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16. Abstract

This project focuses on the development and evaluation of a truck monitoring and warning (TM&W) system for detecting high, long, fast trucks at freeway-to-freeway connections and activating displays to warn the truck drivers of potential hazards as their vehicles approach the curved section of an interchange ramp. The basic study was conducted on the elevated left-turn ramp for traffic moving from southbound on the I-610 loop freeway to eastbound on SH 225 (LaPorte Freeway) in Houston, Texas.

The TM&W system used three infrared light-beam sensors with a special microcontroller-based signal processor, named TDA3 (Traffic Data Acquisition), to determine the speed, length at 7 ft (2.1 m) above the road surface, and arrival time for every vehicle that blocked the light beams. When selected criteria were met, the TDA system sent a warning message to the driver. Software for data collection and processing was developed, and before-and-after speed-change studies were conducted to determine the effect of applying the TM&W system at the curved, elevated interchange ramp.

The results of this research indicate that activating flashing-yellow-light warning displays for only the trucks exceeding the preset criteria caused an average additional 2 mi/h (3.2 km/h) speed reduction beyond normal, before the trucks entered the curved portion of the ramp. Recommendations are made for improving the warning message's impact on drivers and for implementing the TM&W system on a statewide basis.

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TRUCK MONITORING AND WARNING SYSTEMS FOR FREEWAY-TO-FREEWAY CONNECTIONS

by

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Project Summary Report Number 2915-S

Research Project 7-2915
Truck Monitoring and Warning Systems for Freeway-to-Freeway Connections

Conducted for the

TEXAS DEPARTMENT OF TRANSPORTATION

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IMPLEMENTATION RECOMMENDATIONS

The focus of this research was on developing, implementing, and evaluating a system to monitor traffic continually on a freeway-to-freeway connector ramp, identify all high, long, fast trucks traveling on the ramp, and activate warning devices to help prevent out-of-control accidents by these vehicles. The research demonstrated the effectiveness and durability of the infrared light-beam sensor technology and the microcontroller-based data handling processes that were developed and deployed for more than 2 years at the Houston research site. Significant reduction of speed was observed when the system selectively activated supplemental flashing yellow hazard identification beacons above and below standard and experimental warning signs only for those trucks that violated a preset criterion for potentially hazardous operation on the curved ramp. Therefore, it is recommended that TxDOT:

(1) seriously consider implementing the truck detection and warning system on a statewide basis at other candidate freeway-to-freeway connectors;

(2) sponsor and guide the implementation of the prototype truck monitoring and warning system technology into commercial practice for manufacture in quantity;
(3) consider initial procurement of such a commercial system through preparation of a performance-type (end-product-type) specification and subsequent issue of requests for proposals (RFPs) from qualified developers and suppliers;
(4) specify that the same commercially available infrared light-beam sensors that were so successfully demonstrated in the project be incorporated into the production model;
(5) describe in the RFP the sensor mounting and aiming hardware and the microcontroller-based signal processing technology described in the *Project Report* as examples of system components that were used quite effectively to achieve reliable system performance during a 2-year field application; and
(6) consider the recommendations contained in the *Project Report* concerning the effective implementation of warning displays (signs, hazard identification beacons, Amtech Intellitag) when the truck detection and warning system is deployed at each selected freeway-to-freeway connector.

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This research report represents a joint effort of the Center for Transportation Research (CTR) at The University of Texas at Austin and the Texas Transportation Institute (TTI) of the Texas A&M University System. The research was performed for the Texas Department of Transportation in cooperation with the U.S. Department of Transportation and the Federal Highway Administration. The project was funded as Work Order No. 6 under the Federal Highway Administration's Houston IVHS Priority Corridor Program (Project No. IVH-9348[305]). Clyde E. Lee of CTR and Darrell W. Borchardt of TTI served as research supervisors. Robert L. Wright, Duane E. Hartmann, and John M. Gaynor served as project directors, and Thomas D. Newbern served as project coordinator for TxDOT. Special thanks are extended to William Ische and Karl Kelsey of the Amtech Transportation Systems Group, Amtech Systems Corporation, for their assistance and cooperation in providing and adapting the Amtech tag reading software and hardware used in the project. The authors acknowledge the contributions of Musa Misleh and William J. Beichner (TxDOT, Houston District), David Fenno and William R. McCasland (TTI), and Liren Huang, Robert F. Inman, Hussein Tavana, David Crysup, and Kristin Belfield (CTR) for their valuable insights and other contributions throughout this project.

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CHAPTER 1. BACKGROUND AND PROJECT OBJECTIVE

1.1 BACKGROUND

Direct connections (ramps) in freeway-to-freeway interchanges are a major source of traffic congestion and safety concerns. Because the design speed on these connections is usually lower than the design speed on the adjacent mainline roadways, some vehicles tend to enter the connection curves at a higher-than-desired speed. Such ramps should be posted with regulatory speed limits that reflect the desired travel speeds, but the length along the connection ramp is often too short to permit the proper speed reduction distance. Thus, the ramps are provided with advisory signs that describe the safe speeds for the roadway. However, even with proper signs and with additional advisory signs to alert drivers to the critical speed sections, drivers often travel too fast on the ramp. If the vehicle is a large truck with a high center of gravity, the excessive speed can cause the driver to lose control. Additional signs, signals, and markings should be provided to assist the driver in selecting the proper speed at each specific site.

Various types of sensors have been tested in TxDOT's Houston District to measure speeds and to classify vehicles by size and weight. Some of these technologies were considered appropriate for application on the approaches to and within freeway-to-freeway connectors that have sections with low design speeds. For this project, a suitable monitoring system was to be designed to detect large trucks and determine their spot speed. A data processor would be programmed to determine whether the prevailing conditions were considered critical for maintaining vehicle control through the connection. If the measured spot speed was too high for conditions, a warning system would be activated to advise the driver to reduce the vehicle speed. The warning system proposed would be dynamic to increase the target value of visual displays and ideally the compliance to what would be, in effect, an advisory speed limit for each individual vehicle identified by the system.

The I-610 Loop Freeway in the Priority Corridor Study Area of Houston was selected as a site for application of the truck monitoring and warning (TM&W) system. The factors in the project that required intelligent transportation system (ITS) technologies were the requirements to monitor specific characteristics of individual vehicles on elevated roadways and to communicate pertinent information to the driver in a very short time as a truck traveled over a short distance along the connector. Thus, over-the-road sensors were required. Systems that track the vehicle over such short distances would require information that is difficult or perhaps impossible to obtain with conventional methods and equipment. New techniques for displaying messages to drivers might need to be enhanced by special means to communicate timely warnings to the driver within the approaching vehicle.

1.2 SIGNIFICANCE OF WORK

A survey of knowledgeable organizations was conducted in the 1980s as part of a study evaluating the problem of truck stability. Survey responses from twenty-nine states, four motor carriers, a trailer manufacturer, and the Brotherhood of Teamsters overwhelmingly indicated that rollover was the greatest concern, although yaw instability (often resulting in jackknife) was also regarded as highly problematic. It was discovered that hydroplaning could contribute to truck instability on wet pavements under lightly loaded conditions. In the case of freeway connectors, hydroplaning could become particularly troublesome for unloaded trucks on large-radius curves where combinations of high speeds, poor pavement friction, or poor drainage exist. Results of another research study conducted in the 1980s indicated that as many as 21 percent of all truck accidents on urban freeways occur at interchanges. Truck rollovers and jackknife incidents typically occur on curved ramps and are often associated with excessive speed and loss of control. Overturned truck crashes on exit ramps at interstate interchanges represent 5 out of every 100 fatal truck crashes.

The results of another research study indicated that there are several factors that can contribute to loss-of-control accidents involving tractor-semitrailer trucks. These include:

1. **Low roll stability.** Rollover generally results from lateral acceleration forces acting on a vehicle in a steady turn. This is a threat particularly to the driver of a heavily loaded truck because, even in a steady turn, a severe steering maneuver or speeding will cause rollover. Commercial loading practice sometimes places the center of gravity high in absolute terms, as well as high relative to the width of the tire track. The ratio of these two dimensions is a measure of basic roll stability.
2. **Jackknifes.** These accidents generally occur at sites where tire/pavement friction is reduced, and they frequently occur with unloaded or lightly loaded trailers. Jackknifes typically result from a simple traction deficiency at the drive wheels or from light braking, which can cause the drive wheels to lock up. Different tire/road friction levels on the steering and drive axles can cause a truck to jackknife simply from cornering on a slippery curve.
3. **High-speed off tracking.** When operating on curves at low speeds, truck trailers tend to track inboard, but at high speeds, under the influence of lateral acceleration, the rear trailer wheels of articulated truck combinations track outboard dramatically. This dynamic process, which is a function of speed and roadway geometry, is disorienting to the driver. Confused by the opposing responses at different speeds, drivers can lose control. Where curbs line the outside of a curve, high-speed off tracking can cause tires to hit the curb, forcing the truck to roll over.
4. **Excessive speed.** Each driver must make a conscious decision to select an appropriate speed for the prevailing roadway and traffic conditions, especially on downgrades and when negotiating a curved ramp.

A review of information supplied by the City of Houston Police Department accident division over a 3-month period concluded that approximately one-third of the incidents to which police responded on freeway-to-freeway connectors were attributable to high speed.

Incidents involving trucks on interchanges in Houston have resulted in spilled loads, disruption of traffic for several hours, extensive damage to the roadway infrastructure, and loss of life. As part of a research study in Houston in 1994, the impact on truck drivers of passive ("truck tipping" warning signs) and active (flashing lights mounted above and below warning signs) warning devices on a freeway-to-freeway connector was evaluated.

1.3 OBJECTIVE OF THE PROJECT

The objective of this project was to implement and evaluate a traffic monitoring and warning (TM&W) system that identifies potentially unsafe speed conditions for high, long, fast trucks operating on freeway-to-freeway connectors and activates warning devices to help prevent out-of-control accidents by these at-risk vehicles.

The tasks listed in the project proposal for accomplishing this objective include the following:

1. Develop a detailed implementation plan.
2. Prepare plans and specifications, and design, develop, and install a TM&W system, called Traffic Data Acquisition (TDA3) in this report.
3. Prepare software for the collection, processing, and evaluation of the TM&W system information.
4. Operate the TDA3 system.
5. Evaluate the effectiveness of the TDA3 system.

CHAPTER 2. THE TDA3 SYSTEM

2.1 SYSTEM DESCRIPTION

The TM&W instrument system (TDA3 system) developed specially for this project is designed to

1) detect high, long, fast trucks operating on a freeway-to-freeway interchange exit-ramp terminal;
2) compare a truck's speed, height, and length with preset (adjustable) criteria that are considered to be appropriate for safe operation on the curved portion of the ramp; and
3) activate warning devices when the criteria are violated.

2.2 INSTRUMENT CONFIGURATION

This instrument configuration consists of three infrared light-beam sensors and a microcontroller-based Traffic Data Acquisition (TDA3) system. The sensors are commercially available, thru-beam, modulated infrared light-beam devices that switch a normally ON electric circuit OFF whenever the light beam between the infrared (IR) source and its paired receiver is blocked by an opaque object, such as a vehicle. A TDA3 unit processes the continuous ON-or-OFF signals from the three sensors with respect to time to count each vehicle that traverses one of the low-height sensors. The light beams of the two lower IR sensors are aligned transversely across the roadway, exactly 2 ft (0.6 m) apart in the direction of traffic flow and approximately 22 in. (0.6 m) above the road surface. They are used to sense and record the vehicle's arrival time and to measure its speed. The third IR sensor is mounted 7 ft (2.1 m) above the road surface and centered between the two lower sensors. Its blocked-time signal is combined with signals from the two lower sensors to calculate the length of the moving object (truck body or load). The TDA3 system is programmed to provide an output signal that closes an electric switch and keeps it closed for a selectable time interval to activate a traffic-warning device(s) when any detected vehicle violates the selected criteria.

The system stores the date, arrival time, speed, and measured length of the high part of every violating truck. It also calculates and stores summary statistical data for the hourly vehicle count (of all types of vehicles) and the hourly frequency distribution of the vehicles' measured speeds. A communication feature of the TDA3 provides a means of monitoring the system status and downloading stored data either via modem and telephone line from a remote location or by connecting a PC microcomputer directly to the RS232C port on the TDA3.

For implementation at the I-610/SH 225 research site in Houston, the individual IR source and receiver (detector) units were equipped with special aiming hardware and contained inside protective housings. They were mounted on posts just behind the guard fence or bridge rail. A paired source and receiver compose a sensor unit. The source generates an IR-wavelength light beam, and the receiver detects the beam. An important feature of the IR sensors used for this project (OPCON 70 series) is that the light beam is modulated by a controller unit at a special frequency. The receiver circuit responds only to the modulated signal from its paired source. Thus, the sensor signal is not adversely affected by other sources of IR light, such as sunlight. It is necessary to have a cable connecting both the source and the receiver of each sensor pair to its common control unit. At the I-610/SH 225 site, the cables from the sensor sources on the far side of the ramp were buried in conduit, routed across the roadway in an existing pavement joint, and run into a roadside cabinet. All source cables were connected to their respective control units, along with the matching sensor receiver cables.

The TDA3 circuit board was enclosed in a rugged, weather-resistant housing (4 in. diameter aluminum tube) and placed inside the roadside cabinet along with a modem. The cabinet was supplied with 110 VAC electric power and two data-quality telephone lines. A buried cable took the TDA3's output switch-closure signal downstream beside the edge of the ramp some 800 ft (250 m) to a traffic signal controller cabinet, where it was used to activate the load switches of the flashing yellow signal beacons. The beacons were mounted along the bridge in advance of, and on the curved section of, the elevated ramp. Similarly, another cable took this signal to a cabinet some 200 ft (60 m) downstream, where it was used to switch the transmitting antenna of an Amtech Intellitag microwave communication system. These warning displays are described in greater detail in the following sections.

Three sets of OPCON 70 series thru-beam infrared sensor units were used to implement three infrared frequency light beams. Each unit had one infrared source (S), one receiver (R), and one control unit (C). Whenever an object on a vehicle blocked one of the infrared beams, it generated a pulse on the corresponding output terminal of the control unit. The three outputs from C1, C2, and C3 were each sent to a separate channel of the TDA3 traffic data acquisition board. The TDA3 design is based on a Motorola MC68HC11E9 micro-controller and includes other circuitry used to process the sensed signals, store data, and control warning devices. The TDA3 has a 32K x 8-bit memory that can be used to record information for 4,094 individual vehicles in which the vehicles are higher than 7 ft (2.1 m), longer than 16 ft (4.9 m), and faster than a preset speed. A laptop PC microcomputer is used to start the system or to download data directly through the RS232C port. Alternately, a modem can be connected to the RS232C port to access the TDA3 via telephone line from a remote location.

2.3 DATA FORMAT

Stored traffic data that can be downloaded into a file include the following:

- Header
- Summary traffic data

- Individual vehicle data
- End information

All data are in text format. The header information includes filename, start date, start time, threshold speed, filter delay, flasher time, and site number. The filename is designated T001, followed by the current month, day, and year. The threshold speed is a selectable speed value chosen by the user to be the safety criterion for triggering warning devices. Filter delay is also an input parameter for the infrared pulse time filter, which is usually set between 0.2 and 0.5 s; in this study 0.4 s was used. Flasher time is the control parameter for the flasher to remain ON to warn an approaching truck driver. It can be set from 0 to 255 s depending on the travel time of the violating truck from its detection point to its passing the display; at the project site, 12 s was used. The site number code can be set between 0 and 255. For each violating truck, time at end of truck, speed, and high-part length are recorded. After all the stored data are downloaded, the end date and time are added to the data file automatically. These data are arranged in the file in the following format:

Header

Filename: T001mmdd.yy
Start Date: mm-dd-yy
Start Time: hh:mm:ss
Threshold Speed: xx mph
Filter Delay: 0.xx s.
Flasher Time: xx s.
Site number: x.

Summary Traffic Data

Hourly Count:
xxx xxx xxx xxx xxx xxx xxx xxx xxx xxx xxx xxx xxx
Speed Distribution: (*By Speed Range)*
xxx xxx xxx xxx xxx xxx xxx xxx xxx

Individual Vehicle Data

Time *Speed* *Length*
hh:mm:ss **xxx** **xxx** (*one line for each vehicle)*

End Information

End Date: mm-dd-yyyy
End Time: hh:mm:ss

All the stored data can be assigned to a user-defined file and downloaded through the RS232C port to a PC. During long-term running, if the memory overflows before downloading, the system will lock, and data will be lost. The reset button must be pushed manually on-site to restart the system.

2.4 SIGNAL WAVEFORM

An advantage of using the infrared light-beam sensor is the ON-or-OFF characteristic of its digitized output signal. For each blocking of the beam, a time-related pulse is generated at the output terminal of the control unit. In the TDA3 application, the pulse indicates that some part of a vehicle passed through the beam and interrupted it. The duration of the sensed pulse depends on the length and speed of the vehicle. Under constant speed, the longer the vehicle, the longer the duration of the pulse will be. According to the time relationships among the pulses from the three sensors, the speed and length of the various parts of the vehicle that were sensed can be calculated.

2.5 SIGNAL PROCESSING

Software embedded in the TDA3 processes the IR sensor output signals to determine the speed and length characteristics of each observed truck that might indicate impending danger in negotiating the ramp curve ahead at the measured speed. The critical length value that is chosen to indicate potential overturning propensity or a handling problem is that length measured from the front edge of the first object to the rear edge of the last object on the same vehicle at a height of 7 ft (2.1 m) above the road surface. This is the mounting height of the high infrared light-beam sensor. The critical length value chosen for the study was 16 ft (4.9 m), as this value does not include most truck tractors running without a trailer or pulling a semitrailer likely to have a low center of mass. It does, however, include most tankers, box-body single-unit trucks, and semitrailers (empty or loaded), as well as all standard cargo containers, insofar as these are either 20 ft (6 m) or 40 ft (12 m) long.

2.5.1 Speed

The speed measurement was based on the known distance between the two low-height light-beam sensors and the calculated time difference between the front edges of the signal pulses from the respective control units. Speed is the distance divided by the time.

2.5.2 Vehicle Length

To measure the vehicle length value of interest (overall length), as discussed above, it was necessary to use a digital filter to process the signal from the sensor mounted at a height of 7 ft (2.1 m) above the road surface. Because at this height there were sometimes short openings on a truck through which the infrared light beam could shine and thereby indicate that no object was present to block the beam (beam ON), a digital filter was programmed to ignore all such momentary ON times of less than a chosen duration, called filter time. The filter time, which could be set by the user, effectively defined the minimum time gap between successive high objects that indicated two separate vehicles, rather than two high objects on the same vehicle. The TDA3 was programmed to calculate the time from the appearance of the first object on the front of the truck until the passage of the last object at the rear of the truck. This time multiplied by the truck speed (see 2.5.1) was the overall vehicle length measured at a height of 7 ft (2.1 m) above the road surface.

2.5.3 Comparison with Warning Criteria

The TDA3 was programmed to compare the calculated speed and length values that resulted from processing the three infrared light-beam sensor signals for each individual truck with the user-selected warning criteria values set into the TDA3. It was programmed to produce an output trigger signal (switch contact closure) if the criteria were violated. Any truck that exceeded the preprogrammed warning criteria was called a *violating truck*. The TDA3 output signal was used to activate warning displays visible to the truck's driver as the vehicle approached the potentially hazardous, curved section of the ramp at what was considered to be an excessive speed. The TDA3 maintained the warning signal display for a user-selected time interval, chosen to terminate the display immediately after the violating truck had passed the last display. This interval was called *flashing time*. Its duration was set in integer seconds within the TDA3 by the user for the truck speeds observed at the site.

2.6 WARNING SIGNS AND HAZARD IDENTIFICATION BEACONS (FLASHERS)

Warning signs are used when it is deemed necessary to warn traffic of an existing or potential hazardous condition. The signs may sometimes be supplemented by a hazard identification beacon — a flashing circular yellow signal indication — herein called a *flasher*. At the study site, the first such sign is an advisory exit speed sign, "EXIT 35 mph," with an 8 in. (0.2 m) flasher on top, located at the exit ramp gore. This flasher operates continually and apparently has little effect on the speed of exiting vehicles. The second warning display consists of two 8 in. flashers (one above and one below the warning sign), a truck overturn sign, and a 35 mph advisory speed plate; it is located 550 ft (168 m) from the beginning of the exit ramp terminal. The third warning sign group includes a curve sign with a 35 mph advisory speed plate below it and an 8 in. flasher above it. This array is 1,056 ft (320 m) from the beginning of the ramp and 64 ft (19 m) in advance of the first horizontal curve. The fourth sign array is the same as the second. It is located 1,256 ft (380 m) from the beginning of the ramp on the horizontal curve. All sign assemblies are post-mounted along the right-hand side of the ramp.

2.7 SYSTEM PARAMETER SETTINGS

System parameters used to implement the criteria for a violating truck include its *speed* and *length* (at a selected height). Other parameters that must be set according to the site road geometry and traffic are *filter time* and *flashing time*.

1. Speed criterion
   The speed criterion was set to 56 mi/h (90 km/h). This value will be discussed in Chapter 4.

2. Truck length at a selected height
   The IR sensors were set at a height of 7 ft (2.1 m) above the road surface to avoid detection of vans and pickup trucks. These vehicles were not considered to have a high risk of overturning. All standard production vans sold in America in 1985 were 6' 10" in height or lower. An object length of 16 ft (4.9 m) was thus used to focus the dynamic warning displays on trucks with high loads or bodies of sufficient length to suggest a high center of gravity.

3. Filter time
   The filter time was set at 0.4 s. During the filter time, a truck traveling at a speed of 56 mi/h = 82 ft/s (90 km/h) will move a distance of 82 * 0.4 = 32.8 ft (10 m). Normally, the gap between two objects constituting one vehicle will not be more than 32.8 ft (10 m). Therefore, the filter time of 0.4 s can ensure that a vehicle exceeding the speed criterion and loaded with two objects separated by less than this distance will not be recorded as two vehicles.

4. Flashing time
   According to on-site observations, the average travel time from the TDA3 to the beginning of the ramp curve for violating trucks was about 12 s. The flashing time was, therefore, set to 12 s so that the flashers would stop operation after the approaching truck entered the curve.

2.8 COMMUNICATION INTERFACE

In the TDA3 system, the communication interface between the signal processor software and external devices is implemented in software and passed through the RS232C communications port of the Motorola MC68HC11E9 microcontroller. Software for both signal processing and communication is retained in the electrically erasable programmable read-only memory (EEPROM) of the microcontroller. An IBM, or IBM-compatible, microcomputer has been programmed to communicate with the TDA3 system signal processor unit through its RS232C communication port for gathering and storing traffic data. The data are displayed in real time on the screen of the microcomputer. Control signals can also be sent via the RS232C communications port and modems to traffic warning devices on-site or at remote locations. The programs stored on the microcontroller EEPROM are changeable from a remote location through the communication link.

2.9 AMTECH SYSTEM

A basic Amtech Intelligent-Tag-On-Vehicle system consists of tags, antennas, and readers. The reader's radio frequency source is either integrated or kept as a separate component. The reader broadcasts radio frequency energy over an adjustable area called the read zone or reader footprint. The tag on the vehicle reflects a small part of this radio frequency energy back to the antenna and can also send a sound and flashing visual message to the driver. The reflected radio waves incorporate the tag's unique identification code and other stored data. The antenna relays the signal to the reader, which can add information such as date/time to the tag's identification code, and stores it in a buffer. The reader can transmit the tag's identification code to the customer's information management system, with the entire process taking only milliseconds. The basic system components include the following:

- Tag
  The IT2101 Intellitag is an RF-programmable, battery-powered radio device designed for high-speed, two-way communications.
- Antenna
  The RF antenna can be mounted beside or over the roadway. In this study, two AA3110 Parapanel antennas were arranged together on a post beside the ramp.
- Reader
  The microprocessor-controlled IT 2001 reader conducts two-way RF communication with the Intellitag 2000 series tags using an open communications protocol based on Title 21 of the California State Code of Regulations, AVI Compatibility Specification.

The system includes an RF transceiver, logic control unit, fault-tolerant memory, RS-232 communications port, RS-485 reader synchronization port, low-noise power supply, and rugged enclosure.

The IT 2001 reader transmits an RF polling signal to a nearby IT 2100 series tag, which responds by encoding the signal and reflecting it back to the reader using a reliable and proven modulated backscatter technique. Upon receiving the modulated signal from the tag, the reader decodes the ID information, confirms the message's integrity, and transmits the code to the host computer system. When writing information to the tag, the reader formats data into a modified Manchester coded signal sequence for transmission to the tag.

In this joint research effort, the Amtech system antenna was not always turned on. When the TDA3 detected a violating truck, it sent a signal to trigger a radio-frequency (RF) switching relay to activate the antenna on the Amtech system at the same time the flashers on the warning signs were turned on. As a result, the driver of an Intellitag-equipped truck received two warning signals: flashers on the roadside and a tag warning light and sound inside the truck.

The Amtech system was first installed at the project site on June 29, 1998, and fifty tags were subsequently distributed to five trucking companies. From noon to 5 p.m. on February 17, 1999, and again on February 24, 1999, speed-change data were collected using the Amtech system and manual observation. Only six violating trucks were recorded. This sample size is much too small to provide useful statistical data.

2.10 THE TEST SITE

The test site was on the curved, elevated, left-turn, directional ramp at the interchange where I-610 and SH 225 cross in the southeast area of Houston. This interchange was designed circa 1965.

CHAPTER 3. SYSTEM EVALUATION

Important objectives of the TM&W system evaluation were to determine the effectiveness of the IR light-beam sensors and the TDA3 instrument system in providing traffic data for truck monitoring and to measure the effectiveness of applying the system to effect a speed reduction by trucks that could be in danger on the curved interchange ramp.

3.1 EFFECTIVENESS OF THE TDA3 SYSTEM FOR TRUCK MONITORING

During a time period lasting from January 1998 to May 1999, the TDA3 system continually collected traffic data on the ramp carrying vehicles southbound on I-610 to eastbound on SH 225 in the southeast area of Houston. These data included:

- hourly traffic volume for all vehicles,
- daily speed distribution for all vehicles, and
- arrival time, speed, and length of every violating truck.

All real-time data were saved into daily files (text format) and downloaded via modem and telephone line to a remote server at CTR in Austin. It should be noted that the TDA3's infrared light beams extended across both lanes on the two-lane ramp; therefore, two vehicles running side-by-side interrupted the counting beam simultaneously and registered as only one vehicle. The volume count value was, then, somewhat lower than the actual value because of this phenomenon.

Analysis of the data files obtained during this 17-month period indicated that the TDA3 system produced consistent and reliable traffic data on a virtually continuous basis. Two interruptions lasting for several days occurred when the electronic components of the system were damaged by what appeared to have been a lightning strike; another interruption occurred when a vehicle backed along the shoulder and hit one of the high IR sensors, knocking it out of alignment (though not damaging it). Thus, it can be said that the TDA3 system was overall quite effective in providing traffic monitoring data for the interchange ramp.

3.1.1 Traffic Volume

The average daily traffic volume on weekdays during the period from January 1998 to May 1999 was calculated and analyzed. The average weekday traffic volume was about 20,500 vehicles per day on the two-lane ramp. It was slightly lower on Monday than on other weekdays. Analysis of the hourly weekday volumes indicated that the hourly traffic volume was very stable on Tuesdays and Wednesdays and that the time periods from 6 a.m. to 7 a.m. and 5 p.m. to 6 p.m. were peak hours.

3.1.2 Violating Trucks

Any truck that was longer than 16 ft (4.9 m) at a height of 7 ft (2.1 m) and that was traveling faster than the selected criteria speed of 56 mi/h (90 km/h) was designated as a violating truck. On weekdays, the average number of violating trucks per day was about 2,000, and the largest number of violating trucks per hour was around 170. The peak hour for violating trucks was usually the hour between 9 a.m. and 10 a.m.

3.1.3 Speed of Trucks

The largest percentage of the trucks that met the selected length-at-height criteria were running within a speed range of 54 mi/h (86 km/h) to 64 mi/h (102 km/h); this speed range is called the 10-mi/h pace. The ratio of the number of violating trucks (at speeds exceeding 56 mi/h) to the total number of trucks on weekdays ranged between 62 percent and 76 percent. This ratio was higher on weekends, at 83 percent on Saturday and 76 percent on Sunday.

3.2 EFFECTIVENESS OF APPLYING THE TDA3 SYSTEM

The main objective of applying the TDA3 system is to help prevent out-of-control accidents by high, long, fast trucks on freeway interchange ramps. A critical element in avoiding out-of-control accidents is reducing the speed of these trucks. A before-and-after study was conducted to determine whether the TM&W system could compel the drivers of high, long, fast trucks to decrease their speed on the research site ramp.

3.2.1 Layout of the Before-and-After Study

The before-and-after study was designed to compare the speed change of violating trucks as they traveled from the exit ramp terminal — just off the main lanes, where they were detected by the TM&W system sensors — some 790 ft (241 m) toward the beginning of the first curve on the ramp. At each end of this section, spot speed measurements, within 1 mi/h (2 km/h), were made with a special arrangement of two IR light-beam, reflex-type sensors positioned just above the pavement surface in order to sense the tires on the vehicle. These were teamed with a TDA2 microcontroller unit to calculate speed and vehicle length. Speed change was calculated for each individual truck that had been identified via its wheelbase and arrival time at the two speed traps. The “before” case study was conducted without the flashers being actuated by the TDA3 system, and the “after” case study had the TDA3 turn the flashers ON for every violating truck detected. By comparing the measured speed changes of individual violating trucks under these two conditions, the researchers evaluated the effectiveness of applying the system.

3.2.2 Observation Period

An important element in any before-and-after study is determining the appropriate observation period. In order to make the samples representative of the population, the appropriate observation period should be the time when the hourly traffic volume is most stable and the frequency of violating trucks is highest.

Pursuant to the results of the traffic data analyses described previously, the time period from 9 a.m. to 5 p.m. on Tuesday or Wednesday was selected as the time frame for collecting sample data and analyzing the effectiveness of the warning system on the ramp traffic.

3.2.3 Before Study

Observation period: 11:55:30 a.m. to 03:24:57 p.m. on Tuesday, January 26, 1999. During this observation period, speed measurements for 141 individual violating trucks were positively matched at the two speed traps 790 ft (241 m) apart, and the speed difference was calculated for each truck. This observed speed reduction was due to the drivers' normal responses to the road geometry (including a short -2.4 percent grade, a 250 ft [76 m] long sag vertical curve, and about 500 ft [150 m] of +2.5 percent grade), traffic control devices, and other vehicles. The time headway between successive violating trucks was also determined.

3.2.4 After Study

Observation period: 10:18:18 a.m. to 02:52:33 p.m. and 03:22:38 p.m. to 05:03:57 p.m. on Wednesday, February 17, 1999. The TDA3 system settings were the same as those in the "before" study.

In the "after" study, when a high, long, fast vehicle was detected by the TDA3 system, the driver was warned of the potential hazard ahead by the activation of three flashing signals located along the edge of the ramp. The warning signals were activated only if a vehicle was longer than 16 ft (4.9 m) at a height of 7 ft (2.1 m) and running faster than 56 mi/h (90 km/h). A total of 280 violating trucks that met all the matching conditions was detected by the TDA3 system during the "after" study.

3.2.5 Findings from the Before-and-After Case Study

The before-and-after case study of speed change of violating trucks indicated that all such trucks decreased speed as they approached the curve. (Violating trucks are defined as those detected by the TDA3 system which were at least 16 ft (4.9 m) long at a height of 7 ft (2.1 m) above the road surface and were traveling at or above a speed of 56 mi/h (90 km/h) on the straight, tapered section of the ramp terminal soon after exiting the main lanes of I-610 and some 950 ft (290 m) in advance of the curved portion of the ramp proper.) However, those observed during the "after" study, when flashers (hazard identification beacons) were activated by the TDA3 system only for violating trucks approaching the curve, decreased their speed on average more than those sampled in the "before" study, when flashers were not used.

After stratifying the observed speed-reduction data sets according to speed ranges and headway groups, the researchers found the following results.

1. On average, violating trucks in the higher initial speed range, 62 to 70 mi/h (100 to 113 km/h), reduced speed more — by 8 to 10 mi/h (13 to 16 km/h) — than did those in the lower speed range of 56 to 62 mi/h (90 to 100 km/h) — which reduced speed by 6 to 8 mi/h (10 to 13 km/h) — under both the "before" and "after" operating conditions.

2. The additional average speed reduction for all violating trucks attributable to the effect of the flashers being activated in the "after" case study was 2 mi/h (3 km/h). This magnitude of speed reduction was statistically significant at the 99 percent confidence level. That is, in the "after" study, this much additional speed reduction would be expected to occur by chance alone only 1 time in 100 observations.

3. When speed-reduction data were grouped according to time headway between pairs of violating trucks, trucks operating at a headway greater than 0.1 minute (6 seconds) were observed to respond to the warning flashers by reducing speed, on average, an additional 2 mi/h (3 km/h) more than when the flashers were not activated. This value was statistically significant at the 99 percent confidence level.

4. Those trucks operating at a headway equal to or less than 0.1 minute (6 seconds) also responded to the warning flashers by reducing speed, on average, an additional 2 mi/h (3 km/h) more than when the flashers were not activated. However, the statistical confidence with which this much additional speed reduction would be expected to occur was only 90 percent to 95 percent. At these shorter headways, the speed of the vehicle ahead affects the speed of the vehicle behind it, and the choice of speed by the following driver is not independent.

CHAPTER 4. CONCLUSION AND RECOMMENDATIONS

4.1 CONCLUSION

This study was undertaken to develop an instrument system that could reliably detect high, long, fast trucks on freeway-to-freeway interchange ramps and activate displays to warn their drivers of roadway geometry ahead that might warrant a speed reduction in order to avoid hazardous operating conditions. Such a system was developed and installed for evaluation on the elevated directional interchange ramp that carries traffic southbound on I-610 and turning eastbound onto SH 225 in Houston, Texas. The system was installed in January 1997 and was used to monitor traffic successfully at the site for more than 2 years with only three brief interruptions: once, a vehicle backing along the ramp shoulder hit a sensor behind the bridge rail and knocked it out of alignment, and twice lightning (apparently) struck the area and burned several electronic components in the microcontroller unit and the modem. Data were downloaded via modem to the CTR lab in Austin at midnight every 2 days. The TM&W instrument system, called the TDA3 system in this report, was demonstrated to be quite effective in providing traffic monitoring and warning data for the interchange ramp during a 2-year period.

The trucks that activated a series of hazard identification beacons (flashers) to supplement an array of standard and experimental warning signs and advisory speed plates were trucks that were at least 16 ft (4.9 m) long at a height of 7 ft (2.1 m) above the road surface and that were traveling at or above a speed of 56 mi/h (90 km/h) on the straight, tapered section of the exit ramp terminal. Any truck that exceeded these numbers was called a violating truck.

After evaluating the historical pattern of traffic volume and speed at the site, the researchers scheduled and conducted a before-and-after speed-change study on two selected weekdays when large numbers of violating trucks had been consistently observed. In the "before" study (Tuesday, January 26, 1999), the flashers were not activated, but in the "after" study (Wednesday, February 17, 1999), the warning system activated the flashers only for violating trucks. (The warning flashers had been enabled since Wednesday, January 27, 1999). Speed was measured at two locations 790 ft (240 m) apart on the ramp in advance of the curved section through the use of a pair of infrared light-beam sensors placed just above the road surface to detect the passage of the vehicles' tires — the most accurate way to measure speed with the reflex-type infrared light-beam sensors. Speed measurements were accurate to within 1 mi/h (2 km/h). The speed difference between these locations (always a speed reduction) was calculated for 141 violating trucks in the "before" case and 280 violating trucks in the "after" case.

Analysis of the before-and-after case study data sets revealed that the additional average speed reduction by all violating trucks attributable to the effect of the flashers being activated by the TDA3 system in the "after" case study **only for individual violating trucks** was 2 mi/h (3 km/h). This magnitude of speed reduction was statistically significant at the 99 percent confidence level. That is, in the "after" study, this much additional speed reduction would be expected to occur by chance alone only 1 time in 100 observations.

The portion of the study that was intended to evaluate the potential additional safety benefits of using the capabilities of the Amtech Intelligent-Tag-On-Vehicle system met with only partial success. The basic Amtech instruments were adapted operationally to send a signal from the roadside antenna to the on-vehicle tag only when the warning criteria described above were exceeded. The TDA3 system initiated the trigger signal to the Amtech system at the same time it activated the flashers. When the signal from the Amtech antenna was received by the tag mounted in the truck cab, a small light on the tag was illuminated and a faint sound was momentarily emitted. Tags carried in test vehicles confirmed the proper operation of the system over the full range of speed in both lanes of travel observed on the ramp, but the visual and audio tag emissions were very difficult to detect, even in a passenger van. Only fifty tags were distributed to five different trucking companies. In the 14 hours during which speed measurements were made in February 1999, only six tag-equipped violating trucks were detected. This sample size is far too small to provide useful statistical data.

4.2 RECOMMENDATIONS

Based upon the experiences described above, the following recommendations are made for improving the effectiveness of the TM&W instrument system, called the TDA3 system in this report, for future applications on freeway-to-freeway interchange ramps.

1. Use more and larger-diameter flashers

The hazard identification beacons (flashers) used in the study consisted of pairs of 8 in. (0.2 m) diameter circular yellow lenses that were illuminated simultaneously and intermittently and were displayed above and below a warning sign at three locations along the right-hand side of the ramp. In the spatial expanse that is visible to drivers using the two-lane, high-speed, elevated ramp, the flashers had little visual impact. To increase the visibility of the flashers, and thus their attention value, **it is recommended that the same flasher/sign array be placed on both sides of the ramp at each location and that 12 in. (0.3 m) diameter circular yellow lenses be used. The illumination sequence should alternate between the top and bottom lens units (bouncing ball effect) to create a sensation of movement.** Tests have shown that movement improves visibility of warning signals and response time.

2. Raise value of speed criterion

From the research, it was found that about 70 percent of all trucks using the ramp triggered the warning system when the speed criterion was set to 56 mi/h (90 km/h). This percentage seems excessive. If the speed criterion value had been set to 60 mi/h (96 km/h), only about 43 percent of the trucks would have set off the warning system. Moreover, if the speed criterion had been set at 65 mi/h (105 km/h), only about 13 percent of the trucks would have been picked up by the warning system. As the posted speed limit on the main lanes of I-610 has been raised to 60 mi/h (96 km/h), it might be more effective in the future at this site to **set the warning speed criterion to 65 mi/h (105 km/h) and actuate the flashers for only about 13 percent of the long, high, fast trucks on the ramp.**

3. Increase the intensity of the visual and audio signals on the Amtech tags

If the additional warning intelligence that the Amtech tag could provide to the driver inside the noisy truck cab is to be realized**, the intensity of the visual and audio signals on the Amtech tags must be increased significantly**. Additional field studies will be needed to evaluate the relative effectiveness of this information.