashion similar to a user logging onto a networked computer. The CDPD system can bump users off the network, requiring them to register again. The registration process can be slow and has difficulty giving understandable feedback to the modem user. CDPD coverage is also an issue, as it is currently provided only in metropolitan areas or very high capacity corridors.

Problems with the weigh-in-motion system for this application include missed vehicles and the need for predictable processing time (to predict image capture position). It was expected that the WIM would take a very small but consistent amount of time to process raw data and output an ASCII stream, but WIM processing time varied significantly.

It should be noted that none of the negative issues are expected to be long-term problems. The image capture software problems can be corrected either in the anticipated upgrades to the product tested or with other more costly products already on the market. Also, radio modems will be undergoing change quickly. Part of the problem with the CDPD system is that it is an add-on component of an older analog cellular phone system. Tomorrow's cellular phone service will be an all digital design delivering data at rates in the range of 10 times the speed of the CDPD system. Radio modem speed is expected to approach LAN performance. These systems are slated for deployment early in the next century. Service coverage will soon increase with the entrance of Motorola's Iridium satellite-based mobile communication system.



## INTRODUCTION

The highway network in the state of Texas represents an enormous investment, and one upon which the motor carrier industry depends for delivery of goods. Nearly two-thirds of the communities in Texas depend on trucks entirely to transport goods to principal markets (1). Therefore, the economic well being of the state and the trucking community depends upon continued maintenance and preservation of the state's highway infrastructure. The economic consequences of overweight trucking cost the state between \$6 million and \$48 million each year (2). There is also a cost associated with safety enforcement.

## BACKGROUND

Reasons for heightened concern regarding heavy trucks include increases in truck numbers both at state and international border crossings and elsewhere, and the lack of resources for adequate coverage for highways in Texas. Based on the Truck Inventory and Use Survey (3) (TIUS) of 1992, there were a total of 4.1 million commercial trucks nationwide, which reflected a 4 percent increase over the previous (1987) count. For the largest trucks, those with five or more axles, there was a much larger increase from 1987 to 1992. According to this survey, there were 976,000 five-or-more-axle trucks in 1992, which is a 22 percent increase over 1987. Although it will probably result in a conservative estimate, assuming a similar growth rate in the ensuing five year period results in approximately 1.2 million large trucks today with five or more axles. Texas also experienced substantial growth in truck traffic, including traffic at international border crossings.

Because of its strategic geographic location, Texas has a substantial economic interest in the increased trade that is expected from the North American Free Trade Agreement (NAFTA). However, Texas could also sustain a disproportionate share of the highway infrastructure damage and reductions in highway safety and capacity as NAFTA accelerates growth in commercial motor carrier activity. In a recent study published in 1995, transborder freight traffic growth was especially pronounced at Texas border crossing points. The study found that, in 1994, northbound truck traffic grew over 11 percent, with Laredo, El Paso, and Brownsville serving between 60 and 85 percent of the traffic demand. Seventy-three percent of the dollar-value of freight, amounting to over \$60 billion, crossing the U.S.-Mexico border did so along the Texas border. Of that total, 88 percent of the freight crossed the border by truck. Almost half of the 2.55 million truck shipments moving through Texas in 1994 had origins and destinations in other U.S. states. Over 89 percent of the U.S.-Mexico trade value by rail passed through Texas (4).

The Department of Public Safety (DPS) is responsible for the enforcement of weight, dimension, and safety regulations of motor carriers in Texas. A total of 321 troopers patrol and enforce the truck size and weight (TS&W) and safety regulations on the 204,660 miles of rural highways in Texas. This means that, on average, there is one trooper for every 638 miles of rural road in the state. Furthermore, there is one trooper for every 45 million vehicle-miles traveled (VMT) by truck in the state (14.5 billion vehicle-miles by truck in 1994 and 321 troopers). Comparatively, using 1994 VMT figures for California and New Mexico, there is one trooper for every 21 and 12 million vehicle-miles traveled by truck, respectively (815 officers in California

and 154 officers in New Mexico) (5,6,7). These rate calculations imply that troopers in Texas are responsible for more than twice as many vehicle-miles traveled by truck as troopers in California and almost four times as many truck vehicle-miles as troopers in New Mexico. This relatively low ratio of enforcement personnel to numbers of trucks is one reason DPS utilizes roving patrols as their dominant method of enforcing TS&W and safety regulations.

The increased truck traffic noted above creates the need to enhance enforcement capabilities. Unfortunately, enforcement agencies seldom receive increases in resources to match increased need. One solution is the use of technology to improve the efficiency of enforcement personnel. The sections that follow describe first the concept then the details of equipment needed to monitor trucks unobtrusively.

## **ESSENTIAL EQUIPMENT**

In this research, the Texas Transportation Institute (TTI) evaluated technological methods to improve commercial vehicle enforcement efficiency. Critical elements of the enforcement scenario for commercial vehicles include a “smart police vehicle,” a weigh-in-motion (WIM) system, and a means of capturing and sending vehicle identification to the police vehicle. The smart police vehicle has enhanced capabilities utilizing state-of-the-art technologies. To simplify this demonstration, researchers used a standard vehicle enhanced only by selected elements of the full police vehicle package. In this enforcement scheme, the patrol officer can be roving or stationary, but would typically not be in visual contact with the data collection site as trucks pass. The data sent to the car will, at a minimum, include vehicle axle weights, gross weights, axle spacings, and vehicle classification. The system includes user-definable thresholds to send data only when specified conditions are met. There must also be a means of identifying the truck for purposes of apprehension. Upon receiving information about a truck, the DPS trooper makes a decision on pursuing it. If the trooper cannot pursue an apparently illegal truck, he/she can have dispatch relay the need to other officers.

### **Smart Police Vehicle**

TTI has developed a family of “smart police vehicles” in cooperation with local, state, federal, and industry partners. In general, the smart police car includes a set of high-technology components that are implemented in or near the vehicle and at the police dispatcher location. These technologies provide enforcement agencies and their officers with capabilities not previously realizable; they enhance officer safety, improve data collection and dissemination, and optimize incident response and management. The key components of the vehicle system include an on-board computer with a touch screen display, an on-board global positioning system, an in-car video system, and data communication links. Supplemental systems used by the officer outside the car include a hand-held data collection unit and a hand-held digital camera. A wireless local area network facilitates a data link between each of these devices and the smart police vehicle, thus allowing the officer great freedom of movement while maintaining electronic access to his vehicle. The police car, in conjunction with the WIM system, may be thought of as a mainline screening system. The WIM system provides an officer an initial indication of some parameters of the vehicle, particularly weight, allowing a more informed decision regarding the need for apprehension and static weighing.

## **Weigh-in-Motion (WIM)**

Both data collection and enforcement screening applications today utilize WIM systems to approximate the gross weight of a vehicle or the portion of the vehicle weight carried by a wheel, an axle, or a group of axles. The WIM system measures, during a short time interval, the dynamic load that is applied to a desirably smooth, level road surface by the tires of a moving vehicle. WIM systems have demonstrated several advantages over static enforcement weighing. Trucks incur no delay as they pass over WIM weight transducers. In contrast to static scale operations, there are typically no safety problems created by WIM operations; WIM systems can be operated continuously, and they do not result in trucks bypassing the monitoring site as with static operations. Some WIM systems are portable and can be easily moved from site to site if WIM transducers are available.

Oregon has been using WIM since 1984 to screen heavy vehicles at ports-of-entry (8). Sorting of vehicles based on WIM output decreases the volume of trucks required to pass over the static scales, resulting in reduced delays to motor carriers and improved safety by reducing queues in the proximity of high-speed main lanes. WIM systems have been implemented in other states for both enforcement sorting and for data collection. When strategically placed for data collection, WIM systems also potentially offer enforcement opportunities. Data collection efforts must conform to guidelines as documented by the FHWA in its *Traffic Monitoring Guide*. Additional assistance is available in the American Association of State Highway and Transportation Official's *AASHTO Guidelines for Traffic Data Programs* (9, 10).

WIM equipment can be portable or permanent. For this project, TTI used a portable WIM system by International Road Dynamics utilizing piezoelectric sensors with inductive loops providing "presence." In general, multiple-sensor WIM stations are more accurate than single-sensor setups in the estimation of static axle-loads (11). For purposes of both enforcement sorting and weight data collection, WIM equipment collects large amounts of pertinent data unobtrusively. Because WIM accuracy is inadequate for direct enforcement of axle and gross vehicle weights, suspect vehicles must be weighed statically.

## **Vehicle Recognition System**

Traditional size and weight enforcement practice in Texas utilizes either of two methods for identifying possible violators. These methods are: 1) a roving trooper visually searches for trucks that appear to be overweight or otherwise illegal and stops them one at a time, or 2) a small contingent of troopers open a roadside weigh/inspection station for a period of several hours where all trucks are required to stop. In either case, a trooper stops trucks and requires operators to drive onto a static scale. This process is slow, accommodating only one truck at a time. Due to the widespread use of CB radios, drivers of overweight trucks quickly divert to a bypass route or otherwise avoid the enforcement site. Weight statistics generated at static sites reveal that almost all trucks are legally loaded, so enforcement resources might be better spent on other, less conspicuous methods of enforcement. Then, only the trucks that appear to be overweight would need to be weighed statically.

For identification methods used this research, TTI evaluated transponders, a license plate recognition (LPR) system, and a video image capture system. Equipment availability was a problem for transponder and LPR testing, so the research team chose a video capture system that transmitted a color image of the suspect vehicle and weight information to a patrol vehicle. Upon receiving a transmission of information, the officer decides whether to apprehend the truck to weigh it statically. Again, the static weighing is required to achieve the accuracy needed to issue a citation.

The use of a video frame grabber with the WIM system extends the usefulness of a standard WIM beyond its typical use at ports-of-entry. It is conceivable that a system of multiple and widespread WIM systems (already available in many states for data collection), the necessary communications network, and a fleet of properly equipped patrol cars could be quite effective in deterring overweight violators. Truck images, either recorded locally and/or transmitted to a remote client (officer) could be used to better understand the types of trucks as well as their loading characteristics. Stored weight data would indicate patterns in truck volume as well as abuse. Close scrutiny of the image data would likely reveal repeat violators and determine times when overweight vehicles are more prevalent. This combination WIM and imaging system, hereafter called the WIMAGE system, can become an integrated highway tool in a rural or urban ITS program providing advance information to ports-of-entry and a surveillance/data gathering point on heavy use roadways. The sections that follow provide more details on the WIMAGE system and its components.

## **WIMAGE SYSTEM**

To accomplish the stated goals, two complete hardware/software products were built that operate in unison—a field component to gather and forward data and a client-side application which receives and displays the information for the end user. The field data gathering equipment must provide the following services:

- interact with a weigh-in-motion sensor to extract the weight, length, and speed data from passing vehicles;
- process data to determine if the vehicle is in violation;
- control an image capture system to precisely snap a picture of the selected truck;
- transfer WIM data and vehicle picture to a remote client; and
- support image snap time adjustment and violation criteria input from a remote user.

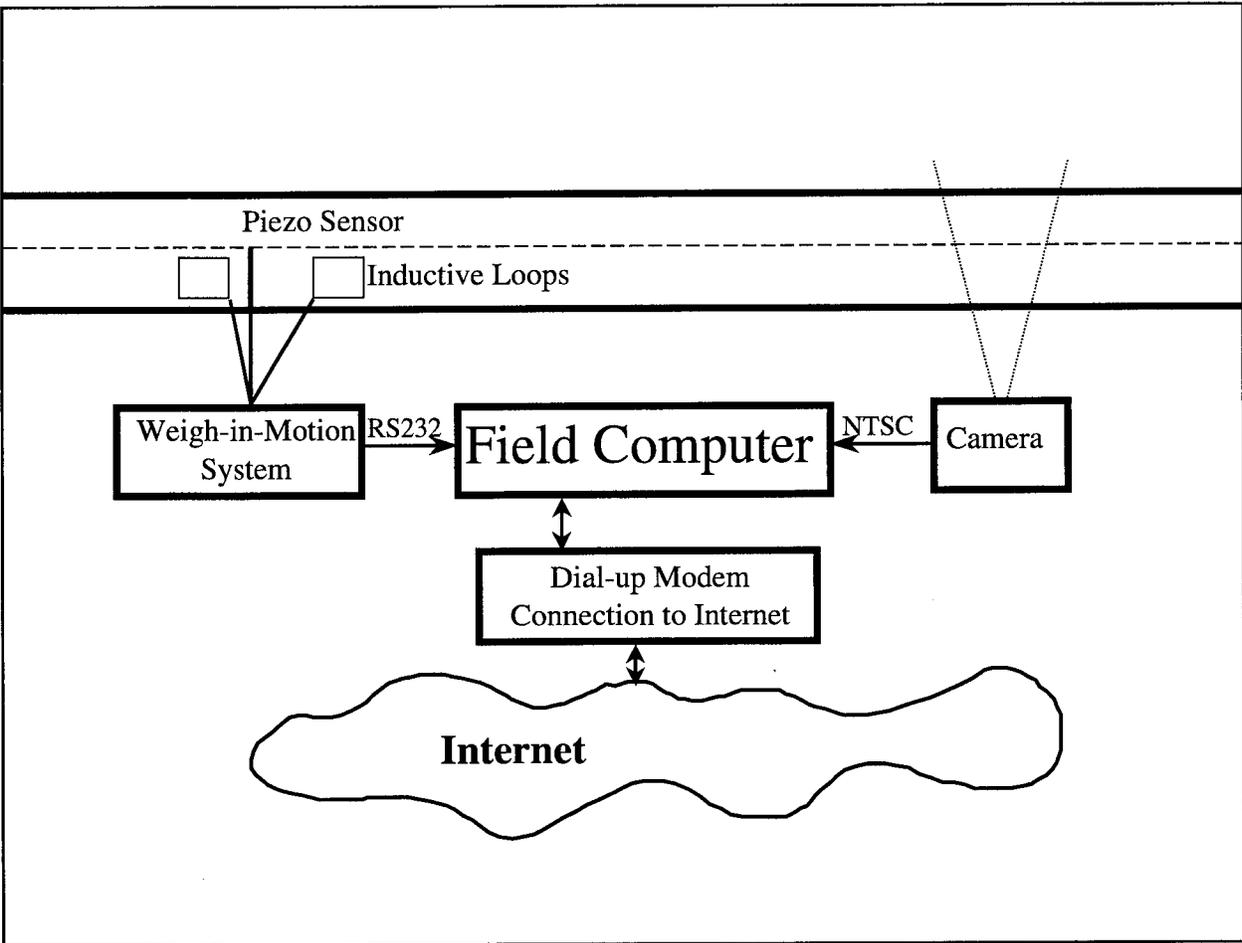
The client system provides the following functionality:

- receive and store WIM data and vehicle picture;
- present the information via a graphical user interface,
- alert the user to the arrival of new information,
- provide the ability to update violation criteria in the field system, and
- reside in an enforcement vehicle.

The above statements provide a broad description of the functional requirements of the WIMAGE system. Each element will be discussed in greater detail.

## **FIELD SYSTEM**

Figure 1 shows the WIMAGE field system hardware architecture. The system provides a connection to a data network and consists of a medium-speed central computer interfaced to a WIM system and an image capture system. The field system's microprocessor is an Intel Pentium-based single board computer (SBC) running the Microsoft Windows95 operating system. The SBC receives a serial data stream from the WIM system, hosts the video imaging system hardware/software, controls data network access, and provides the platform for the overall system control software application. The main requirements of the SBC are to provide enough processing power to adequately run the imaging software and provide a stable, reliable platform. Windows95, while not the most respected real time operating system for field applications, is attractive due to the wealth of low cost hardware and software tools available to accomplish this demonstration project. As with all research, it is important to have easy access to material resources and staff who are familiar with the available tools. Windows95 offers both.



**Figure 1. Field System Hardware Architecture.**

### **Weigh-in-Motion (WIM)**

The WIM system provides the axle weight and axle spacing information to determine vehicle compliance with user inputs that generate alarms. In addition, if there are no external means to signal to the WIMAGE system the position of a vehicle on the roadway (e.g., inductive loop near the camera or radar presence sensor), the WIM system must provide an accurate speed measurement. To make the output data useful, the WIM system must be able to process all its input signals, make its calculations, and send the processed data in near real time. The delay between raw data into the WIM system and processed data out must be somewhat constant or at a minimum predictable. Inordinate variation in this data delay time (or data processing time) will make capturing the vehicle at the proper location difficult or impossible. The vehicle speed information and WIM processing delay are critical variables in a time delay algorithm to trigger the image grab and therefore must be well understood. Without another sensor to give a positive indication of vehicle presence, the WIM speed method is the only option.

A serial data connection is the conduit for all communication between the WIM and the central control program. All data output from WIM must follow a well-known protocol, both at

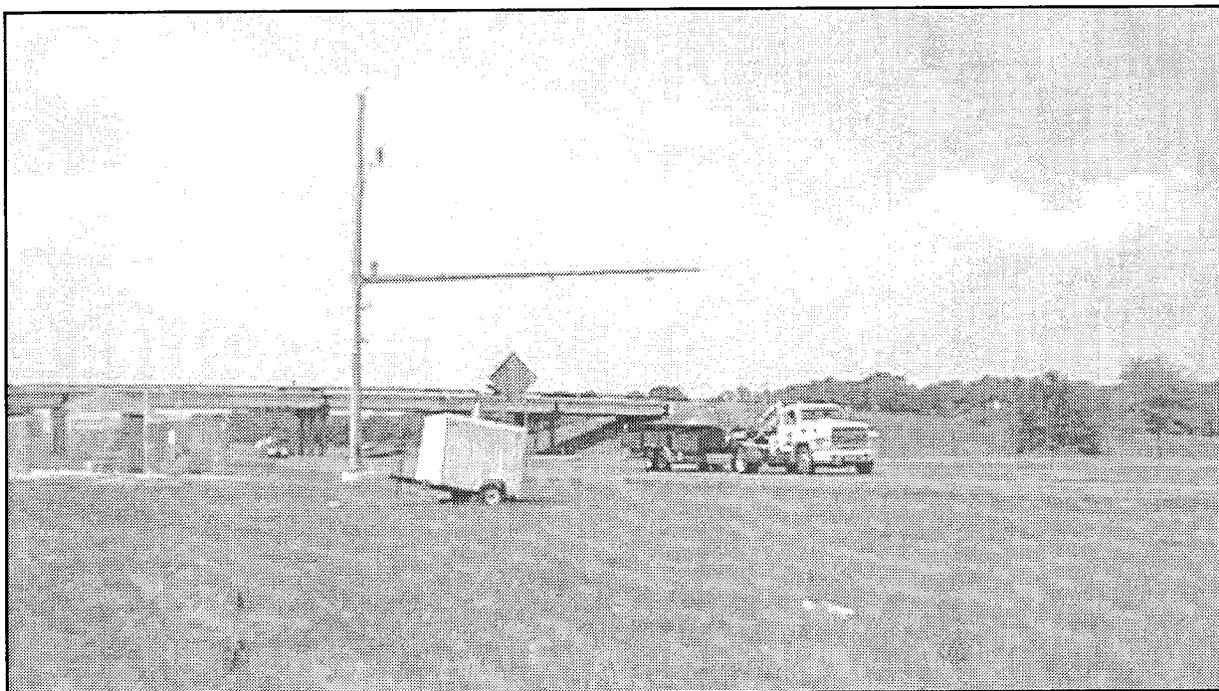
the physical level and at the data link level. Common systems provide an asynchronous RS232 physical interface and an ASCII-based data link level. Documentation must be available to fully describe the output protocol to allow a solid, dependable connection to the central control program to be coded. Finally, the WIM component should be a totally stand alone system. The WIMAGE interface will only expect to log into the WIM system via a simple script and begin receiving a well-known format data stream. All WIM setup and adjustment will be done external to the WIMAGE system. The WIM chosen for this role is the International Road Dynamics Model 1070.

## **Image Capture System**

An image capture system is the second field component in the WIMAGE system. The component is comprised of a video camera unit, a camera frame grabber, and image rendering software/hardware. The video camera must be ruggedized and able to withstand the outdoor environment; a traditional surveillance camera is probably adequate. The camera's field of view must include the entire truck or at least the front 75 percent from a range of approximately 50 feet. The expected typical mounting location is on a roadside utility pole at a height of approximately 20 feet. This stipulation will drive the focal length of the lens. As the focal length of the lens increases, the area captured per grab is smaller, also increasing the amount of detail captured. A longer focal length is preferable if the image capture system can accurately predict the vehicle's location or if the camera can track the moving vehicle. If the camera is able to track the target, then the system can also use lower shutter speed imaging equipment. The camera should have an automatic background balance to compensate for bright skies that may occur at certain times in the morning and afternoon. Very bright background light forces the camera iris to close, resulting in a very dim foreground picture that is ineffective for identification purposes. Cameras can adjust for this brightness, and improvements can be made with image processing software, but direct sunrays into the camera will likely render the images useless. Camera position must be selected carefully to achieve the best overall images during an average day. East- or west-facing camera installations are not advised.

The camera chosen for this research was a Phillips Communication Security Systems, Inc. (formerly Burle) camera model TC 391 with a 2.8 mm wide-angle lens. The video camera was installed at the Highway 6 test site on a small trailer outfitted with a pneumatic extension pole and platform, as shown in Figure 2. The camera was positioned at a height of approximately 7 feet above ground and 40 feet from the roadway, and aimed perpendicular to the roadway.

Image capture hardware inputs the video signal and delivers a digital representation. It is of paramount importance that the equipment captures a useable image of a vehicle traveling at the prevailing highway speed of 70 mph. Many products are sold to grab frames from a video stream, but using low-cost hardware to stop high-speed movement usually produces marginal or undesirable results. Due to fairly rapid changes in hardware, future investigations should evaluate low cost systems in order to identify current options.



**Figure 2. Video Camera Mounting and Placement.**

### **Frame Grabbers**

Low-cost frame grabbers are available in two different types with distinct characteristics. The first and possibly most common system is made to fit in traditional consumer-grade desktop computers as a card installed in one of the PCI slots. These systems are designed for image grabs from video camcorders and NTSC video feeds. The products are manufactured for the low-end video conferencing market and home consumer use but some upper-end industrial systems provide a software development kit. As a rule, products in this category can capture at a rate of 15 frames per second or higher, but the quality of single frames of rapidly moving targets is poor. The full image is comprised of two true captures of the scene that are interlaced in final image production. As the speed of the target increases, the interlacing becomes increasingly unmatched, resulting in a blurred, smeared image. The value of these grabbers is simply the ability to quickly grab multiple frames from a video feed.

Another frame grabber technology was made popular by Play, Inc. The company markets a product called "Snappy," which connects to a computer's printer port. As with the previous group of devices, this machine accepts camcorder and NTSC video inputs. The product is used to extract image frames from video recorders or live feeds and converts the frames to a standardized image format. The capture quality of slow moving targets is at least equivalent or better than the PCI card-based systems. A large difference is noticed in the capture quality of rapidly moving targets. The technology that Play employs samples a scene only once to derive a complete frame. The technique eliminates interlacing problems for high-speed targets. Unfortunately, the technology does not allow for multiple rapid-fire image captures, so it

effectively limits itself to a single image in the current application. Play, Inc. has indicated that a software development package upgrade (for use in building custom applications with the Snappy hardware) is underway and scheduled for future release.

## **Communications**

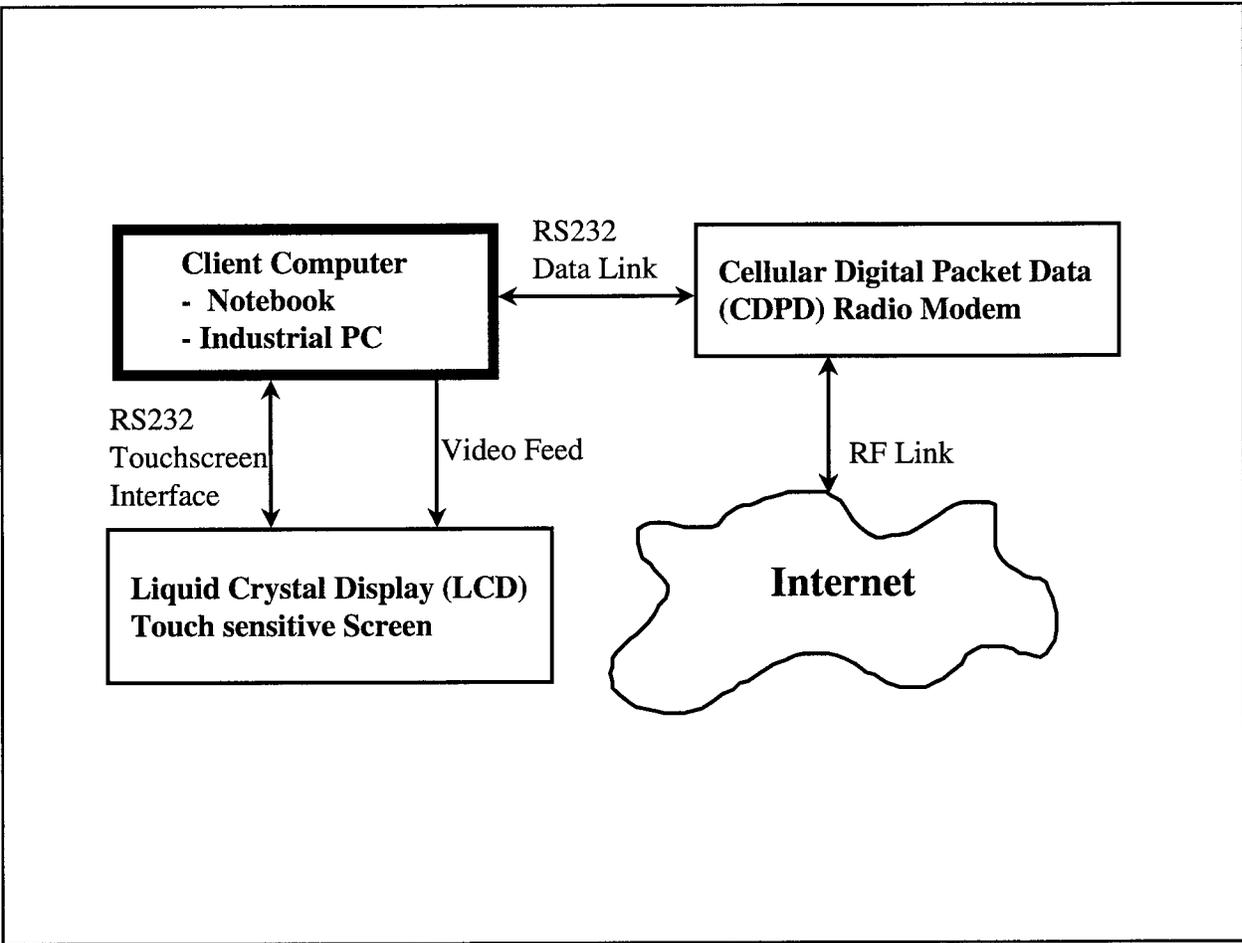
Networking is provided by a standard public switched telephone network (PSTN) dialup modem that is linked via a local Internet service provider to the Internet. This provider could be a public or private sector operation, depending on the level of service desired or potential security issues. The dialup Internet connection is envisioned to be active continuously, yielding a medium speed connection (28.8 kbps to 33.6 kbps). The network connection to the Internet allows for easy remote access to the WIMAGE system via a variety of means. Options include access via LAN (local area network), PSTN network, and the emerging wireless IP (Internet protocol) networking systems. Other networking options for the WIMAGE system in the field are available depending on the level of infrastructure in the area. This could be by connection to a local area network, ISDN digital service, private remote access services, or private wireless systems.

## **CLIENT SYSTEM**

The client side architecture of the WIMAGE system, shown in Figure 3, is comprised of a computer running Windows95 and a custom software application, a touchscreen display, and a network link to the Internet.

The networking function can be provided by a LAN or telephone modem for an office environment or a radio modem for mobile clients. Windows95 networking is invisible to the application software; therefore, several different connection methods and associated speeds are available with no change to the application software. Specifically for this project, the client system must support installation in a motor vehicle. A typical platform would be a good quality notebook computer or a small industrial computer with at least two serial ports available to accommodate the touchscreen and the network link. For the notebook computer option, the extra serial ports will likely be provided by an insertable PCMCIA card that yields several extra serial ports. Since user interaction with the computer will be through the LCD touchscreen display, the computer can mount outside the cockpit area of the vehicle, thus freeing up valuable space in the passenger compartment. All user input and program control must be introduced via the touch screen and channeled back to the computer. A significant consideration in selecting the display is that it must be easily readable in sunlight. This requirement is the driving force behind the external LCD touchscreen display specification. The notebook computer's LCD display can be used as an alternative but will be very difficult to use under outdoor conditions.

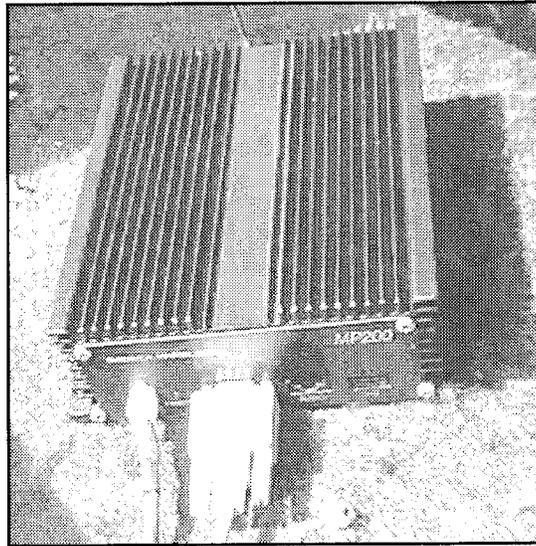
The vehicle, being a mobile object, requires a radio modem for the link into the Internet. A Cellular Digital Packet Data (CDPD) modem offers a TCP/IP connection into the Internet through the local cellular phone system. The CDPD system utilizes inactive cellular phone channels to provide customers a continuous link into the Internet as opposed to a connection-based link such as a traditional dialup modem. Although the modem is connected at all times,



**Figure 3. Client System Hardware Architecture.**

the user is only billed for data transfer. The CDPD modem is commonly used by networked point of sale terminals and other machines that need instantaneous, secure access to a network but are mobile in nature. The CDPD modem option is very attractive for the mobile networking function of the project. Its ability to emulate a standard dialup modem enables seamless integration into Windows95 networking. Figure 4 shows the CDPD modem used in this research; it is the Sierra Wireless model MP210.

Although the modem offers a LAN-like link into the network, the data transmission speeds and throughput are very limited. The transmission speed of the CDPD modem is stated to be 19200 bits per second, which is comparable to an older technology telephone modem. Actual data throughput over a link is much less. CDPD communications tend to move in bursts with a significant dead period between data blocks. Throughput over an average data link in College Station, Texas, is between 500 and 900 bytes per second. At this rate, a file of 15000 bytes will



**Figure 4. Sierra Wireless CDPD Modem.**

require between 15 and 30 seconds to transfer. It is obvious that the choice of current technology radio TCP/IP modems will limit the amount of data that can realistically be sent from a field site to a mobile client. The data is time significant and must arrive within approximately one minute to a mobile police vehicle to be useful for a downstream inspection point.

## **SYSTEM SOFTWARE**

Both the field and remote client components require custom software. The development package chosen must have capabilities for communicating with the WIM (communication port control), building client-server TCP/IP-based applications, designing user interfaces, and integrating custom controls from other vendors. The term TCP/IP represents a suite or collection of protocols used for data communication on the Internet. Microsoft offers several software development platforms based on their ActiveX technology. ActiveX is a software design concept that allows small, full-function applications that do specific jobs to be inserted and used within a large software build. Many hardware vendors are offering ActiveX controls for their products. Visual Basic is one of the Microsoft family of development suites and is a good environment to quickly produce attractive user applications. Unfortunately, the ease of building complicated software has its consequences. Visual Basic tends to deliver end product software that is larger in size, and slower and more wasteful of system resources than other development systems. These issues are always to be considered when embarking on a software project, especially projects that have tasks that are extremely time-sensitive. Bulky code requires a faster processor and more memory resources (RAM and mass storage) to give comparable performance to efficient code. For this demonstration project, the ability to quickly arrive at a working prototype took precedence over code efficiency and resource conservation.

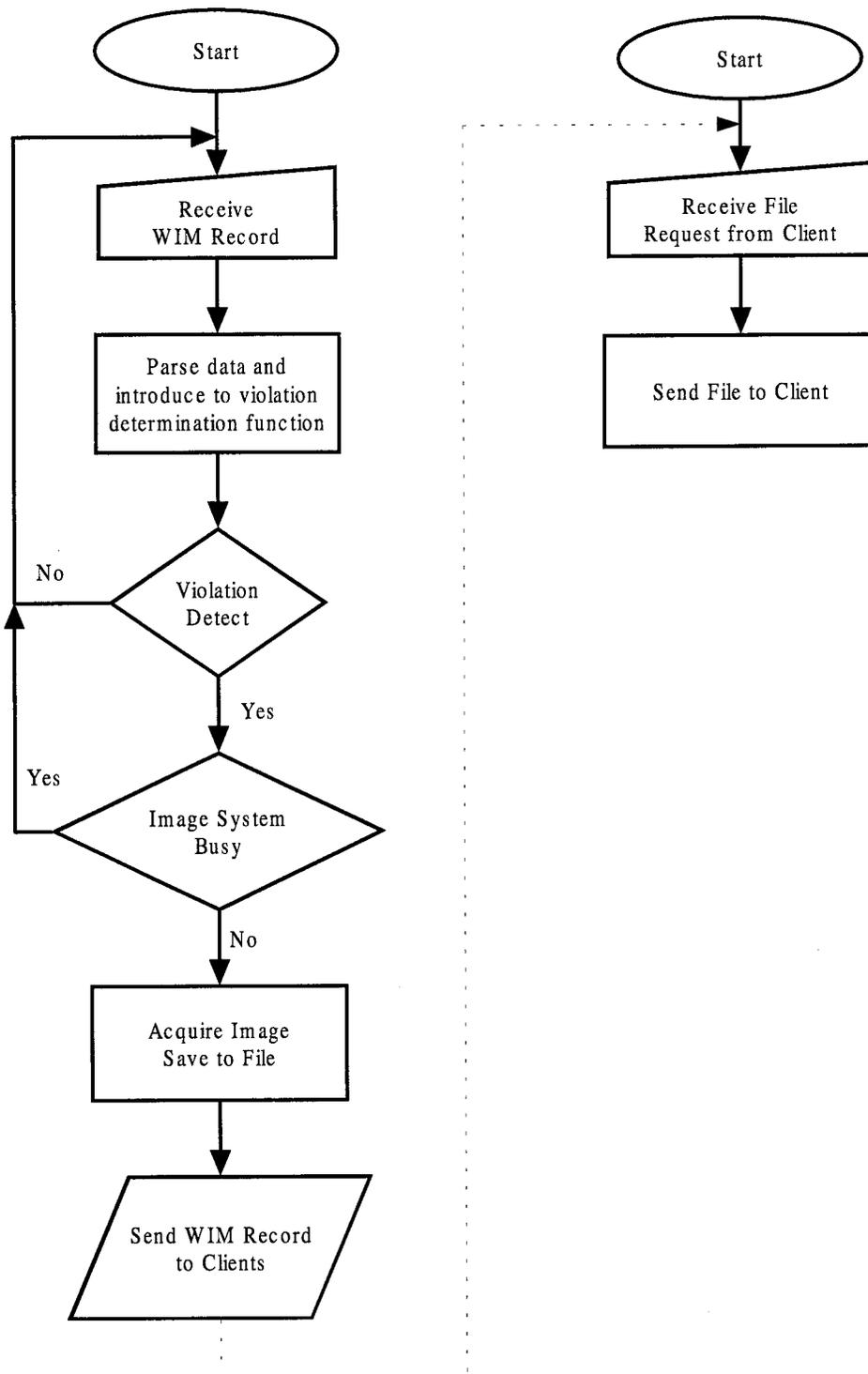
The field system software can be broken into two main functions: hardware control and client communication. The field architecture assumes that the WIM system will be manually setup to output data to WIMAGE on each passing vehicle. WIMAGE will not pass any control data other than a login script to the WIM system to begin the data feed. After login, the WIM operates as a totally stand-alone external data provider. The video camera system is also totally external to WIMAGE, with no provisions at this time for pan/tilt controls. The camera must be manually aimed at the defined point on the roadway. The field system will provide no means of fault detection or recovery from errant signals from either WIM or the video camera. WIMAGE automatically dials the modem, establishes a network connection with the Internet service provider, and maintains the connection even if dropped.

## **Field Software**

Figure 5 is a diagram showing the logical operation of the field control system software. The field system begins operation by logging into the WIM system and establishing a data feed. The data feed is unidirectional, from the WIM to the WIMAGE. Upon passage of a vehicle that equals or exceeds the set FHWA class, the WIM outputs a stream of ASCII characters that contains the following data:

- Record Number
- Lane in which the detection was made
- FHWA vehicle class
- Gross vehicle weight
- Vehicle length
- ESAL
- Vehicle speed
- Maximum gross vehicle weight
- Timestamp from the WIM system (not the WIMAGE)
- ASCII vehicle axle spacing and loading diagram

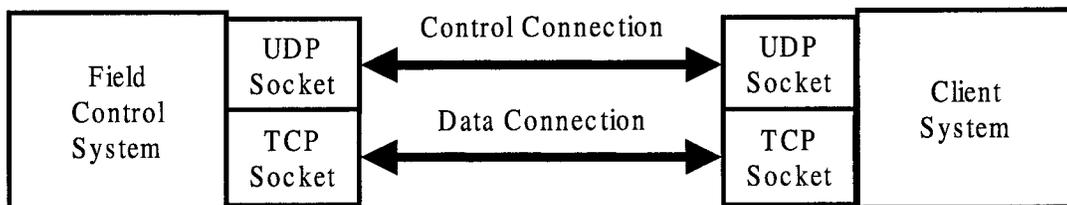
At this point, the WIMAGE introduces the data to an algorithm to determine if the vehicle is in violation. At the present time, the algorithm consists of a changeable FHWA class test. If the vehicle meets or exceeds the class that is set by the client software, a violation is declared. The system updates the WIM record number field with an ASCII representation of the current date and time from the WIMAGE computer (e.g. "Aug\_10\_1998\_11\_13\_25") which becomes the filename for the upcoming image save. This begins the process of capturing an image of the vehicle. Since there are no supporting image trigger devices in the roadway



**Figure 5. Field System Software Logic**

(inductive loop detectors or other presence detectors), the system uses vehicle passage over WIM sensors to determine vehicle position along the roadway. An algorithm within WIMAGE accepts vehicle length, speed, estimated WIM processing delay, and a value that is client adjustable to calculate a time delay. The delay accurately positions the vehicle along the roadway to fill the field of view of the video camera. At the end of the delay, WIMAGE grabs, renders, and saves a frame from the video camera with the new ASCII date and time from above as the filename. Messages containing WIM data are then sent to all connected clients. The client accepts the data packet, populates its display with the WIM information and extracts the image filename. The client sends a request for the file named in the WIM data packet to the server in the field. Arrival of the image file at the client ends the sequence.

The WIMAGE network communication scheme utilizes two different types of connections: control and data connections. These are depicted in Figure 6. In Internet terminology, the connections are referred to as “sockets.” Each socket uses one of the standard Internet protocols within the TCP/IP family. The control connection between the client and the server is established with a User Datagram Protocol (UDP) socket. The UDP protocol is best suited for this service since all the data per transaction can be contained in a single packet. Advantages of using UDP include low protocol overhead and a user controlled packet content. The later property is important when sending WIM data to the client to avoid data being split between two packets. Each packet must follow the defined format for correct decoding. TCP sockets are utilized for the image data transfer connections. TCP sockets are required when a transaction, such as a file transfer, cannot be contained within a single packet. The field application is designed to be an information server, and the remotes are designed as data clients and will be referenced in that manner in subsequent discussion.



**Figure 6. Communication Model.**

**Client Software**

The client software opens by requesting a session with the server in the field and establishing a UDP control socket link. The control socket provides the means to relay data from WIM and the field control application (image file name) to the client. The client waits for an incoming packet from the server. Packet arrival signals that the field

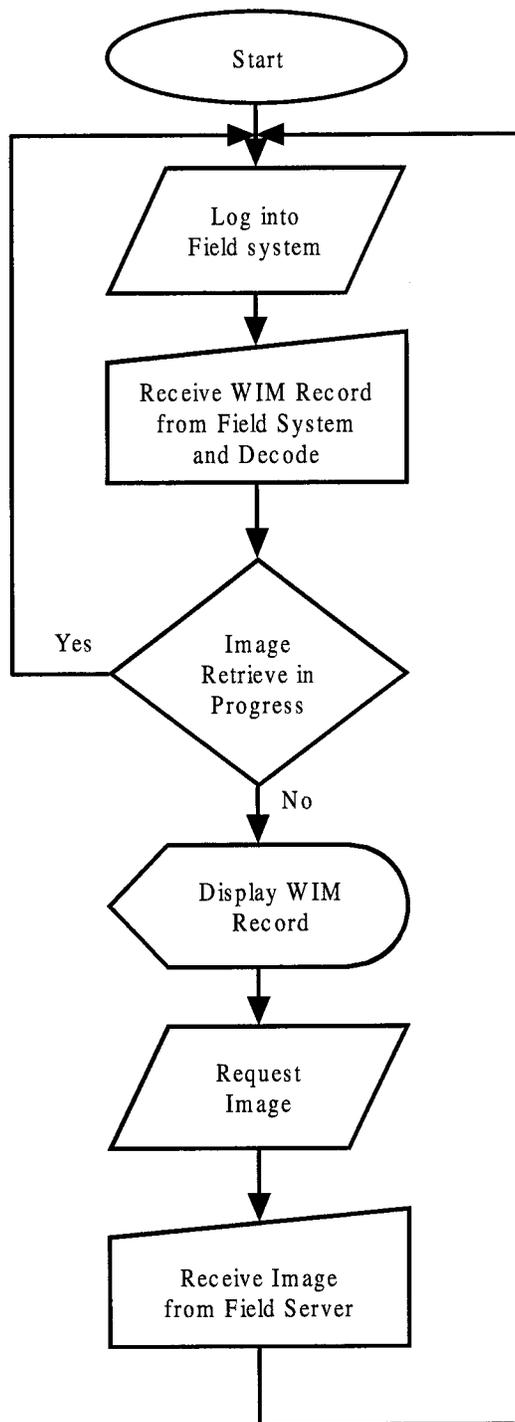
equipment has detected a violation and that an image file is available. The client accepts the UDP data packet, decodes the information, and populates the user interface with the received WIM data. Within the data packet is the filename of the associated image. The file name is extracted from the UDP packet and a TCP data socket is opened with the field server. The client sends a request to the server to retrieve the named image. Since the system uses the Internet, the image file can be retrieved using either a standard file transfer protocol or a custom protocol. The file transfer system will be discussed in greater detail below. Upon arrival of the image file, the client displays the picture to the user, saves it and the associated data file on the system hard disk drive, and terminates the data connection. At this point, the system is ready to accept another UDP WIM packet from the field server and start the process again. Figure 7 depicts the client system program flow.

The File Transfer Protocol (FTP) is widely used and quite adequate for medium and high-speed network links. In addition, several low-cost FTP daemons (server programs) are readily available for this specific purpose. Low-speed connections, such as the CDPD modem, present some problems. The FTP protocol is elaborate and supports many services. This flexibility requires more back and forth communication between the client and server than other simplified protocols such as the Hypertext Transfer Protocol (HTTP). Since more packets must be exchanged between client and server, there is a much greater chance that the transfer session will fail due to a lost packet in the network. It is not uncommon for the CDPD system to “lose” a packet or to be very slow in relaying packets. A streamlined protocol was needed to increase image transfer time and to increase the reliability of getting the image.

To overcome the FTP problem, project staff designed a custom protocol based on the HTTP protocol. The new protocol limits overhead traffic and significantly decreases the transfer time. The client receives WIM data, including the image filename, over the control socket as before. The client then opens a new data socket with the field and sends a “get file” command along with the filename. The field system simply adds a new block ahead of the binary file, which contains the file length information, and transmits the entire package to the client. Upon receiving the first block from the server, the client decodes the file length and continues to receive data until all data are acquired or the user cancels the transaction. The overhead is approximately 6 bytes for the average image file, which is approximately 15000 bytes. Unfortunately, this streamlining has a down side. The protocol is designed to provide only a single service, which can transfer one file to a client per connection. This stipulation requires that the client open and close a new socket for each file requested.

## **USER INTERFACE**

As noted above, the WIMAGE system requires two software applications, one running at the field site and the other with the user or client hardware. Both software applications support user interfaces.



**Figure 7. Client System Program Flow Diagram.**

## **Field System Interface**

The field system interface is simple in function, with all adjustment/operation functions contained within a single window. The window shows a real time display of WIM output, the status of all control and data sockets, and the current values of adjustments provided by a connected client system (discussed later). Buttons on the window enable the program to log into the WIM system, send simple commands to WIM, and enable/disable processing of WIM data. A pop-up overlay window shows the image that was captured if WIM record processing is enabled.

## **Client User Interface**

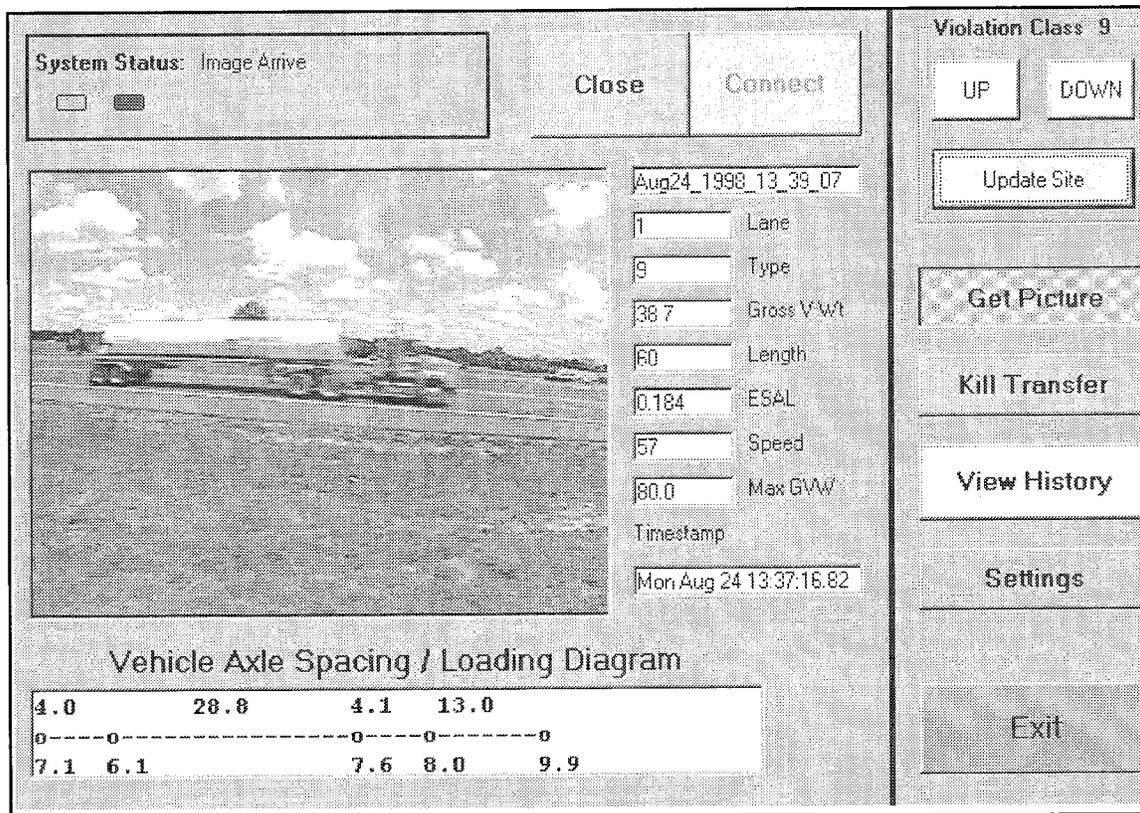
The client user interface consists of two full display screens (forms) and several support boxes. To support the visual interface, a voice annunciation follows select events. For example, upon arrival of a WIM record packet, a voice stating “data arrive” is played. A successful image transfer triggers an “image complete” message.

The application opens with the startup (main) form, as shown in Figure 8. The window displays the most recent WIM information, including an axle spacing/loading diagram and a picture of the measured vehicle, as well as buttons for application control. Large buttons have been provided for the routine control inputs. The oversized buttons make for easy access on the touchscreen.

A system status box resides in the upper left area of the screen. This box returns information about the condition of the program and any current transfer sessions. A CONNECT and CLOSE button establishes and terminates the control connection with the field server. An announcement of “connected to host” follows establishing a link and “disconnect from host” is heard upon termination of a control connection.

In the rightmost quarter of the screen resides a button “tree.” At the top are buttons to select the minimum FHWA class to cause a violation and a button to send the setting to the field software. The field system uses these criteria to determine a “violation.” At present, any vehicle’s FHWA class that equals or exceeds this value is considered in violation. A GET PICTURE button disables the image retrieve function if so desired and is used to disregard any new WIM records that arrive while the previous record’s image is being downloaded. A KILL TRANSFER button is used to recover from a dropped or very slow session with a “stop transfer” voice announcement. A VIEW HISTORY button calls up another window that will be discussed later. Finally, the bottom EXIT button closes all links and terminates the program.

The bar at the top of the window (not shown in Figure 8) provides drop down boxes for saving files, testing the field system, adjusting the image snap delay, and setting the image retrieval retry interval. The field system can be tested by artificially stimulating the image capture code with a prepackaged WIM record. The user can also control a fine adjustment value on the image capture delay timer. The adjustment



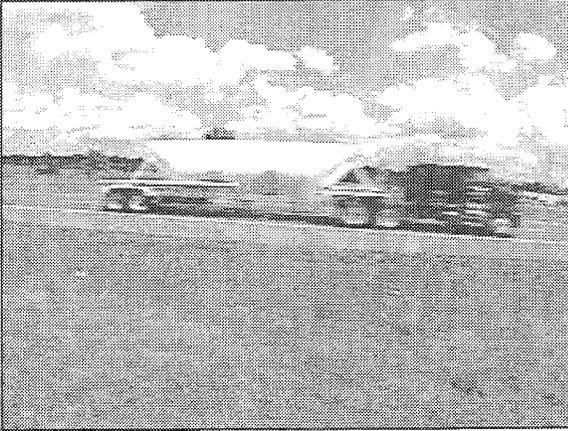
**Figure 8. Client System User Interface Main Window.**

overcomes variations in WIM processing delays and unforeseen burdens on the field unit operating system. Client software has a feature that attempts to retrieve a file three times. A drop down box sets the amount of time in milliseconds between file request attempts. These “buttons” are kept small and not placed near the large buttons because they are infrequently used.

The VIEW HISTORY button draws a window designed to review archived events. Each WIM data record is stored in a text file and the associated picture in an image file of the same name. A box is shown on the left that contains all the captured events residing on the hard drive; and the user can simply point at the file of interest, and the WIM record and image are displayed. Below the box are user buttons to move up and down the list and a button to go directly to the most recent record. A large EXIT button at the bottom unloads the history window. It should be noted that while the history window is displayed, current events are still being received and stored. Figure 9 shows the history window.

**File List**

Sep14_1998_13_37_	Rec Num
Sep14_1998_13_37_	Sep14_1998_13_37_00
Sep14_1998_13_37_	
Sep14_1998_13_37_	1 Lane
Sep14_1998_13_38_	
Sep14_1998_13_39_	3 Type
Sep14_1998_13_39_	
Sep14_1998_13_40_	90.6 Gross Veh Wt
Sep14_1998_13_40_	
Sep14_1998_13_41_	63 Length
Sep14_1998_13_41_	
Sep14_1998_13_41_	4.123 ESAL
Sep14_1998_13_42_	
Sep14_1998_13_42_	63 Speed
Sep14_1998_13_42_	
Sep14_1998_13_43_	800 Max GVW
Sep14_1998_13_43_	
Sep14_1998_13_45_	Timestamp
Sep14_1998_13_45_	Mon Sep 14 13:34:58 85
Sep14_1998_13_46_	
Sep14_1998_13_46_	
Sep14_1998_13_46_	



**Vehicle Axle Spacing / Loading Diagram**

3.9	29.7	4.1	15.8	
*-----*				
19.0	19.0	20.3	20.6	11.8

UP DOWN

Latest

Exit

**Figure 9. Client System User Interface History Window.**



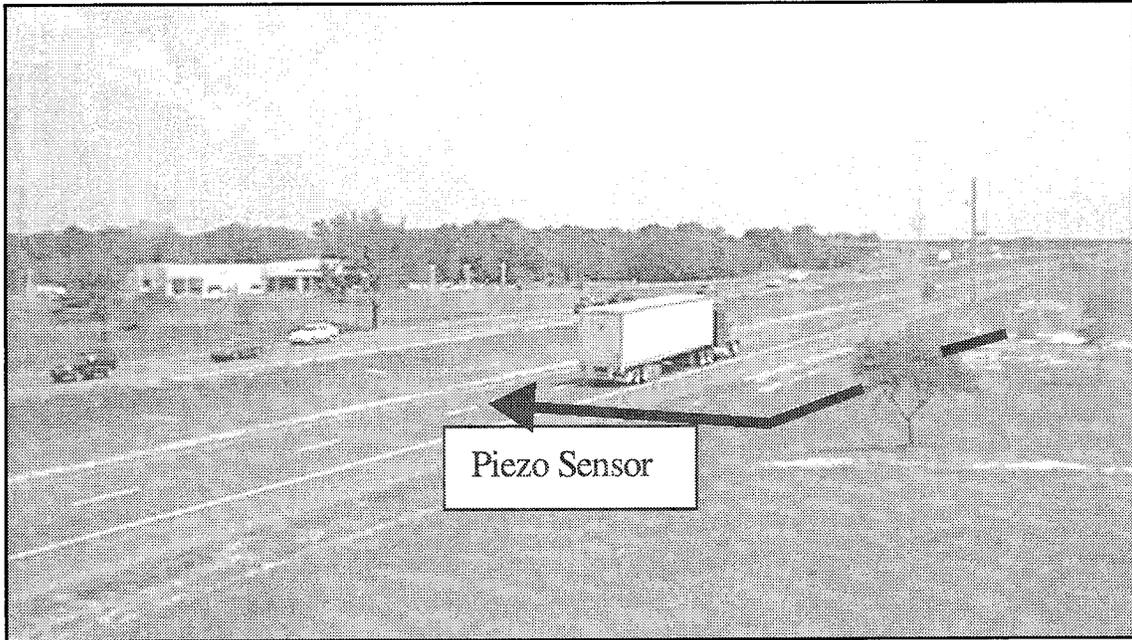
## FIELD TESTING

Figure 10 shows a view of the TTI sensor test bed in College Station, Texas, where functional testing of WIMAGE occurred during August 1998. A black arrow superimposed on the photograph indicates the WIM transducer and its connection to the equipment cabinet. Laboratory versions of the field and client systems were operational in late July 1998. The International Road Dynamics WIM was available at the site and ready to be used as the WIM data source. The location of the piezo sensor was used as the reference point for image capture timing by the field control software. A short time after a vehicle's rear axle passes the sensor, a WIM record is generated and relayed to the field control computer. Figure 11 shows the following equipment inside one of the test site's equipment cabinets: the International Road Dynamics WIM system, WIMAGE field control computer, monitor, image capture hardware, and modem. The final component of the field hardware is the video trailer that was shown earlier in Figure 2. Its location was approximately 300 feet downstream of the WIM roadway sensor and 40 feet from the edge of the shoulder lane.

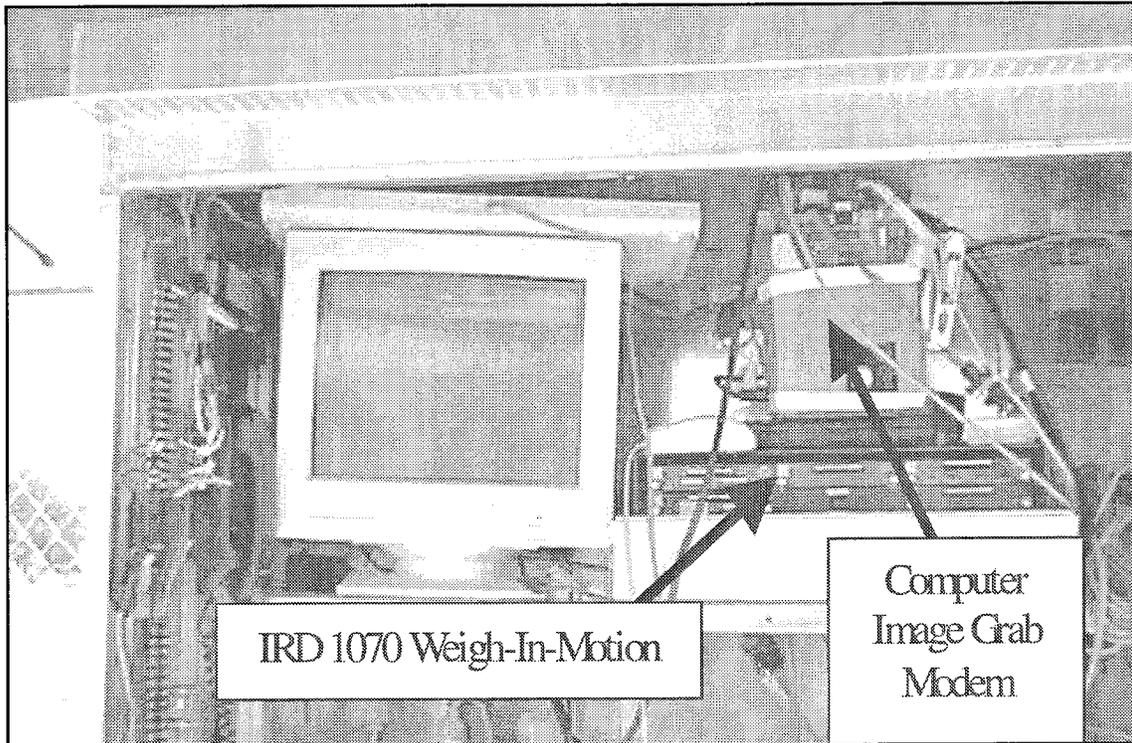
Field tests of the system during August 1998 required development of a method to estimate a vehicle's location after passing over the WIM piezo sensor. Field experiments logged pictures taken with different timing schemes to determine the level of timing accuracy needed and attainable. The final algorithm incorporated WIM processing delay, vehicle speed and length, distance to the video trailer, snap delay of the imaging hardware (time between sending the command and an actual frame grab), and an externally adjustable delay to tweak the time. WIM processing times were found to vary much more than expected, significantly affecting the precision of the location estimate.

## FINDINGS

Image quality using Snappy was found to be acceptable, especially considering the cost of the product. Vehicle images were blurred slightly but were recognizable and identifiable. The wide-angle lens was a good choice for capturing trucks since all or most of the vehicle could be captured in the frame at a reasonable distance from the roadway. However, image quality can be improved by upgrading the video camera, as verified in field tests using a camcorder. Field personnel experimented with the camcorder by zooming in to fill the entire screen with a single passenger vehicle, as indicated in Figure 12.



**Figure 10. Highway 6 Test Site.**



**Figure 11. Field Hardware in Equipment Cabinet.**



**Figure 12. Image Capture from a Camcorder Source.**

During this field test period, the research team utilized a TTI research vehicle hosting the mobile client system and the mobile client software running on a computer connected to the public access Internet. Figure 13 shows the client software running in the vehicle and supporting a touchscreen display. Tests of the client system determined that the minimum distance downstream for the enforcement vehicle to receive and process information, then be able to apprehend a truck was 0.6 to 0.7 miles at the prevailing speed of approximately 70 mph. The maximum distance that images and data can be transmitted using CDPD vary significantly when multiple packets are relayed, but tests in College Station demonstrated that distances between 1.2 and 1.5 miles, or perhaps more, are achievable.

The mobile client exercise revealed that the CDPD service varies greatly when multiple packets are relayed. It was not uncommon to intervene in an image download and stop the transfer due to excessive delays between packets or even a complete halt of data transfer. On occasion, the CDPD modem would not stay registered with the service provider, requiring user intervention to reestablish a connection with the provider. In tests of client software on a computer connected directly into the Internet, performance was very good, with the only limitation being the upload speed of the dialup modem in the field.



**Figure 13. Touchscreen Display and Client Software.**

The evaluation revealed several important findings about each segment of the WIMAGE system. On the field equipment side, the SBC chosen for the field computer came equipped with an onboard image capture daughter card and included a software development kit (SDK). The SDK was somewhat complicated and did not support rapid code development, especially for a project that uses Visual Basic as the overall development package. The SDK did not provide an ActiveX control but rather a host of functions in a dynamic link library (DLL). Although this method was adequate and typical of past SDKs, the research team was not conversant in the use of the functions and spent an inordinate amount of time learning the image capture functions and routines. The final useable product developed by researchers used an architecture that stored grabbed images in memory and processed them when time was available. The system worked well but was slow to process the image into a useable file structure (such as JPG). Since a suitable file conversion function was not included in the SDK, researchers had to incorporate an external program that just performed an image conversion function. The technique, though quick, introduced a segment of processing in which TTI's controlling program could not get direct feedback. Poor feedback ultimately causes problems.

Image capture quality of the onboard system was acceptable for stationary or slowly moving objects but became progressively worse as the movement of the subject increased. Sample captures from a camera at the test site showed significant smearing of the grabbed image to the point where identification of the vehicle was obscured. A better system was needed, but cost was an obstacle in moving to a faster image capture board in the computer. An investigation of current low-cost frame grabbers indicated that parallel port systems such as Snappy had superior shutter speed to the onboard system. A product named "Dazzle" performed slightly better than Snappy. However, subsequent investigation found the Dazzle image grabber could not be controlled by an external program, so it was eliminated from further consideration. One limitation of the parallel port frame grabbers is the time interval between captures. An image can only be acquired approximately every 3 seconds, allowing only a single frame grab per vehicle passage. This feature alone was not deemed to be a fatal limitation since the slow data transfer nature of the CDPD modem would not support multiple image transfer to the enforcement personnel. The research team decided to use Snappy and acquire only one image of the passing vehicle.

Interfacing the frame grabber with the SBC presented another challenge. Early software development focused on using the included Snappy program with control provided via the Visual Basic field application. A system using this combination showed promise and went into full-scale test at the Highway 6 test bed. However, once again, the lack of feedback caused system failure after a few hours of operation. Play, Inc., makers of Snappy, supply an ActiveX control with the frame grabber and have posted example Visual Basic code on their Internet website. At the time of the WIMAGE software development effort, a new ActiveX control was being developed by engineers at Play but was not ready for release. Therefore, researchers decided to utilize the old version of the ActiveX control and the Snappy hardware in the interim. They added control and supporting custom code to the Visual Basic field application and began testing. Early testing revealed a couple of problems in the Snappy ActiveX control, but software "workarounds" were added to overcome the issues. To date, there have been few problems with using the old control, but the new control and a current software build should be incorporated when available.

The CDPD radio system is the most limiting item in the entire WIMAGE system design. The radio only provides a data transfer rate of approximately 800 bytes per second on a good connection. It is not uncommon for the connection to provide much slower throughput or for a transfer to simply stop. By the nature of the CDPD system, voice traffic receives the highest priority on the cellular grid, leaving data communication to operate on unused channels. The lack of dedicated bandwidth can lead to unpredictable service. Along with the problem of throughput is the issue of registration stability. The CDPD system requires users to register on the network in a fashion similar to a user logging onto a networked computer. The problem lies in the fact that the CDPD system can bump users off the network, requiring them to register again. The registration process can be slow and does not consistently give understandable feedback to the modem user. CDPD coverage is yet another issue. Currently, the service is only provided in metropolitan areas or along very high capacity corridors. More CDPD

information is available at the following Internet site:  
<http://www.attws.com/nohost/data/wip/index.html>.

The performance of the CDPD modem also determines the downstream placement of enforcement personnel. Processing time following an overweight truck triggering an image capture and save consumes approximately 5 seconds. A 200 byte UDP WIM record packet goes out to the remote, and the remote requests an image file of approximately 12000 bytes. At 500 bytes per second throughput, the image file arrives in 25 seconds. Therefore, a total of 30 seconds is required to move a single image to the remote. A vehicle moving at highway speeds will travel approximately ½ mile in this time, so an officer should be 0.6 to 0.7 miles downstream, giving a margin for slow data transfer.

Problems with the WIM system included inconsistent processing times, need for calibration, and missed vehicles. Currently, WIM processing time is considered constant in the capture delay algorithm, so a method to estimate WIM delay should be considered for future refinements. WIM calibration and periodic checks of its performance are of utmost importance in accurately identifying overweight vehicles.

## CONCLUSIONS

Field testing of the prototype, which occurred at TTI's Highway 6 test bed, demonstrated these important points:

- A reasonable quality image can be captured of a vehicle moving at over 70 mph with low cost hardware.
- Although the image quality was good, the reliability of the hardware-specific capture software (vendor supplied) was not acceptable.
- No external presence detector was required to accurately trigger the camera; the system uses WIM speed data to predict the vehicle's position.
- CDPD modem service quality can be unpredictable.
- WIM processing speed is a variable that needs to be better understood.

It should be noted that none of the negative issues are expected to be long-term problems. The image capture software problems should be corrected with the next release of the vendor's SDK. Even if the next software update is inadequate, products are available from other vendors using the same image capture/render technique. Unfortunately, the SDKs are more expensive than Play's.

Today's radio modems will be undergoing improvement quickly. Part of the problem with the CDPD system is that it is an add-on component of an older analog cellular phone system. Tomorrow's cellular phone service will be an all digital design, delivering data at rates in the range of 10 times the speed of the CDPD system. Radio modem speed is expected to approach LAN performance in the foreseeable future. Service coverage will also improve with the entrance of Motorola's Iridium satellite-based mobile communication system.

Areas worthy of further investigation include use of multiple cameras, use of upgraded cameras, choice of field computer, and software enhancements. For considerations of multiple cameras, one overhead camera could focus on the vehicle's front license plate and a side-fire camera could capture the truck's DOT number. Camera quality similar to a camcorder delivers sharper images than the Phillips camera used in these tests. Review of the field control computer is needed to determine the most economical hardware configuration for effective operation. Processor choice, program memory, mass storage, and communication ports are the important variables. The parallel port image capture system will be the most demanding on computer processing power. Both the field system and client system software should be upgraded with more configurable features. A more elaborate method of programming the violation criteria is required to allow flexible operation. The violation warning should be based on Bridge Formula violations rather than on vehicle class.



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