Project No. HR 3-76B, Task Order 4 COPY NO._____

AN ANALYSIS OF LOW-COST ACTIVE WARNING DEVICES FOR HIGHWAY-RAIL GRADE CROSSINGS

PHASE II DRAFT FINAL REPORT

Prepared for
National Cooperative Highway Research Program
Transportation Research Board
National Research Council

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Craig E. Roco, Associate Transportation Researcher
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College Station, Texas

NAS 118 HR 3-76B

January 2007

ACKNOWLEDGMENT OF SPONSORSHIP

This work was sponsored by the U.S. Department of Transportation, Federal Highway Administration, High-Speed Rail Program and was conducted in the National Cooperative Highway Research Program, which is administered by the Transportation Research Board of the National Research Council.

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ACKNOWLEDGEMENTS

The research reported herein was performed under NCHRP Project 3-76B by the Texas Transportation Institute's Multimodal Freight Programs, under the direction of Dr. Stephen S. Roop, Assistant Agency Director, and supported by Leslie E. Olson, Associate Research Scientist; Leonard G. Ruback, Research Scientist; Craig E. Roco, Associate Transportation Researcher; and Annie Protopapas, Assistant Research Scientist.

ABSTRACT

This research tested and evaluated two low-cost, off railroad right-of-way alternatives for traditional active grade crossing warning systems. The first system was based on radar technology and the second on acoustic train horn detection technology. The data collection and processing utilized real time traffic monitoring technology and specially designed hardware and software. It was found that both test systems successfully detected all trains, but they also had high numbers of false positive detections. The research also examined the institutional and legal changes necessary for the introduction of alternative grade crossing warning systems. Examples from several industries are examined, showing that U.S. tort law is a hindrance to the research, development and implementation of - even successful - technological innovations. The barriers specific to alternative warning systems are explored in detail. An array of much needed tort law reform options is recommended. Excessive, false positive train detections are a major drawback to the implementation of low-cost active systems. At best, unnecessary traffic delay is caused. At worst, traffic safety is compromised as drivers' respect for the traffic control signal is seriously jeopardized.

SUMMARY

NCHRP 3-76 B, Phase II tested and evaluated the two most promising low-cost active warning systems that could serve as alternatives to the traditional track-circuit based system, for installation at passive grade crossings. The detection systems, identified in Phase I, were (1) radar based, and (2) acoustic (horn) based. Both fulfilled the two critical requirements of being low-cost and off the railroad right-of-way in an attempt to alleviate monetary and liability issues respectively, ultimately hoping to improve their potential for implementation in the field.

The field testing was carried out at an at-grade highway intersection with the Union Pacific rail line on the Texas A&M University campus. Innovative hardware and software, including traffic control video cameras, recorded the detections of the two test systems and the existing rail system. The data was then transmitted via a fiber optic broadband network to TTI's TransLink® Laboratory, where it was logged, processed and stored using specially designed software.

The findings indicated that 57% of all radar activations and 94% of all acoustic activations were false positives. Their sensors detected 100 % of trains in addition to adjacent road traffic or overhead air traffic. In a nutshell, their sensoring capabilities failed to distinguish between trains and external environmental features, with the radar system being relatively more capable of discrimination. In addition, variability in the advanced warning times and the release times proved problematic and was sometimes extreme.

Mini case studies of various industries offered insight to U.S. tort liability law being a barrier to research, development and implementation of technological innovations. The institutional and legal issues that need to be addressed to allow installation of non-traditional

systems (even successful ones) were examined, and found to center around tort reform in the U.S. legal system.

In all, the radar-based system showed more potential than the acoustic-based system. The radar may show lower probability of a false positive detection if it is installed in a rural environment, minimizing interference from adjacent road traffic. This work concluded that detecting a train is the easy part – detecting only trains in a complex environment is not easy and likely is not inexpensive.

The high probability of the occurrence of a false positive train detection, teaches drivers to gradually disregard the warning system and inadvertently places them in harms way. The safety risk associated with the performance of the tested systems is far more substantial than anticipated by either the research staff or by the NCHRP 3-76B Panel.

CHAPTER 1

INTRODUCTION

BACKGROUND

NCHRP 3-76 B, Phases I and II were directed at identifying, selecting, and testing low-cost active warning systems for installation at passive grade crossings. The work was also aimed at identifying the institutional and legal issues that would need to be addressed to allow widespread installation of non-traditional systems. The research itself is tacit acknowledgement of the fact that safety at passive crossings should be improved and that the current warning to motorists – the Crossbuck – is increasingly viewed as insufficient when deployed as the sole means of traffic control at grade crossings.

The Crossbuck serves as the principal warning sign for one of the most hazardous intersections in our roadway system – the low volume passive highway-rail grade crossing. Collision with a train is more often injurious or deadly than any other type of automobile accident, and the traffic-related circumstances at these crossings – infrequent train activity – have the tendency to lull drivers into a sense of complacency about the potential danger. This complacency results in more than 400 collisions per year – over 100 of which are fatalities *(1)*. Finding out how to implement low-cost active warning systems for passively controlled highway-rail grade crossings, particularly in today's technology rich environment, was identified by NCHRP as a safety priority.

The advances seen in technology over the past decade or so – from communications and the Internet to computer and sensor technology – suggest that there should be a lower-cost way to signalize some of the thousands of passive grade crossings that exist in our country. It is

commonly agreed that the rural nature of many of these passive grade crossings coupled with lower levels of train activity increases the danger to motorists. So, the question posed in this research was, "Is there not some low-cost device that offers a means of signalizing more crossings than we are able to achieve at the high cost of traditional warning systems?"

Logic tells us that as technology improves, as it becomes more reliable and more capable, as well as less expensive, we should be able to devise effective systems to warn motorists of the approach of something as big as a train – even if it's a relatively rare event. Accompanying this thought may be a second question, "Why hasn't this already been done by someone before?" In fact, it has been tried – is being tried – by some whose thoughts parallel those stated above.

The research described in NCHRP 3-76b Phase I described how TTI undertook an assessment of sensor technologies that could serve as the basis of a low-cost warning system, assessing the potential for low-cost active warning systems to protect passive highway-railroad grade crossings. The research progressed through several tasks designed to:

- Define the cost categories and relative magnitude of costs associated with traditional active traffic control / warning systems to determine the potential for reducing costs,
- Assess technologies employed in other countries and in other settings that offer the potential for application in the grade crossing safety arena,
- Develop and apply assessment criteria and an approach that differentiates between the technological options identified,
- Assess the technologies identified and make recommendations for testing,
- Identify institutional or practical barriers to implementation of low-cost warning systems, and

- Develop a test protocol that will serve as a guideline for field testing of promising low-cost active systems or technologies.

Phase I resulted in the identification of two promising systems that had the dual characteristics of low-cost and off-railroad right-of-way. The low-cost active systems identified in Phase I were, (1) radar-based, and (2) acoustic (horn) detection systems. The fact that the systems are both off- right-of-way was considered important so that there would be an improved potential for implementation in the field and importantly, the evaluation process undertaken in Phase II. The latter was simplified by avoiding potentially difficult liability issues surrounding railroad participation in systems that may be less reliable or robust. A portion of the Phase II research plan was designed to address the legal and institutional barriers to implementation in greater detail and to offer a set of measures designed to facilitate low-cost active warning system implementation.

STUDY GOALS

The central goal of this research was to determine through appropriately configured operational tests if there are viable options to traditional active warning systems available for some of the thousands of passive crossings that remain a hazard to motorists and railroad personnel. Our evaluation of the Federal Railroad Administration's grade crossing inventory indicates that more than 62,000 at-grade passive crossings may be candidates for low-cost active systems. Secondary goals consisted of gauging the potential benefits associated with low-cost systems by looking at the total number of candidate passive grade crossings in the U.S. and determining the incremental safety benefit derived from the installation of an active system, even if it were somewhat less reliable.

The work plan proposed for Phase II of NCHRP 3-76B consisted of three broad task elements:

1. Field Testing – this task consisted of testing the identified technologies in field settings that would allow a direct comparison between the low-cost systems identified in Phase I and traditional track-circuit based active warning systems.
2. Risk / Impact Analysis – the results of task 1 would empirically establish the level of reliability and the operational parameters within which the low-cost systems operated in a field setting. Task 2 would use these findings to determine the overall benefit-risk relationship that could be expected if implementation of the system or systems were to proceed.
3. Policy / Institutional Analysis – the final task element involved an evaluation of the barriers to implementation.

The bottom line goal for this research was to demonstrate the potential efficacy of low-cost grade crossing systems in safety-critical settings and chart a path toward those policy and institutional changes that would allow an appropriate assumption of risk by the public sector. This assumption of risk could thereby facilitate increased active warning system implementation at many more passive crossings than is currently the case.

REPORT ORGANIZATION

The second chapter of this report describes in detail the assessment approach and test site. Then it explains the particulars of the hardware and software equipment and technologies employed in the collection of data in the field as well as in the subsequent tasks of logging, processing and storing the data collected.

The third chapter discusses the results of the data analysis and the performance measures developed in order to effectively assess the two test systems. Diagrams to illustrate concepts, tables and charts are presented. A brief discussion as to how the system performance results might affect successful implementation is offered.

Chapter four assesses the impacts of tort liability law as they affect grade crossing warning systems and technological innovation in general. A historical summary of tort law is included, and numerous industry examples are explored individually. General recommendations on tort law reform are offered and enacted reforms are discussed.

The final report of this research concludes with chapter five, where the study findings and their implications are elaborated on and future research options are explored.

CHAPTER 2

RESEARCH APPROACH

OVERVIEW

TTI employed a standardized evaluation protocol to assess the performance of each system tested. The protocol included the tasks, the testing context, the sequence under which the testing procedures were undertaken, the measurement system(s), the criteria used to assess performance, and the training, role assignments, and management plan for carrying out the evaluation.

The protocol established by the research team for assessing low-cost active grade crossing systems focused on those criteria that are safety-related and associated with minimum warning time and the ability to detect trains under a variety of conditions. TTI carried out the testing along an instrumented corridor adjoining the active Union Pacific rail line that bisects the Texas A&M University campus.

Union Pacific Railroad's Navasota subdivision passes through College Station and Bryan with a passing siding located at the border of Bryan and College Station. The subdivision is an artery for freight rail traffic moving between the Midwest and the Houston and Gulf Coast area. The line sees approximately 20 train movements per day including a mixture of manifests, unit coal, grain, and aggregate traffic. UP's single track mainline bisects Texas A&M University's campus along Wellborn Road (FM 2154), which is a relatively high traffic area of College Station with average daily traffic on the order of 20,000 vehicles per day.

TTI's TransLink® Laboratory anchors one end of the network and was used to host all support equipment including video and data recording. The rail preempts at the test location

were monitored as the 'ground truth' indication of a train's passage for testing the low-cost active system technology. Traffic control video cameras were used at the test intersection of Holleman Drive and FM 2154 (Wellborn Road) to monitor activity at the test location. The cameras provided a clear view of the test grade crossing. The cameras transmitted full motion video over the entire field test period.

The TransLink® Research Center collects, monitors, processes and stores real time traffic data. It was designed and installed by TTI engineers several years ago and has been proven adaptable and reliable as to the specific data requirements of various research projects, as well as unconstrained in terms of capacity. The system collects active, transportation related data along a fiber optic broadband network route and transmits it to the TransLink® Research Center, as shown in Figure 1. The data for this project was collected at the intersection of Wellborn Road and Holleman Drive, the 'test' intersection. It was then transmitted to the TransLink® Research Center via the portion of the network parallel to Wellborn Road.

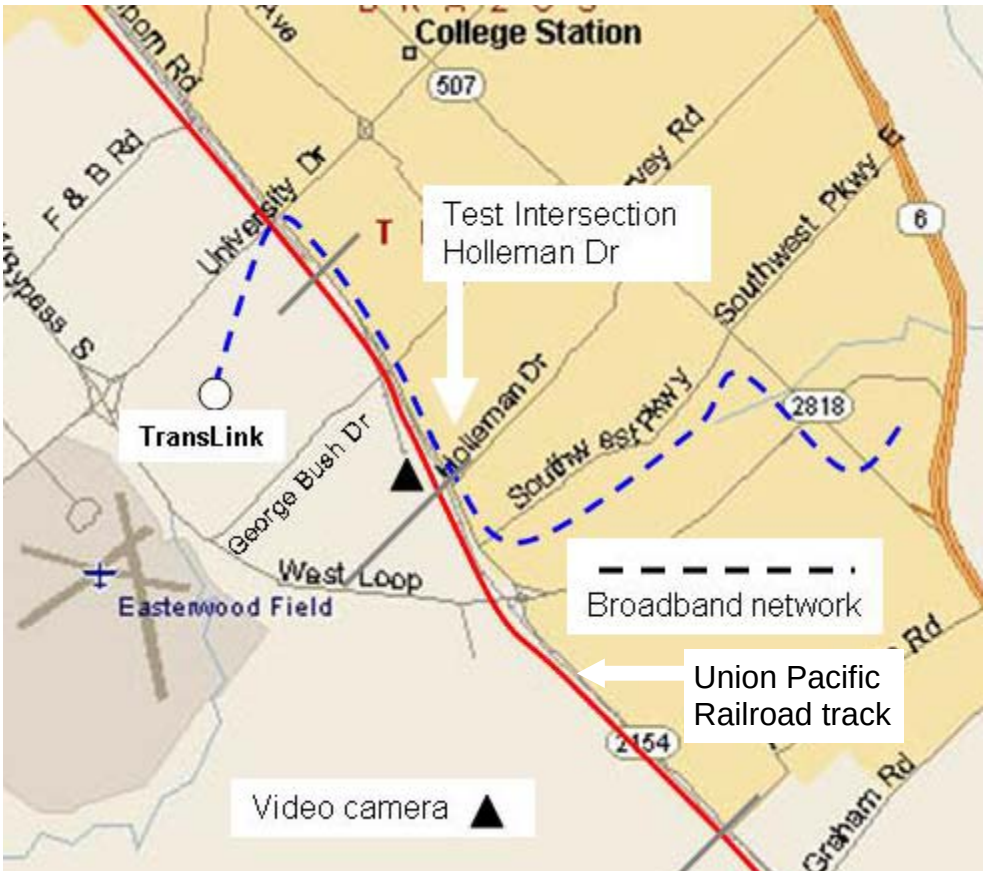


Figure 1. Fiber Optic Broadband Network Route.

VENDOR CONTACT

Phase I of this NCHRP project concluded with the identification of two potentially viable alternative technologies to the traditional track circuit based train detection system. The two alternatives were a radar technology system and an acoustic technology system, to be evaluated through on-site testing in this Phase II of the project. The systems selected fulfilled the requirements prescribed in Phase I. They both were commercially available low-cost warning systems, i.e. manufactured, available for purchase, installed and technically supported by the vendor. They also fulfilled the critical requirement of being located off the railroad right-of-way, to avoid any interface with the traditional railroad track circuit system. A completely independent operation, thus an unbiased platform for performance comparison, was ensured.

Both systems' manufacturers were contacted and asked to provide as much information as possible on their systems' operational specifications, capabilities and performance. After reviews of the two technologies, TTI was satisfied that both systems met the criteria established in Phase I. Arrangements were made to purchase one unit from each manufacturer. The radar technology system was purchased by TTI for $18,000 and the acoustic technology system for approximately $3,500. The vendors were informed of the reason for the purchase and asked to actively and fully participate throughout the entire test process, to which they agreed.

At this point it is imperative to state that highlights of the communication between TTI and each vendor are documented in Appendix A of this report.

TEST SITE SELECTION

The vendors were initially involved in the test process through selection of the test intersection, which, for technical reasons, was prescribed to be located along TTI's instrumented Wellborn Road-Union Pacific Railroad corridor. First, each vendor was provided with photos of two alternative grade crossings along the corridor to visually evaluate compatibility with their respective system's operating characteristics. Then, upon TTI's invitation, both vendors visited College Station and examined the two alternative test sites in person. Using their respective test equipment and instrumentation they evaluated their system's performance at each of the two alternative sites.

Figure 2 shows the first alternative site proposed by TTI, at the intersection of Wellborn Road and George Bush Drive. This location was not favored by either vendor because of its heavy vehicular traffic. Further, the four quadrant gates on the divided roadway were considered undesirable by the radar system vendor.

Figure 2. Alternative Test Site 1-Wellborn Road and George Bush Drive.

The second alternative site, shown in Figure 3, was located about a half mile south, at the intersection of Wellborn Road and Holleman Drive. The radar system vendor indicated his system's performance would not be affected if it were mounted on the traffic light pole, located on the Wellborn Road (east) side of the railroad track. The acoustic system vendor, however, indicated that his system would perform better if mounted as far away from Wellborn Road as possible, i.e. on the opposite (west) side of the railroad track.

The concensus stemming from both vendors was in favor of the second test site, at the intersection of Wellborn Road and Holleman Drive.

Figure 3. Alternative Test Site 2-Wellborn Road and Holleman Drive.

PRE-TEST PHASE

Each manufacturer was asked to provide as much prior information as possible on their system's operational specifications, capabilities and performance. At TTI's standing invitation, both vendors also made multiple visits to the test site to refine their systems' components and performance starting in early January 2006 through the (delayed) start of the data collection phase, which officially began on August 14, 2006. This delay was utterly unavoidable, as the vendors required more time than they originally estimated to optimize their systems' performance in field conditions. However, this task was necessary in order to efficiently initialize the test procedure, consisting of equipment installation, configuration, calibration, initial onsite testing, and finally, data collection. The information collected at this stage was relayed to the vendors and their feedback was incorporated into the test procedure.

More specifically, the radar system vendor made multiple test site visits to refine his system's components to exclude detection of vehicular traffic on adjacent Wellborn Road as much as possible. The acoustic system vendor made multiple visits to develop a 'library' of train horn frequency signatures, with the assistance of TTI researchers.

EQUIPMENT CHARACTERISTICS AND INSTALLATION

Acoustic Technology System

The acoustic system analyzed the frequencies of existing train horns and stored the components of each as a frequency file, or 'library', in order to later compare unknown frequencies against. The train horn detection system used an omni-directional microphone to detect an approaching train by detecting a frequency range in the ambient noise that was also in the known frequency spectrum of known train horns. The system was comprised of a microprocessor that compared the detected train horn with the library of known train horns stored in a look-up table.

The acoustic system incorporated a power supply, an analog microphone, an analog amplifier, an analog-to-digital converter, a digital microprocessor, a logic controller and a digital, electrically programmable read-only memory. Elements of convenience in this system were radio receivers and transmitters which transmitted the system's output to TTI's data collection system.

The system supplier made several exploratory trips to the test site to record local approaching train horn characteristics for the system look-up table. The system supplier stated that the selected test site is not ideal for this system because of the high amount of parallel roadway traffic within 30 feet of the railroad. The system was mounted on the city traffic light utility pole, approximately 14 feet above ground level and at approximately even height with the

nose hood of an American Modern cab locomotive. The city utility pole was approximately 10 feet from the public Wellborn Road curb, meaning the acoustic system was about 20 feet away from the east rail of the railroad track, as shown in Figure 4.

Figure 4. City Utility Pole and Test Site.

The acoustic system consisted of two cabinets, the upper, small gray cabinet and the lower, large gray cabinet, both mounted on the pole, as shown in Figure 5. The internal components of the lower cabinet - the acoustic system processor, programmable controller, and data transmitter/receiver radio - are shown in Figure 6. Figure 7 provides a close-up view of the microphone, which was attached to the bottom of the cabinet and was covered by a foam wind sock.

Figure 5. City Utility Pole and Test Systems.

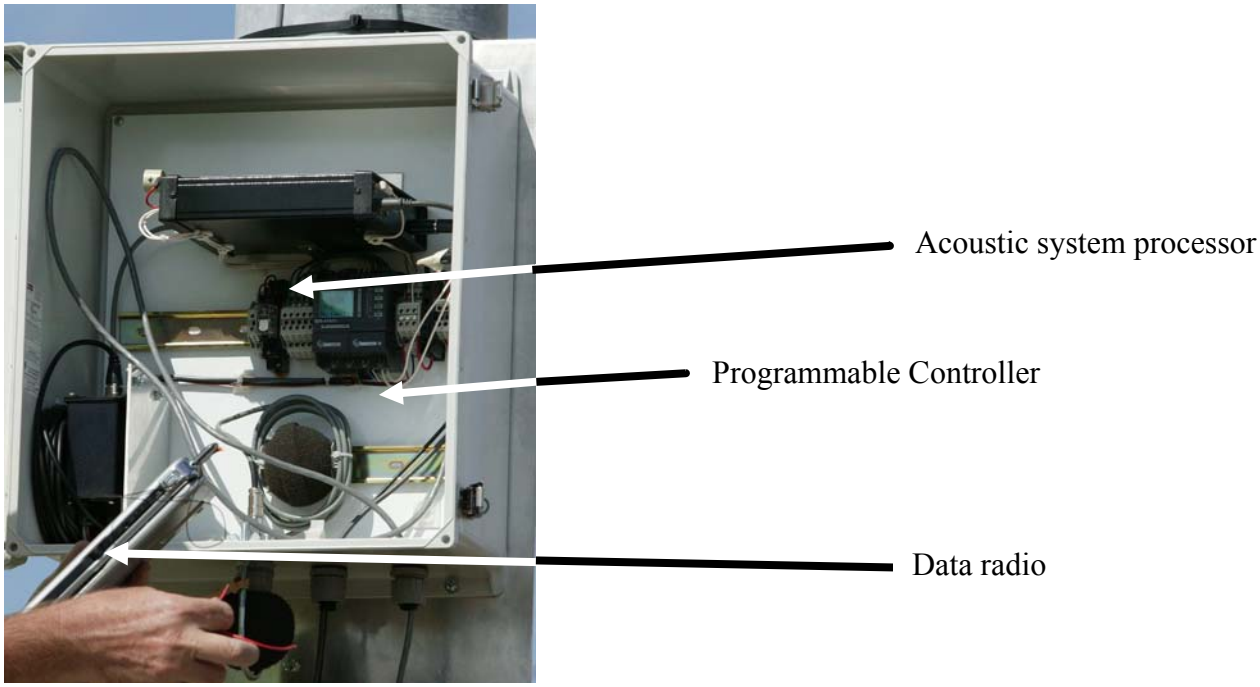


Figure 6. Acoustic System Internal Components.

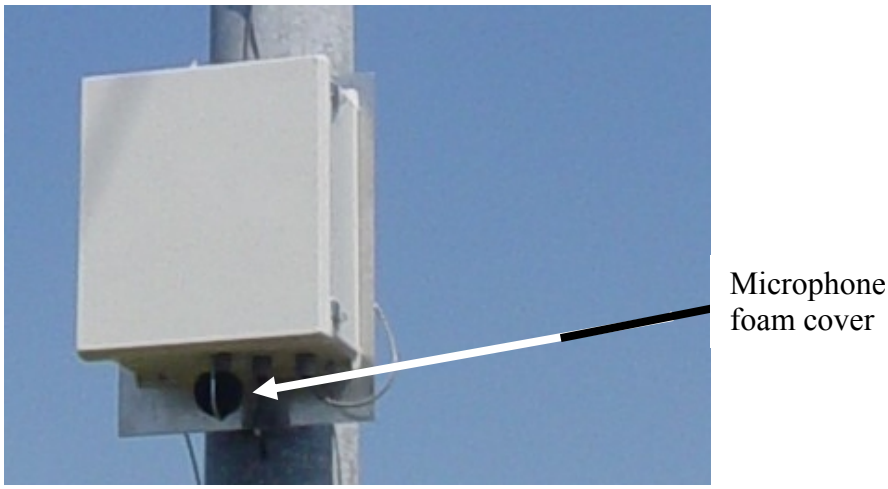


Figure 7. Acoustic System Microphone.

Radar Technology System

This system used a radar return from a large approaching object to detect approaching trains. It incorporated three radar antennas, a microprocessor for signal processing, a logic controller and a power supply. Two antennas accomplished the primary train detection and were enclosed in a single gray cabinet mounted on the city utility pole, directly below the upper acoustic cabinet. The internal components of this cabinet are shown in Figure 8. One antenna pointed in either direction of the railroad track and both were programmed to only look for trains approaching the grade crossing. Once the radar detected an approaching object, it used a proprietary algorithm to test the signal and then determined if the object signal was a train or a false indication. After a positive indication, i.e. a signal due to an approaching train, the system turned on a relay to (theoretically) operate the intended warning device.

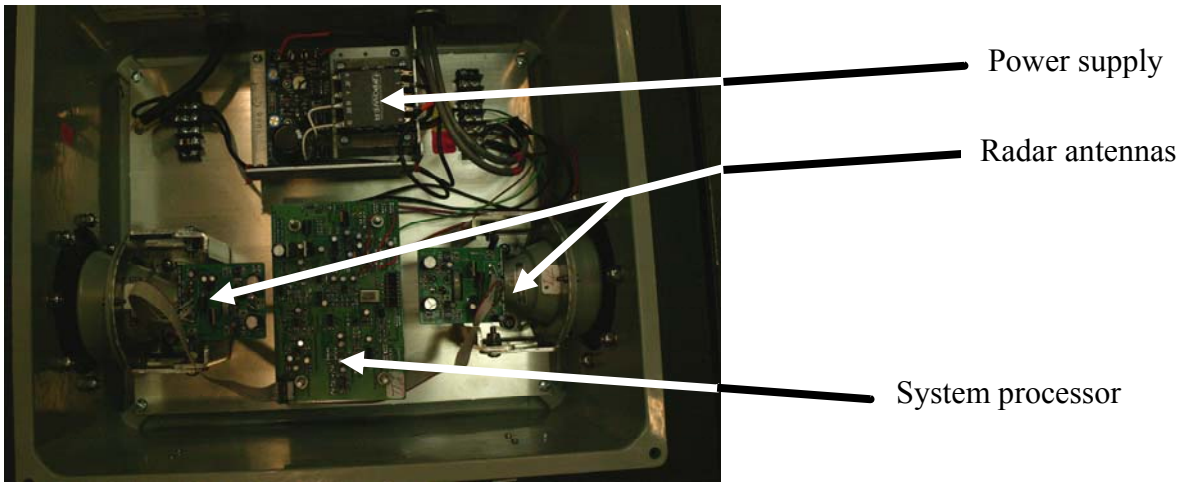


Figure 8. Radar System Internal Components.

To guard against the event of a train stopping in the intersection, the third radar antenna detected train presence at the crossing and maintained the active ('ON') condition of the warning device. The presence detector was pointed perpendicularly to the track and had a programmed region of influence, roughly bounded by the track width at both sides of the detector. The third antenna, shown in Figure 9, was enclosed in a separate small gray cabinet, mounted on the pole below the lower acoustic cabinet but, above the yellow pedestrian walk indicator.

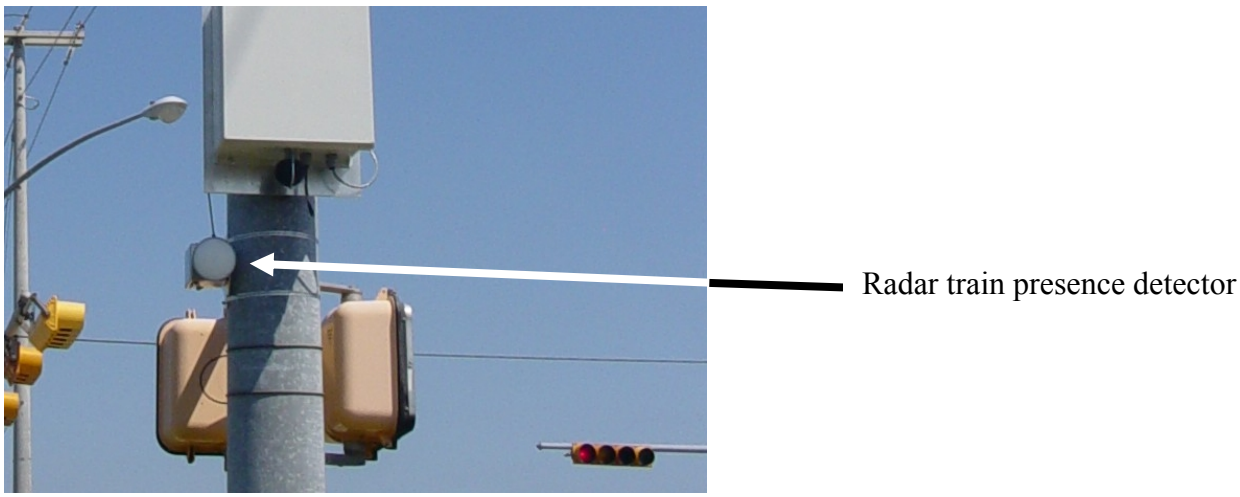


Figure 9. Radar System Third Antenna.

As mentioned above, the radar system vendor made several trips to the test site to re-evaluate his equipment configuration and design approach to optimize the system's performance in the given site conditions. The final configuration incorporated a beam deflector for the first two antennas that detected approaching trains. This deflector, shown in Figure 10, was incorporated in an attempt to minimize the interference of the parallel roadway traffic with the true detection of approaching trains.

Figure 10. Beam Interference Shield.

Manufacturer Descriptions

Radar Technology System

The radar system vendor, at TTI's request, provided his own description of his system's operation, for inclusion in this report. In his own words, the radar system's microwave signals use both Doppler and ranging radar sensors to detect the speed and presence of trains. On tracks with low speed trains, the sensors are mounted on the signal pole at the crossing. The sensor packages can be operated on solar power systems that are also mounted on the signal pole. All necessary electronics for flashing LED lights and sounding the bell are contained in the package.

Each sensor package has two Doppler sensors that detect approaching trains, one sensor for each direction. The narrow beam of the sensors is aimed to intersect the track approximately a quarter mile away. The speed measurement starts when the train enters the beam and continues until it has passed. These sensors detect only moving trains.

An FMCW (Frequency Modulated Continuous Wave) ranging sensor is also included in the sensor package located at the crossing. It detects stopped trains and confirms passing trains. This sensor is aimed across the track instead of up and down the track as with the Doppler sensors. The ranging sensor has the capability to detect train cars within a particular range window, thus eliminating false indications on objects that are not trains, such as fences and other vehicles.

Acoustic Technology System

The acoustic system vendor, also at TTI's request, provided his own description of his system's operation, for inclusion in this report, as well. In his own words, the acoustic detection of activity at railroad grade crossings is accomplished by comparing the local signals to a database of known acoustic signatures. Locomotive horn assemblies, train crossing rumble, and crossing traffic noise are principle signatures, and must be analyzed in real-time.

Utilizing digital signal processing, acoustic signals are analyzed for amplitude, frequency, and timing characteristics, identifying the signals that will be accepted, and those that must be ignored.

Local signals are compared to two acoustic signature libraries. An inclusory library defines the signals that match a known or custom train horn assembly, and the rumble associated with train activity at the crossing. An exclusory library defines the signals that match typical site acoustics, such as automobiles, aircraft, and weather effects. Upon detection of a signal defined

in the inclusory library, external hardware, such as active warning devices and data recorders are activated. The signals defined in the exclusory library are ignored.

A locomotive horn assembly, detected at the appropriate distance, activates external warning devices at the grade crossing. These warning devices remain active until the train arrives at the grade crossing. The "appropriate distance" is defined by federal and state regulation. The "remain active" time is defined by the site, based on train speed and detection distance.

FIELD DATA COLLECTION

TTI staff designed the data management system with simplicity and reliability in mind by keeping the field interface functions at a minimum. The field equipment simply collected each device's outputs and frequently transmitted them in raw format to the TransLink® Research Center. The means of transmittance was, as mentioned above, the adjacent fiber optic broadband network. The TransLink® Center's functions were of a higher order, in that computer applications were utilized to log, process and store the data.

The amounts and type of data output between the two systems differed. The radar system vendor provided a single, serial 9600 baud RS-232 data stream, as requested by TTI researchers. The data stream consisted of the following four data elements:

- south bound train speed
- north bound train speed
- indication of presence detection
- indication of gate activation

The acoustic system vendor provided three discrete data elements, recorded through dry contact relay outputs:

- train horn detection
- track noise detection
- gate activation

The operational context of both test systems mandated placement of their sensory equipment near the rail line. Therefore they were both mounted on a traffic signal pole near the rail line. As shown in Figure 11, they were enclosed in the field control cabinet, together with the field processor that collected the test systems' output. A radio system (IEEE 802.11b) transmitted the output from the field control cabinet to a nearby access point into the broadband network due to the lack of a hardwire connection.

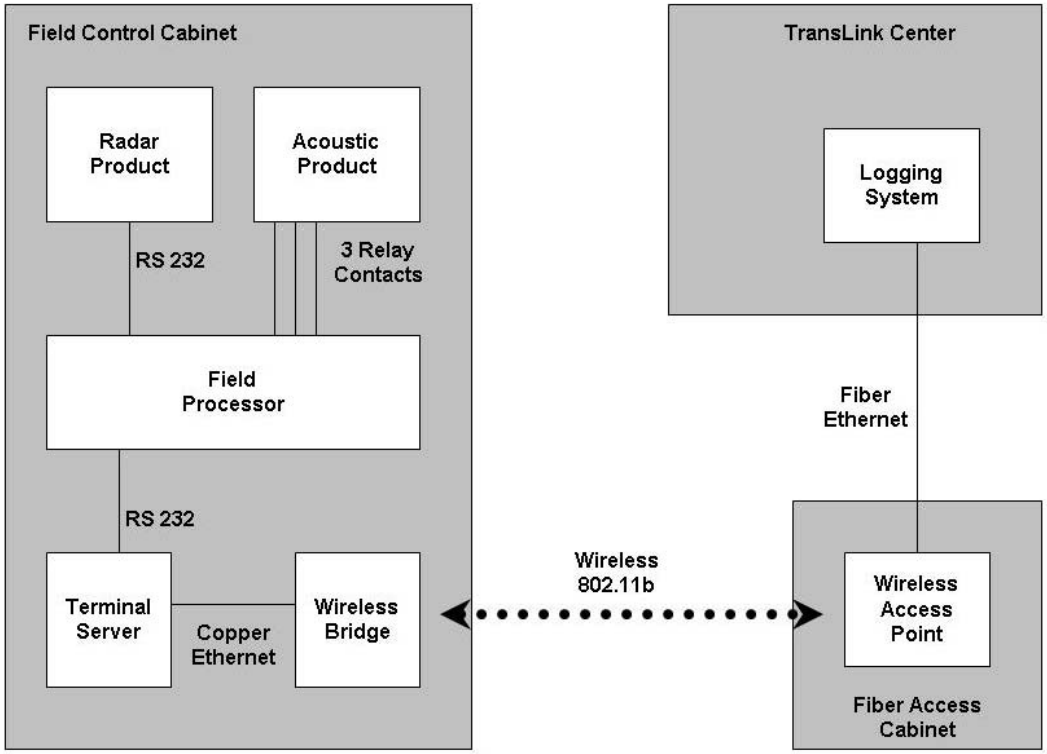


Figure 11. Data Flow: Field to TransLink® Center.

The field processor was designed to be fault tolerant. The first function was to time-stamp and integrate output from both test systems into a single data stream before forwarding it to the logging system in the TransLink® Center. Its second function was system monitoring. The radar system broadcasted its status to the processor as a serial message, whereas the processor continually checked the acoustic system's relays for changes. If any change in the monitored devices occurred, for example a new serial message from the radar system, a new message was immediately created by the processor and transmitted to TransLink®. A message was created and transmitted at regular intervals if there had been no change in system status. The strategy ensured consistent message flow and timely delivery of event changes to the Center, in other words ensuring synchronization between field data collection and data processing. Thus, the 'office' system was always aware of the true field condition, even if messages had been lost in transmission. Similarly, the 'office' was alerted of any irregularity in field conditions through the generation and transmission of an error message.

The field processor also performed calculations based on the vendor sensor output data, such as the time lapse since the last change in status of each device, for instance the last time a radar sensor output was received. It then combined it with external information such as time and packet number data in order to enable identification of possible operational problems. These could include sensor breakdown, interruptions of any duration in data flow from the devices to the processor or failure of the processor log system, i.e. no outflow of data.

The field processor also detected interruptions in the transmission of data generated by the central logging system. If the communication stream was lost, the field processor automatically cycled down its own power and cycled up the power of the communication equipment, in an attempt to reestablish communication. The watchdog effort was designed to

overcome any deficiencies in the communication equipment that could only be addressed by power cycling. The system was designed without the ability to power cycle the vendor devices. This was specifically done to ensure that their performance was not affected in any way.

DATA PROCESSING

The railroad gate activation signal is determined via the preemption signal delivered by the railroad grade crossing signal equipment to the roadway intersection traffic signal controller. The railroad gate activation signal starts when lights begin to flash and gates begin to lower. Similarly, the activation signal ends when the gates begin rising, after the train has cleared the intersection. The test intersection was already outfitted with a simultaneous preemption mechanism, installed by the railroad. Simultaneous preemption indicated both the start and end of the railroad gate activation to the traffic signal controller. The preemption indication was transmitted as a continuous data stream from the traffic signal controller *directly* to the central data logging platform, via the fiber optic network.

The two vendor systems were evaluated on the basis that the intersection railroad track circuit was the 'ground truth'. However, a video camera view of the test site was incorporated to augment the track circuit system. The video functioned as an absolute indication of the intersection status. It was accepted that the railroad track circuit was extremely reliable and accurate. However, there were a few events that triggered false activations of the track circuit system. Examples are shown in the video snapshots of Figure 12. These false activations occurred due to the presence of maintenance of way machines, highway-rail trucks, or railroad signal department technicians testing or making adjustments at the intersection. Video recording was activated by the track circuit preemption system and a detection by the radar system.

Figure 12. False Track Circuit Activations: Video Capture.

A software application was developed to manage data communication with the field. Its tasks included the reception, processing and logging of incoming field data. The application operated on a personal computer (PC) linked to the broadband fiber optic network. The software collected the incoming raw messages of the field equipment and created a pair of simple text files, one for the data log of each test system. The fields included the time the gate activation status of either vendor system or the track circuit changed, thus capturing every event declared by every system, in chronological order.

A second software application was developed to organize the chronological data into detection events. A detection event included the activation and deactivation time of both the test system (either radar or acoustic) and the ground truth track circuit for a single train. An event was declared whenever a test system *or* the rail system was activated. The event ended when *both* the test system *and* the ground truth were deactivated.

The files were then exported into Microsoft Excel spreadsheets and used in data analysis.

In addition, the software captured video images during each vendor system activation or railroad gate activation. Video frames were collected and stored at a rate of two frames per second. This frequency was chosen to provide acceptable coverage without creating an exorbitant number of files. Each video image included a time stamp which also reflected its filename. The video image files verified the activity in and around the test site during any logged event. Figure 13 shows a computer screen snapshot of the software.

Another software application was also developed to support equipment installation during the initial test phase. The wireless radio signal allowed the vendors to receive the raw data of their device on a wireless equipped laptop, while at the test site. Real time data was instrumental in fine tuning the installation of their equipment.

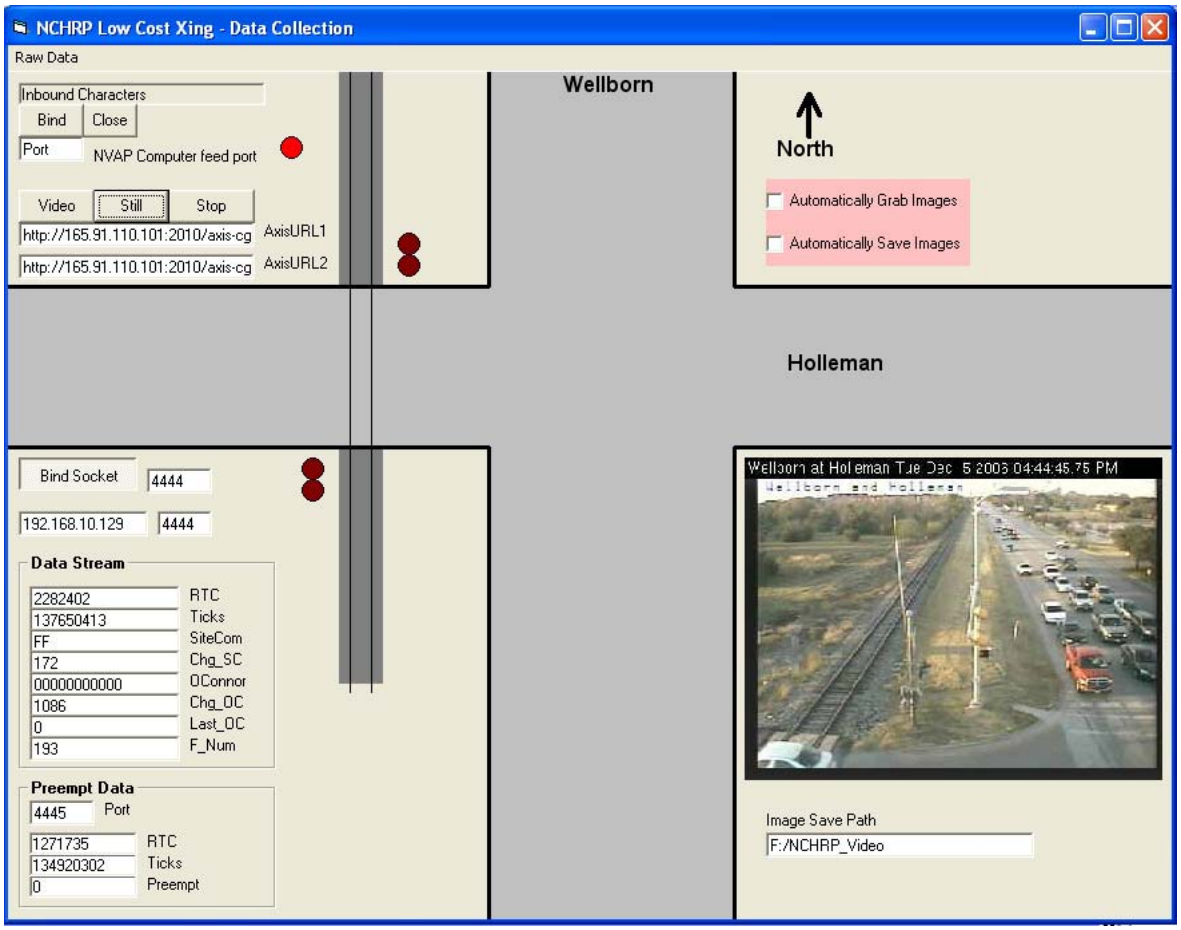


Figure 13. Data Logging Software: Computer Screen Snapshot.

CHAPTER 3

DATA ANALYSIS AND RESULTS

DATA DESCRIPTION

The data collection period consisted of 76 consecutive days (24-hour periods), from August 14, 2006 through October 28, 2006. The total number of trains was 1486, all of which were detected by the existing rail system (track circuit based) and both test systems (radar and acoustic based). Other general statistics include:

- Average number of trains per day = 20
- Standard deviation of number of trains per day = 4
- Minimum number of trains per day = 7
- Maximum number of trains per day = 27
- Average train speed = 26-27 mph
- Maximum train speed = 36-38 mph
- Minimum train speed = < 5 mph (crawl speed)

Two datasets in the form of Microsoft Excel spreadsheets were generated from raw text files. The first file included the radar system and the rail system activation data. The second file included the acoustic system and the rail system activation data, which was the same as in the first file. Both files contained the same data fields, which consisted of:

- Index number for each activation of the test system. Total radar activations numbered 3,459 and total acoustic activations numbered 26,094.
- Test system activation start time. Date and time 'stamp' that each test system made a detection.

- Test system activation end time. Date and time 'stamp' that each test system's activation ended.
- Rail system activation start time for each true test system activation. This field showed a '0' for false test system activations, that is, if the test system activation was not accompanied by an actual train event.
- Rail system activation end time for each true test system activation. This field, too, showed a '0' for false test system activations, that is, if the test system activation was not accompanied by an actual train event.

PERFORMANCE MEASURES

Figure 14 illustrates the concept of the rail system's activation length, start time and end time. It is important to note that in the figure, a time scale, not a distance scale, is utilized. The reason is that the minimum required advance detection time of a train approaching a grade crossing is 20 to 25 seconds. On a time scale, the rail system shows an activation start at a constant 20 to 25 seconds ahead of the crossing, since, after all, it is a Constant Warning Time system. On a distance scale, the speed of each train is a major factor. Fast train detection will be shown to occur at a greater distance ahead of the crossing to allow for the minimum advance detection time. Similarly, slow trains may only be detected only a few hundred feet ahead of a grade crossing. Figure 15 graphically adds the test system's activation length, start time and end time to Figure 14, so that the same concepts between the rail and test system are best illustrated and compared.

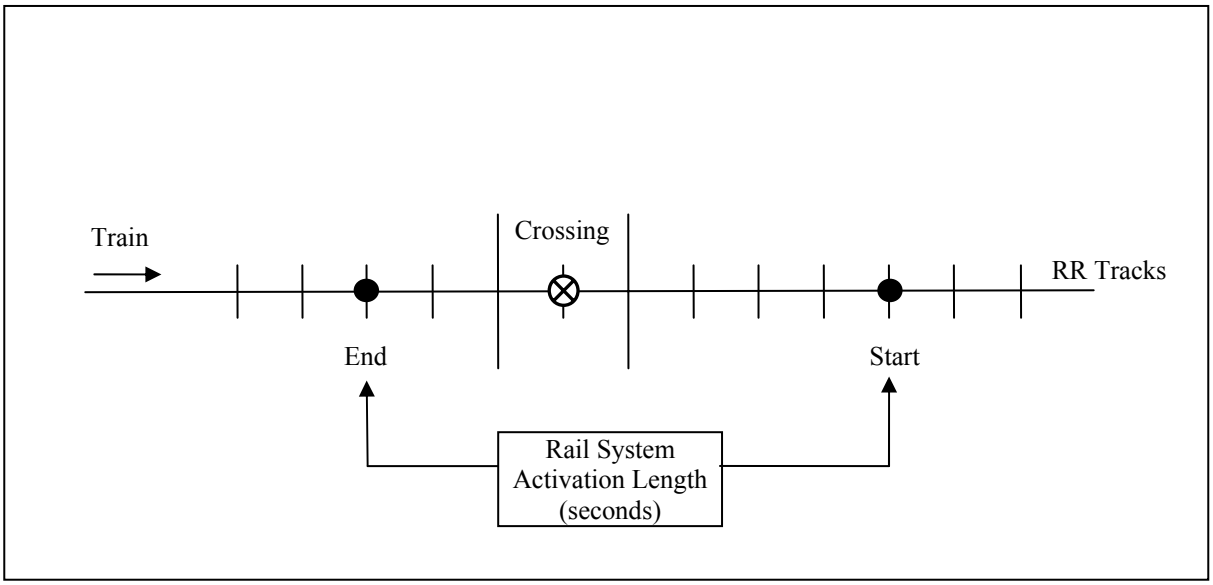


Figure 14. Rail System Activation Length.

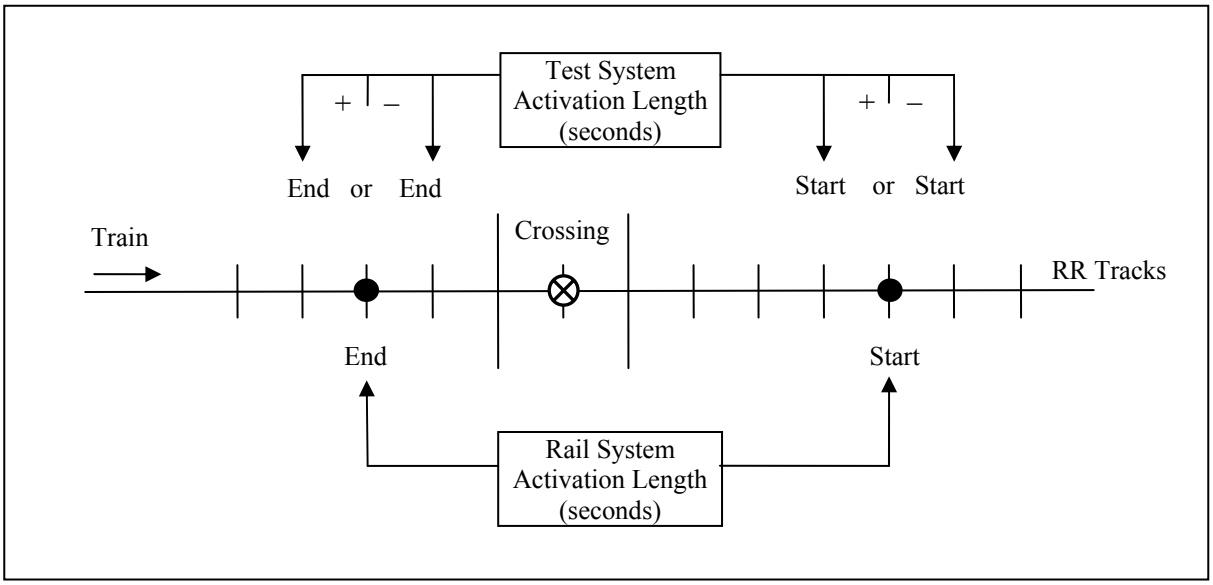


Figure 15. Test System vs Rail System Activation Length.

Four performance measures were chosen to compare each of the two test systems against the existing rail system:

- Activation Length: Time, in seconds, from each system's activation start time to each system's activation end time. This was calculated as activation end time minus activation start time for the rail system as well as each of the two test systems.
- Activation Start after Rail: Time, in seconds, between the rail system's activation start time and each test system's activation start time. In other words, it is the time difference in activation (or detection) time between the rail system and each test system. It was considered to be a key performance measure, as the minimum required advance warning when a train approaches a grade crossing is 20 to 25 seconds. This measure was calculated as the test system's activation start time minus the rail system's activation start time. Hence, if the difference has a positive sign, the test system activated after the rail system. If the difference has a negative sign, the test system activated before the rail system.
- Activation End after Rail: Time, in seconds, between the rail system's activation end time and each test system's activation end time. In other words, it is the time difference in the activation end times between the rail system and each test system. It was considered to be another key performance measure as about 10 seconds of grade crossing clearance time is generally allowed for, due to traffic safety reasons. This measure was calculated as the test system's activation end time minus the rail system's activation end time. Again, if the difference has a positive sign, the test system activation ended after the rail activation. If the difference has a negative sign, the test system activation ended before the rail system activation did.
- Probabilities of True and False Activation: It became evident from the activations data pool that both test systems displayed a far greater number of false rather than true

activations. That is, the test systems' activations, most of the time did not correspond to actual train events. Hence they were termed 'false activations', in contrast with 'true activations'. In contrast, all rail system activations corresponded on a 1:1 basis with actual train events, hence the rail system displayed 100% 'true' activations or 100% 'true' detections. The probability of each test system activation being true or false was estimated as the overall measure of train detection capability of each test system against the existing rail system.

RESULTS

The number of total trains during the study period, as mentioned above, was 1486. Consequently there were 1486 rail system activations all of which were true, i.e. each rail system activation was accompanied by a train event – or a correspondence of 1:1 between rail system activations and train events. Since the rail system is the basis for comparison, the average activation length and standard deviation of these activations are shown in Table 1. The rather large standard deviation value can be attributed to the variability in the speed (and length) of each train. Slower (or lengthier) trains take a longer time to traverse the grade crossing.

Table 1. Rail System Performance.

RAIL SYSTEM	True Activations (Total trains)	False Activations
Number	1486	0
Activation Length, sec Average (Standard Deviation)	149 (65)	–

Radar System

The total number of radar system activations during the study period was 3459, 1486 of which were true i.e. accompanied by a rail system activation and a train event. The remaining 1973 radar activations were false, not accompanied by a rail system activation nor a train event.

Figure 16 illustrates the relationship between the rail system and the radar system activations in the form of a zen diagram. The majority of activations being false, presents a serious implication as the reliability of this low cost active warning system.

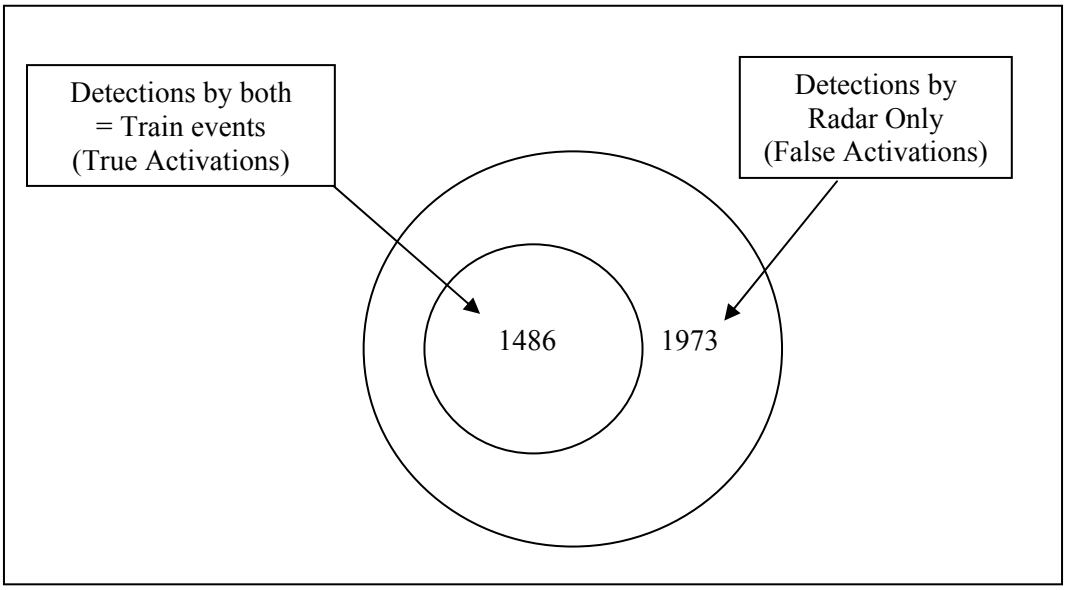


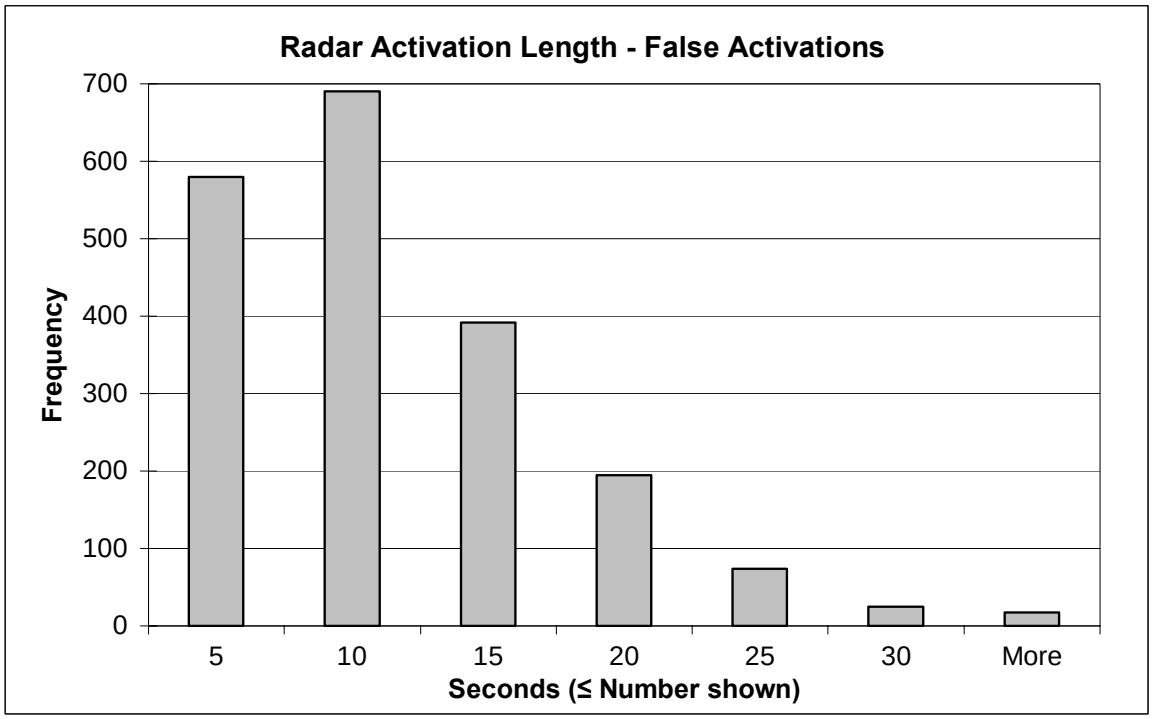
Figure 16. Relationship of Radar System Activations to Rail System Activations.

Table 2 shows that the average length of these false activations was 10 seconds, a relatively fleeting duration. It can only lead to the deduction that these 'detections' were not trains but fleeting objects of some sort. Observations from the initial test phase indicate adjacent road traffic as being the most likely culprit. Further investigation, however, as to the individual triggers of these false detections is beyond the scope of this research.

Table 2. Radar System Performance.

RADAR	True Activations	False Activations
Number (Total=3459)	1486	1973
Activation Length, sec Average (Standard Deviation)	160 (66)	10 (10)
Activation Start after Rail, sec Average (Standard Deviation)	-1 (17)	–
Activation End after Rail, sec Average (Standard Deviation)	10 (7)	–

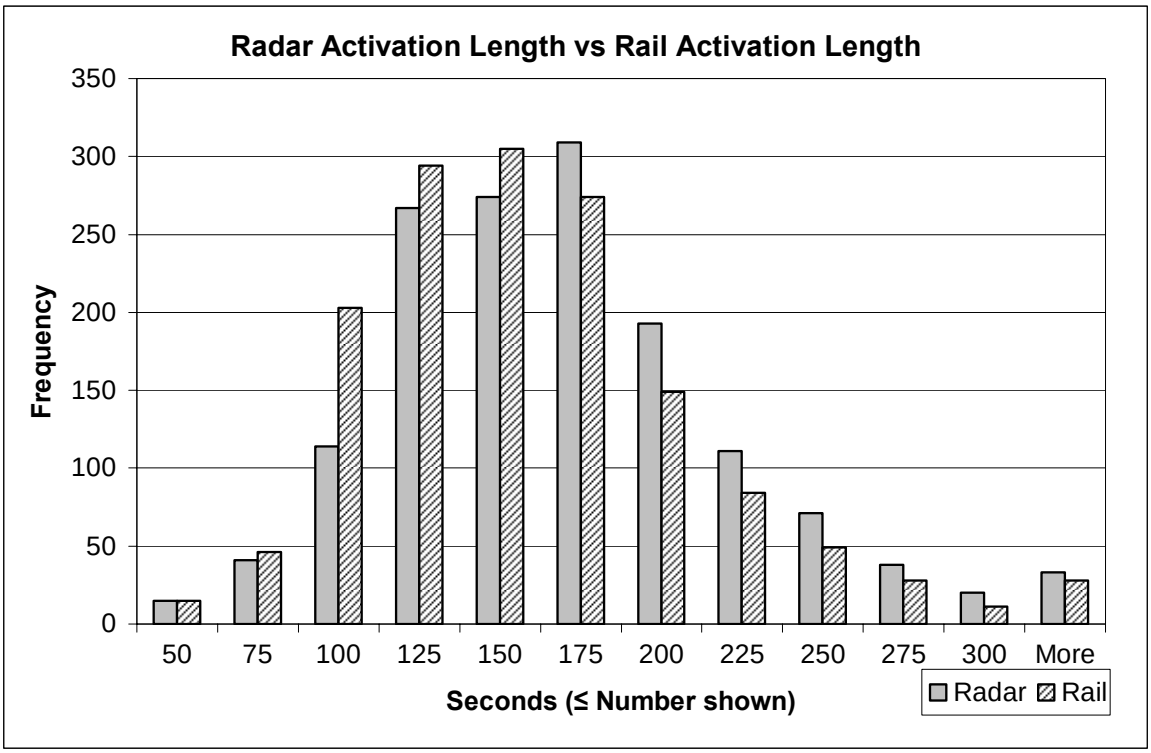
Figure 17 shows the distribution of false activation lengths, with the vast majority lasting 15 seconds or less.



**The data used to generate the chart is presented in Table B-1.*

Figure 17. Radar Activation Length – False Activations.

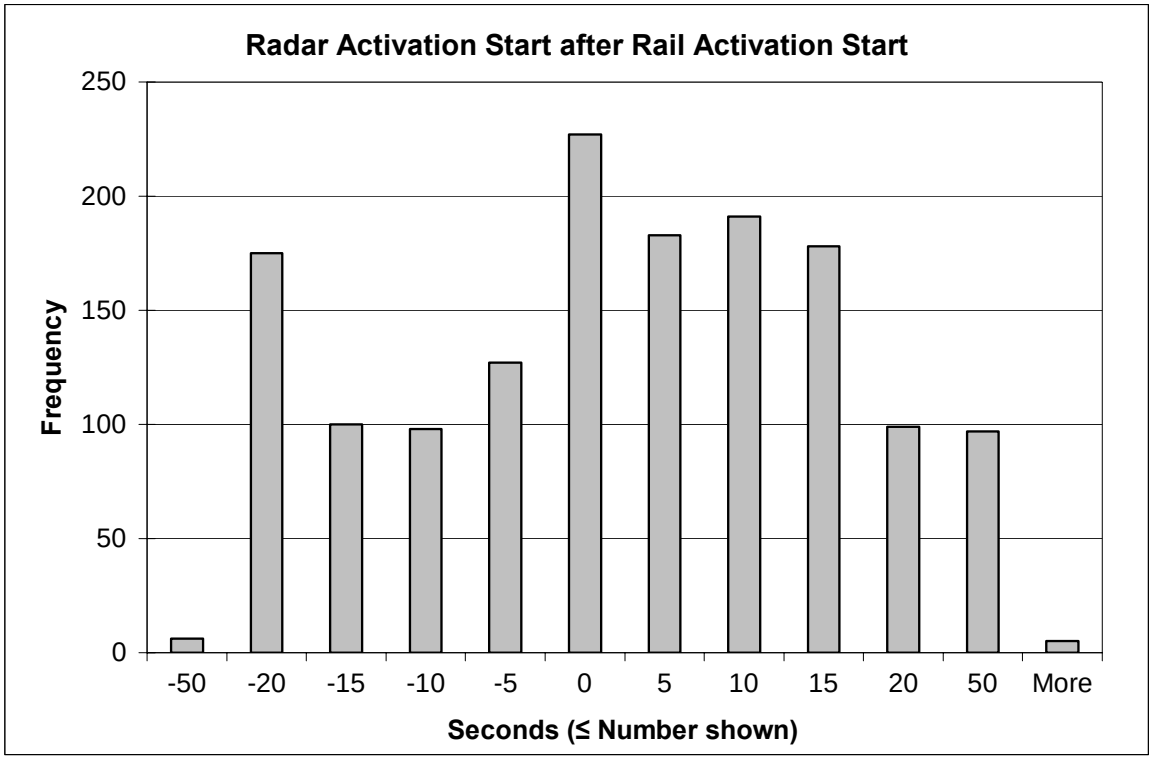
Table 2 also shows that the average radar system activation length was 160 seconds, as compared with the average rail system activation length of 149 seconds (Table 1). The 160 second radar activation length amounted to a 1 second average early start and a 10 second average late end of radar activations with respect to rail. Thus, one can safely deduce that the radar system exhibited more conservatism over the existing rail system in terms of the crossing clearance time. The standard deviations in activation length were similar, thus lending some degree of confidence in the radar system. Figure 18 compares the distributions of the activation lengths of the two systems. On one extreme, shorter activation lengths include the fastest (or shortest) trains that required the least time to traverse the crossing. The other extreme includes the longest activation lengths which provide for the slowest (or longest) trains to traverse the crossing.



**The data used to generate the chart is presented in Table B-2.*

Figure 18. Radar Activation Length vs Rail Activation Length.

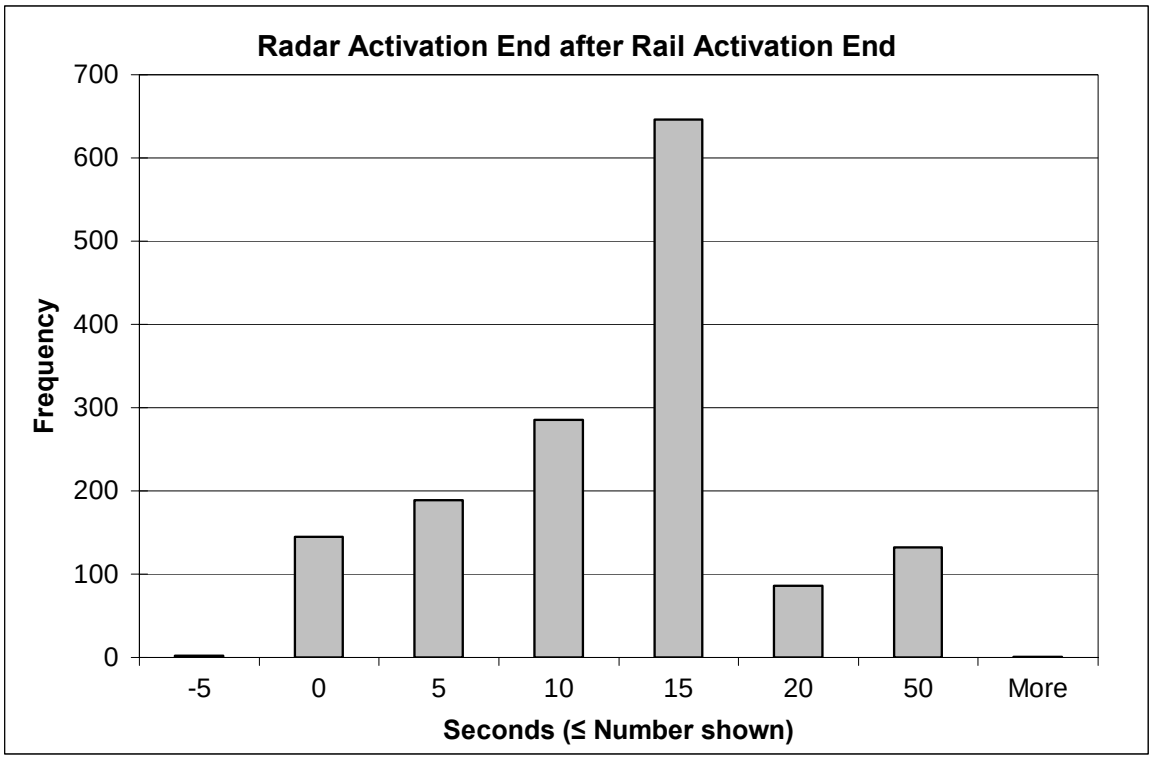
However, wide variability, shown by the standard deviation, was exhibited in the radar activation starts with respect to rail activation starts. The most serious implication was that the 20-25 second minimum advance warning time requirement was in many cases not met. Figure 19 shows the distribution of the radar activation starts after the rail activation starts and evidence is the heavily populated categories on the right of the '0'. The categories on the left of the '0' show the other end of the spectrum, with the radar system activations that started long before the rail system's. The effect could have been additional road traffic delay caused by the pre-extended crossing closure time.



**The data used to generate the chart is presented in Table B-3.* *'0' seconds denotes simultaneous start.*

Figure 19. Radar Activation Start after Rail Activation Start.

The closure time was post-extended by the radar's average activation end of 10 seconds after the rail's, and to some degree, by the respective standard deviation. Figure 20 shows that the vast majority of radar activations ended 10-15 seconds after the rail activations did.



**The data used to generate the chart is presented in Table B-4.* *'0' seconds denotes simultaneous end.*

Figure 20. Radar Activation End after Rail Activation End.

Acoustic System

The total number of acoustic system activations during the study period was 26094, 1486 of which were true i.e. accompanied by a rail system activation and a train event. The remaining 24608 acoustic activations were false, not accompanied by a rail system activation nor a train event. Figure 21 shows the relationship between the rail system and the acoustic system activations in the form of a zen diagram. The large number of false activations has fatal implications for the usefulness of this low cost active warning system.

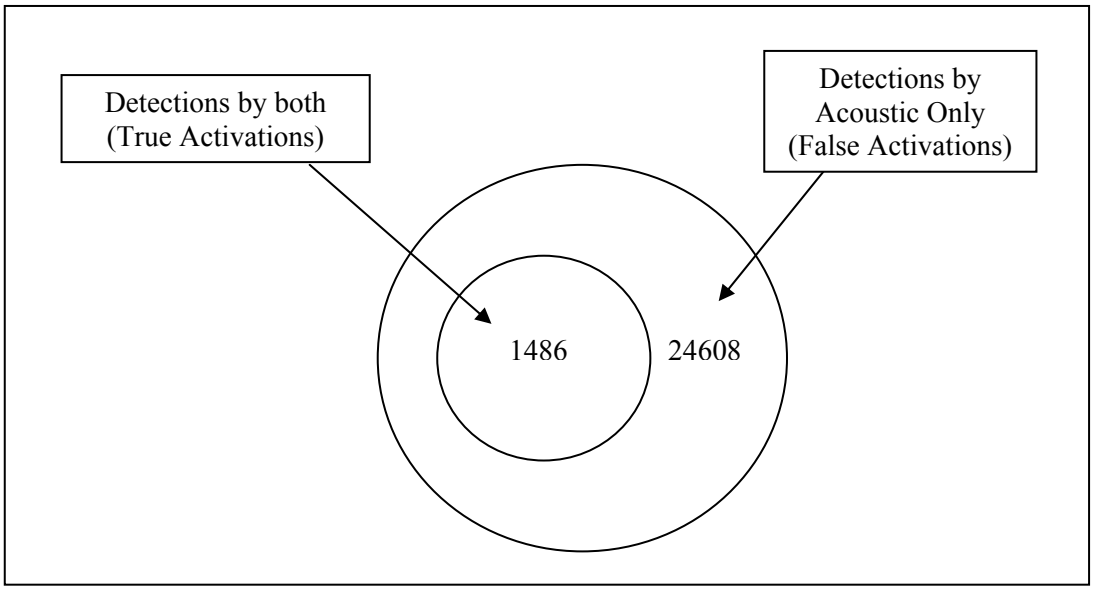


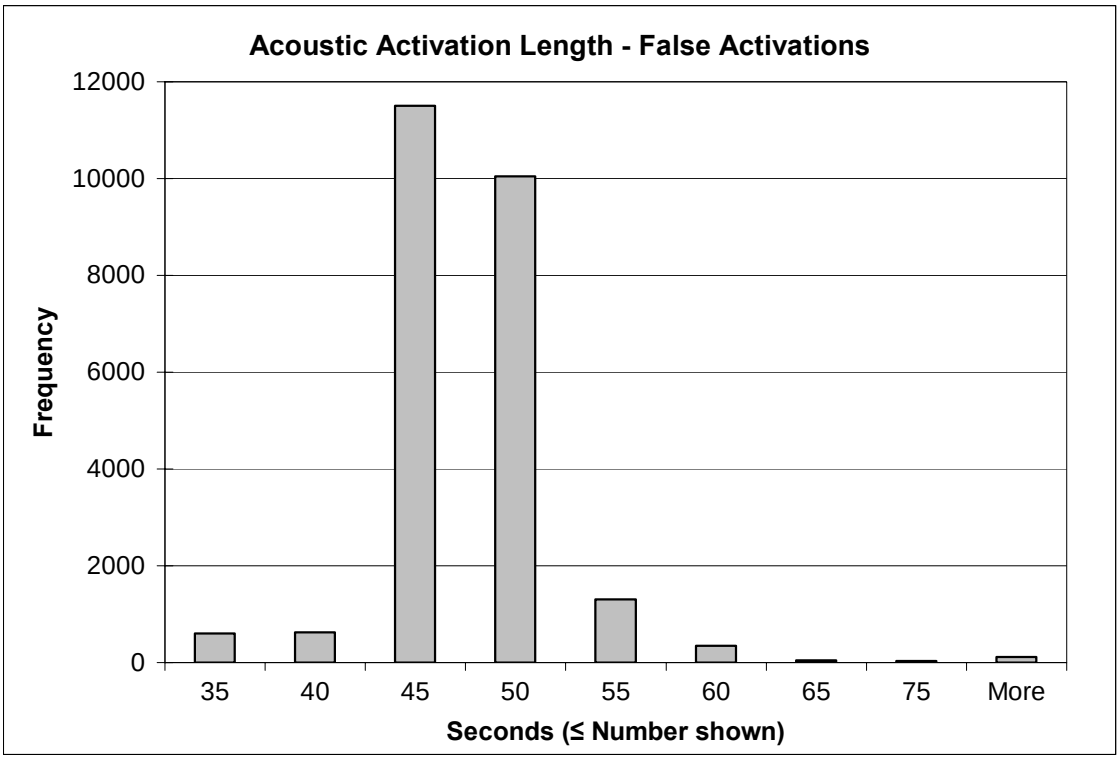
Figure 21. Relationship of Acoustic System Activations to Rail System Activations.

Table 3 shows that the average length of these false activations was 46 seconds. Although longer than the 10 second fleeting durations of the radar system's false activations, these 'detections' were not trains. The researh staff can only speculate as to the nature of the errors, whether external in origin or something internal to the system. Observations from the initial test phase indicate overhead air traffic and adjacent road traffic noise as being the most likely culprits. Further investigation, however, as to the individual triggers of these false detections is beyond the scope of this research.

Table 3. Acoustic System Performance.

ACOUSTIC	True Activations	False Activations
Number (Total=26094)	1486	24608
Activation Length, sec Average (Standard Deviation)	135 (51)	46 (7)
Activation Start after Rail, sec Average (Standard Deviation)	21 (47)	–
Activation End after Rail, sec Average (Standard Deviation)	7 (19)	–

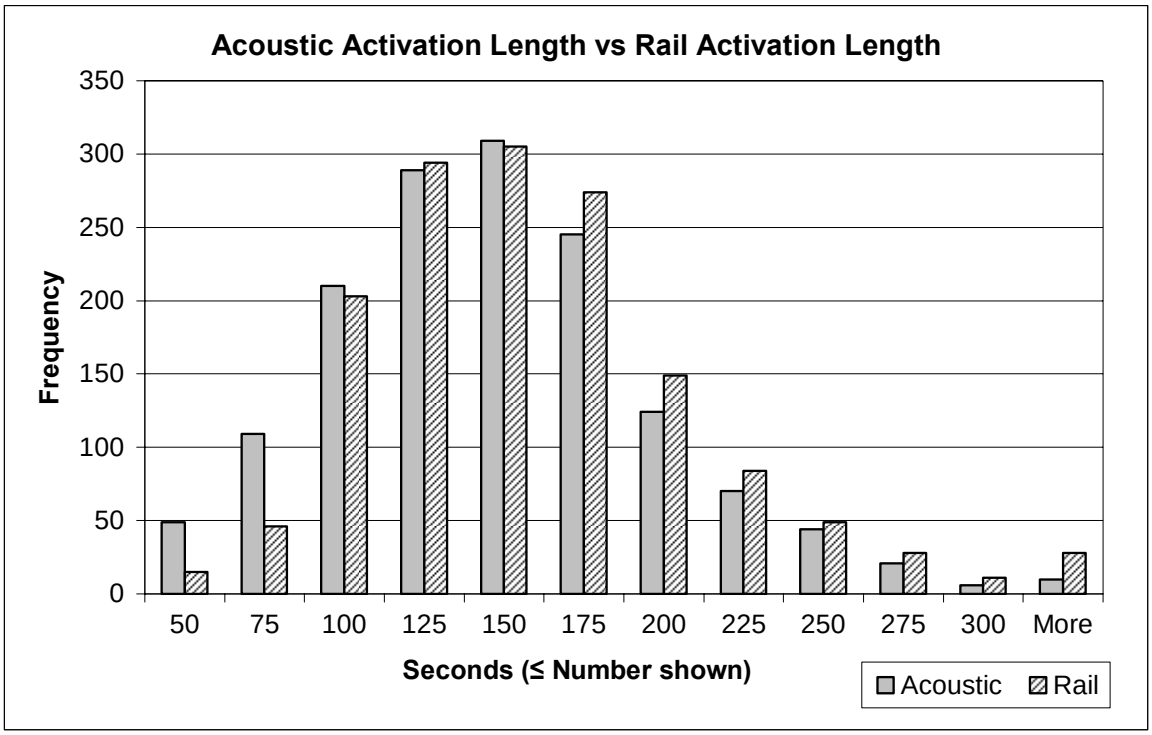
Figure 22 shows the distribution of false activation lengths, with the vast majority lasting 40 to 50 seconds.



**The data used to generate the chart is presented in Table B-5.*

Figure 22. Acoustic Activation Length – False Activations.

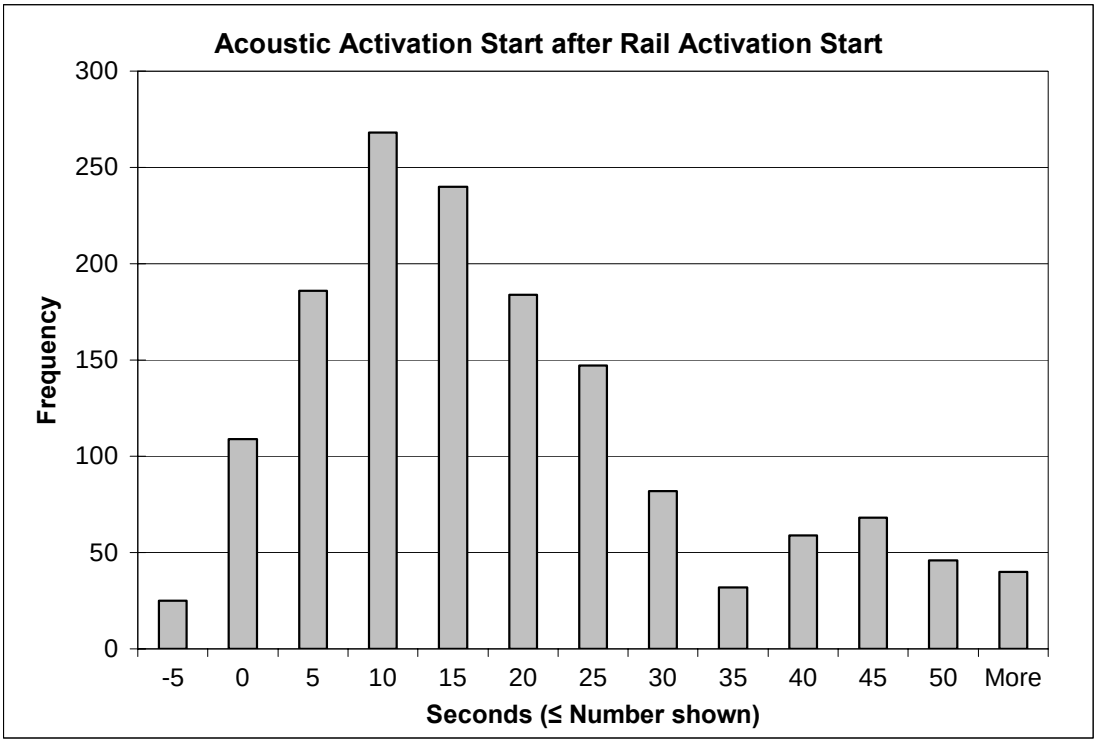
As also shown in Table 3, the average acoustic system activation length was 135 seconds, considerably shorter than the average rail system activation length of 149 seconds (Table 1). The shorter average length can be attributed mostly to the rather large 21 second average late start, somewhat offset by the 7 second average late end of acoustic activations. The implication of this result is that the acoustic system frequently failed to detect the train horn since the sounding of the horn usually corresponds with light and gate activation. Figure 23 compares the distributions of the activation lengths of the two systems. On one extreme, shorter activation lengths include the fastest (or shortest) trains that required the least time to traverse the crossing. The other extreme includes the longest activation lengths which provide for the slowest (or longest) trains to traverse the crossing.



**The data used to generate the chart is presented in Table B-6.*

Figure 23. Acoustic Activation Length vs Rail Activation Length.

High variability, shown by the standard deviation, was exhibited by the acoustic activation starts with respect to rail activation starts. The most serious implication was that the 20-25 second minimum advance warning time requirement was not being met. Figure 24 shows the distribution of the acoustic activation starts after the rail activation starts. The bulk of acoustic activations started simultaneously to 25 seconds after the rail activations. There were few early starts, as seen from the first category (5 to 0 seconds early).

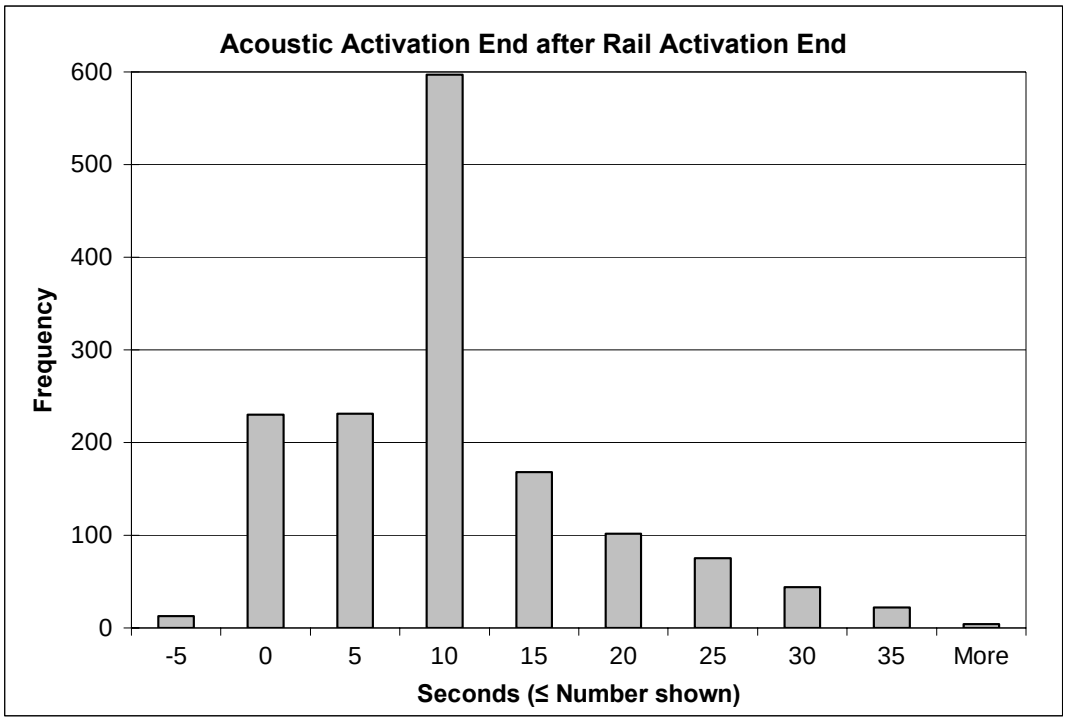


**The data used to generate the chart is presented in Table B-7.* *'0' seconds denotes simultaneous start.*

Figure 24. Acoustic Activation Start after Rail Activation Start.

The majority of acoustic activations ended 5-10 seconds after the rail activations did, exhibiting some conservatism, as shown in Figure 25. However, the high standard deviation, at 19 seconds, hinted premature activation end times not meeting the 10 second clearance time thus

creating potentially unsafe situations, at worst. At best, the crossing closure time was post-extended and caused traffic delays.



**The data used to generate the chart is presented in Table B-8. '0' seconds denotes simultaneous end.*

Figure 25. Acoustic Activation End after Rail Activation End.

Overall Test System Performance

The findings of this analysis clearly show that both test systems, the radar based and the acoustic based, present a far greater probability of false, rather than true, activations. Unfortunately, most of the time, the test systems did not detect actual train events. In contrast, all rail system activations naturally corresponded on a 1:1 basis with actual train events, hence the rail system displayed 100% true activations or 100% true detections. The true or false probability of each activation of each test system was estimated as the overall performance measure (or general indicator) against the existing rail system. The results, in absolute numbers and percent probabilities, are shown in Table 4.

Table 4. Overall Test System Performance.

PROBABILITIES	Detection	True Activation	False Activation
Radar	1486/1486 100%	1486/3459 43%	1973/3459 57%
Acoustic	1486/1486 100%	1486/26094 5.7%	24608/26094 94.3%

The results of the data analysis indicate that detecting a train appeared possible for the low cost systems tested. Far more challenging, was detecting *only* a train. This ability to discriminate appears to be a feature of more expensive active warning systems. The implications of these results are somewhat disheartening. If motorists always stopped for a warning signal, there would be no issue with systems that have many false positive train detections. However, as a rule, motorists tend to disregard and lose respect for low fidelity traffic control devices. Even at very low failure rates, motorists will begin to question the validity of a system.

CHAPTER 4

POLICY AND INSTITUTIONAL ISSUES

IMPACT OF TORT LIABILITY LAW ON GRADE CROSSING WARNING SYSTEMS

The U.S. system of tort liability has had the effect of keeping grade crossing warning systems and related practices in a sub-optimal, yet predictable, balance. The railroads, who largely bear the brunt of litigation resulting from accidents, are adverse to moving away from systems that are highly reliable, long lived, and recognized by the motoring public. Any inclination to do so would likely be punished in the courts either as an act of omission or, paradoxically, as one of commission. By this we mean that if the system put in place to warn motorists of train movement was somehow better than existing systems (i.e., crossbuck or track circuit based), then when an accident occurs at a location equipped with a traditional active system, plaintiffs would contend that the railroads are liable because they know there are better systems available but have chosen to neglect upgrading certain grade crossings — an act of omission. On the other hand, if railroads (or any entity taking responsibility for risk at crossings) install equipment at a grade crossing that is in any way inferior to current technology — independent of cost — then liability will likely be maintained because the responsible entity knows that the alternative system is not as good as existing systems – an act of commission.

This reality, along with all of the other conditions governing grade crossing safety practices (conditions such as train stopping distance, the human propensity to commit errors in judgment or fail in vigilance, and the prevailing sense in our legal system that the motorist's responsibility to yield to train traffic at crossings can be mitigated by a long list of extenuating circumstance), keeps innovation and improvement at bay. When coupled with the railroads'

need to monitor and maintain active grade crossing systems, which understandably drives the desire to keep all but railroad employees off railroad property, we are faced with a calcified and difficult to change equation for safety at grade crossings.

The public sector too is adverse to assuming additional risk, cost, and responsibility. The cost of installing active systems, while largely a public expenditure, is but a portion of the total life-cycle cost of keeping active grade crossing warning systems operational. As long as railroads can bear this expensive burden, they will likely continue in their uneasy public safety role. For a public entity to assume responsibility for active systems that are less expensive, but operationally inferior, in any respect, to the existing, accepted practice, is seen as highly unlikely. Tort liability reform is a necessary precursor to change. Subsequent work in the area of low-cost active systems will need to address both the reliability of the available options and the kinds of legal changes necessary to allow the introduction of systems designed to offer active traffic control at passive crossings. If it can be demonstrated that overall safety is enhanced by new technology — even if some system failures can be expected, like the false positives observed in this evaluation— then the public sector should be encouraged to pursue a higher level of aggregate safety. This research investigated low-cost warning systems as well as options towards facilitating movement in this direction, i.e. changing the apportionment of risk (and liability).

A graphical display developed for Phase I of NCHRP 3-76 B helps explain the conditions under which active grade crossing warning systems are constrained from a cost and risk perspective and how these two considerations interact. Figure 26 shows how the legal environment and tort liability minimizes industry's tolerance for risk in terms of system failure. Thus, only expensive, fail-safe systems are selected for use. The graphic shows that as system

cost decreases, so too does system "performance." Performance declines as system features are eliminated — features such as fail-safe design, the ability to detect only trains, redundancy, and premium components — and risk increases proportionately.

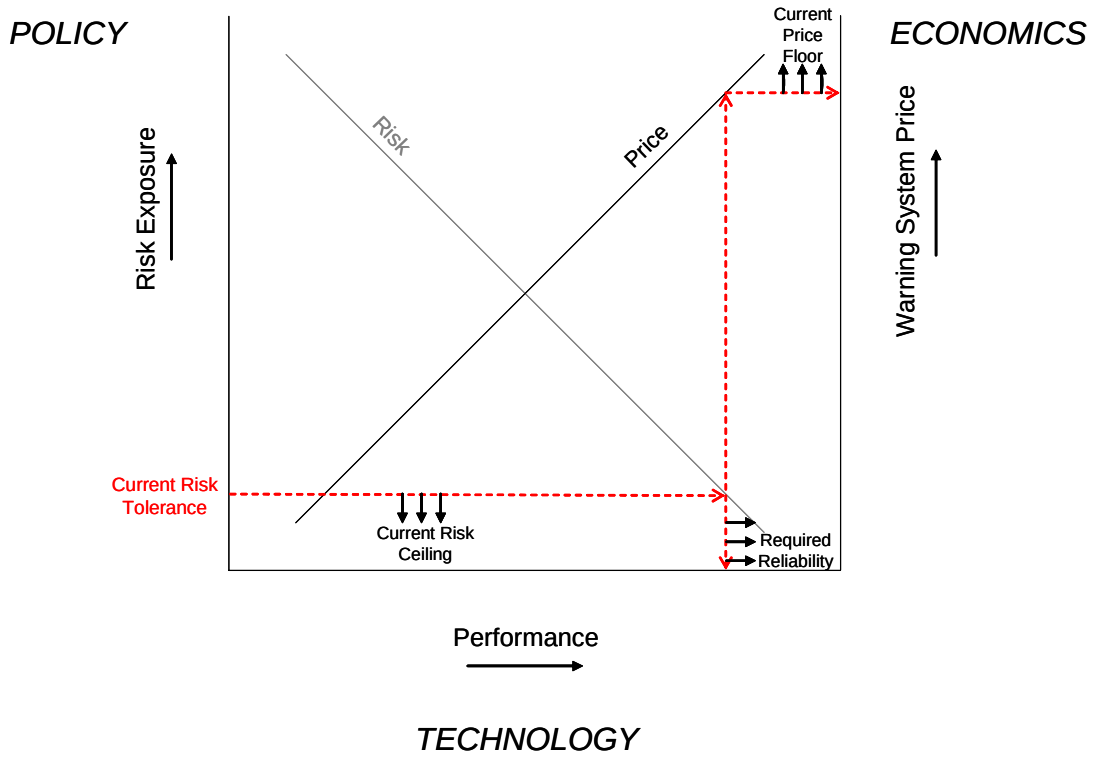


Figure 26. Current Pricing Environment for Active Grade Crossing Warning Systems.

This current research was pursued in the hope that technology can provide the means to accomplish highly reliable active warning at grade crossings for a reduced cost. Figure 27 depicts this pursuit of low-cost systems, which are idealized as being capable of offering the same level of performance (safety) but at lower-cost than those currently on the market or in service, represented as a shift in the price curve from Price 1 to Price 2. This idealized case suggests that lower-cost systems could be implemented without an assumption of greater risk. Our research suggests that this is not the case, at least with the systems tested, because system performance inexorably relates to the number, quality, and design of component parts as well as

to the sensor system being employed to detect train activity and to restrict detection only to trains. Forfeiting features to reduce cost may inherently increase the risk of system failure. Over-detection was proven to be a major drawback of both low-cost systems tested. Both systems demonstrated that although it may be relatively cheap and easy to detect trains, it is undoubtedly more expensive to detect only trains.

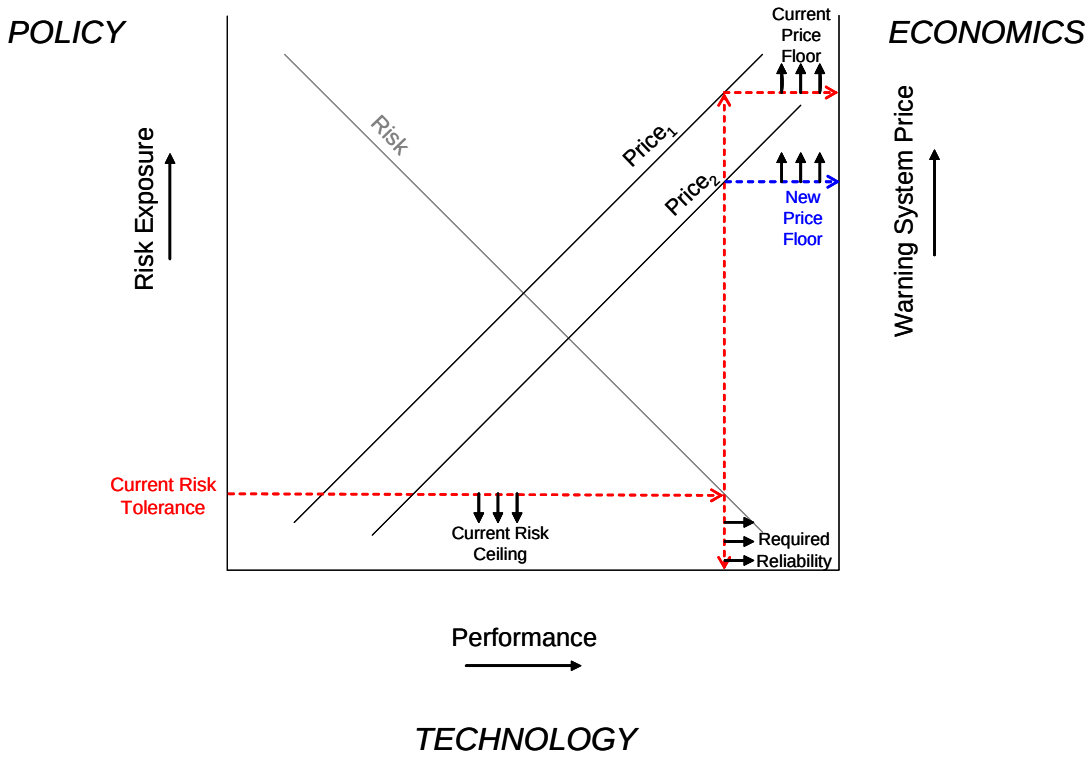


Figure 27. Preferred Approach to the Implementation of Low-Cost Warning Systems.

Exposure to liability places upon industry upward pressure to purchase the best technology available in order to demonstrate the appropriate "standards of care." Lack of lower-cost systems that offer the same level of performance will necessitate a modification in the acceptable level of risk if lower-cost systems are to be implemented. Figure 28 shows that accepting some increased risk of system failure at individual grade crossings can allow the introduction of lower-cost technology. The challenge will be to determine if overall safety at passive crossings can be improved by systems that are better than nothing, but that are still not

perfect. However, the systems tested in this research were so far below a reasonable level of reliability, that no consideration could be given to implementation.

Even so, there will be future innovations that offer a level of performance sufficient to contemplate installation at passive crossings. The following sections relate to what changes in the tort liability system would need to be made to encourage greater levels of technical innovation.

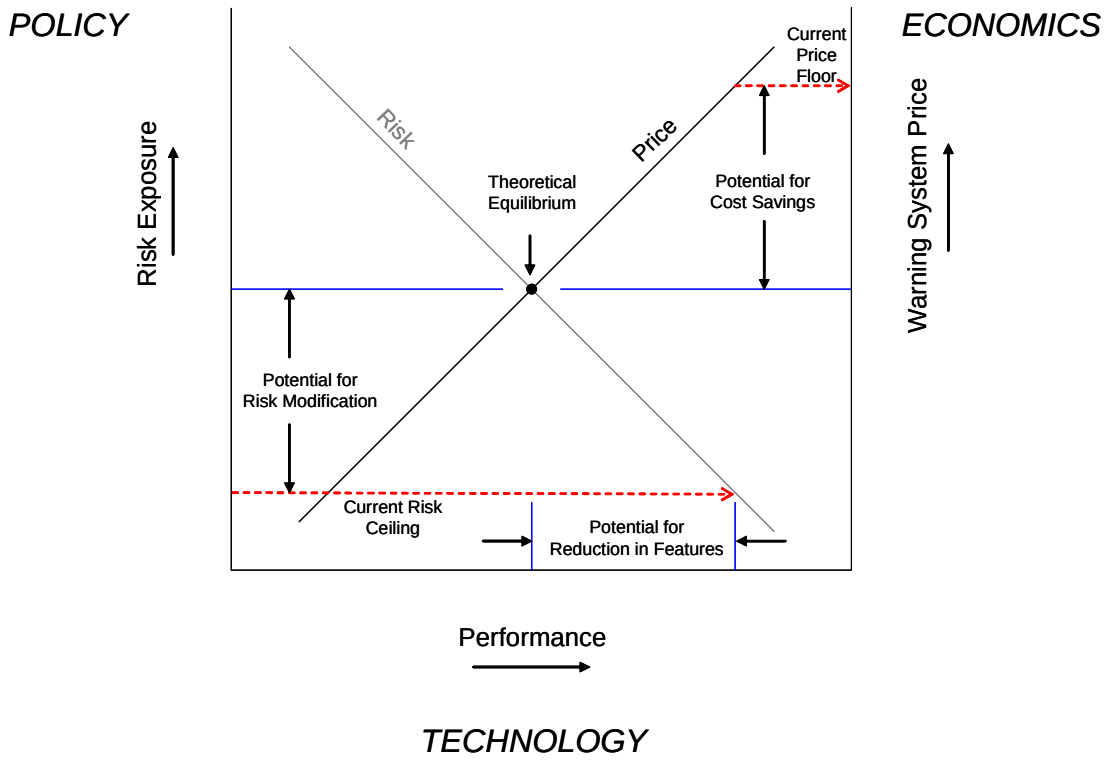


Figure 28. Realistic Scenario for the Implementation of Low-Cost Warning Systems

IMPACT OF TORT LIABILITY LAW ON INNOVATION

The early 1960s saw a product liability law revolution in the U.S. The attitude of the legal system was altered from simple negligence to strict product liability. Previously, manufacturers could not be sued if a consumer misused or abused their product resulting in self-

injury, assuming there was no product manufacture defect. Under the strict product liability system, manufacturers can be sued whenever self-injury occurs, even when their product is misused or abused, and even when there is no product manufacture defect. Although the original purpose of product liability laws was to compensate for injuries, promote safety and penalize gross negligence (hold irresponsible corporations accountable), U.S. courts no longer seem to adhere to these principles.

Proponents of the 'new' law argued that a boom in innovation would follow in order to increase product safety and minimize lawsuits. In reality, the reverse has happened, and is still prevalent today: innovation was suppressed. Companies became more and more hesitant to invest in research and development that could result in new, improved, or safer products. These products might only imply that older versions were unsafe and the road to lawsuits against older versions would be opened. This has blocked market entry of many radically new and improved products, at least in the U.S. Thus, the vast majority of consumers miss out on the benefits due to the potential actions of the minority who may file costly lawsuits.

Liability concerns, not costs and profits, have become the primary basis for many business decisions. Risk assessment often indicates that potential liability costs may not be offset by a product's profits and hence forces the management to decide against introduction of a new product to the market or to discontinue production. Manufacturers are well aware of the unfortunate truth of product liability laws, that the easiest product to defend in court is the one that was made exactly by the book – an antonym for radical innovation. This trend has often led to only incrementally improved models entering the market. In simple terms, doing nothing is legally safer than doing something, even if inertia is really more dangerous in the long run. In the minds of a human jury, the familiar is safe, no matter how dangerous in reality. With the old,

a case must be built against it, whereas the new must prove its advantages. The unfamiliar is perceived as suspect, intrusive and probably dangerous, regardless of any statistical reassurance as to the contrary.

Strict product liability laws also serve to strengthen the bureaucratic role of the government. Public agencies are risk adverse, that is, they get rewarded for avoiding failure, not taking risks. Since their roles are largely regulatory, the regulations have to be based on product accident history. New technologies come with little risk history and threaten an agency by liability exposure.

Liability insurance premiums or lawsuit costs have been a growing drain on company financial resources. Generally, companies are more willing to risk litigation and introduce innovative products if liability insurance is readily available and inexpensive. Spending can be allocated to product research and development instead of insurance premiums or lawsuits. However, insurance companies charge premiums based on track records and the accident experience of products. New, innovative products carry greater uncertainty about risks versus benefits. They have little risk history whereas old technology has the benefit of experience. Therefore they are more likely to be charged exorbitant premiums for modest coverage. Unfortunately, insurance premiums for decreasing coverage have skyrocketed, most rapidly accelerating in the 1980s, about two decades after the strict product liability law revolution.

The chain reaction effects of strict product liability laws on insurance premiums and litigation costs discriminate against small companies, new ventures and entrepreneurs more so than major corporations or manufacturers. As is universally accepted, market entry and business competition come with risk. Small companies or entrepreneurs simply cannot afford to take any high risks. They are faced with a heavier financial burden and their entry into the marketplace

can be prohibited by high insurance premiums and/or potential litigation costs. Sometimes liability insurance is simply unavailable. Ironically enough, small companies and entrepreneurs are traditionally more likely to radically innovate and market new products, by operating outside the industry mainstream. Given expensive or unavailable insurance and potential liability costs, companies are faced with three options:

- Self insurance, which leads to huge product selling price and ends up constituting by far the greatest fraction of it.
- Carry no insurance, and go out of business easily and quickly once the lawsuits come.
- Drop the product if litigation costs (awards, settlements, legal) and/or insurance premiums outweigh revenue potential.

Any of these options naturally filters downwards the employment ladder to trigger chain reaction effects such as workforce layoffs, underemployment benefit cutoffs. The entire economic food chain is, in turn, infected and national economic growth suffers.

Numerous industry sectors provide concrete evidence as to the adverse effects of strict product liability laws on innovation *(3)*. The most densely populated category is undoubtedly pharmaceuticals, more specifically contraceptives (e.g., Norplant, IntraUterine Device (IUD)) and vaccines (e.g., Diphtheria, Pertussis and Tetanus (DPT)). New drugs require increasing lead time to enter the U.S. market – if they ever do. Many never make it here although widely available overseas, Europe being the prime example. It is not uncommon for U.S. companies to invest in research and development of new drugs never intended for the domestic market. The business options above are proven realities for several U.S. pharmaceutical companies since the 1960s: inflated selling prices of simple drugs, drug company bankruptcies and discontinued production.

The small piston aircraft industry provides further insight as to the negative impacts of tort law on innovation. By 1994, most aircraft research and development was performed under government contracts and for military needs. General Aviation manufacturers like Piper and Beech manufactured only one model of single engine, small piston, propeller-driven aircraft, while Cessna had stopped altogether *(3)*. Sales and production fell after insurance costs added about $100,000 to a new aircraft's selling price. The price hike made them uncompetitive with used planes already on market that carried less liability surcharge. Ironically newer models kept off the market were notably safer than the older ones already in use. Since manufacturing of small planes was eliminated, innovation in the general aircraft industry was stifled due to the fact that innovation in aircraft typically starts from smaller planes. Manufacturers were provided relief with the General Aviation Revitalization Act of 1994 *(5)*, and production of single engine, small piston, propeller-driven aircraft resumed. The legislation placed an 18-year 'Statute of Repose' on general aviation products. If a product has functioned satisfactorily for 18 years, it has demonstrated that its original design is not defective and therefore not subject to a liability suit.

The realities of the adverse effects of strict product liability laws have included company bankruptcies and government control of new technology, both of which culminate to limit future advancements and growth of the economy. Professor Stephen Magee of the University of Texas showed, through his 'Magee Curve' *(4)*, a strong negative correlation between the number of lawyers-politicians and the rate of economic growth. He determined the optimum number of lawyers per thousand white collar workers to be 23. Too many or too few, and a country's economic growth suffers. He estimated that the U.S. with 38 lawyers per thousand white collar workers suffers an annual reduction in its economy of $600 billion or 10%. Japan with 20, and

Germany with 27, are closer to the optimum and enjoy the fastest economic growth. The U.K. with 12, and France with 7, show slower growth. Another non-coincidence is the fact that from 1960 to 1990 the number of lawyers in the U.S. grew proportionately with the number of federal lawsuits: both tripled.

Companies, like Volvo, have long been at the forefront of safety technology *(7)*. European engineers are free to brainstorm, try and test new ideas without fear of potential litigation. After all, lawsuits are rare in Europe and almost nonexistent in Japan. European and Japanese firms can speedily transfer research results to the marketplace while U.S. firms are still evaluating the risks and costs of trying something new. Liability concerns have led U.S. companies to discontinue products, not introduce them to the market at all or discontinue product research. Low risk designs are favored by practitioners; stability, not innovation, is rewarded.

Today, America's $246 billion civil justice system is the most expensive in the industrialized world *(5)*. This enormous amount could perhaps be put to better use in research and development or, as a large scale example of primary urgency, rehabilitation of the nation's deteriorating infrastructure system. U.S. product liability laws are not conducive to business: they have increasingly chilled innovation and rendered U.S. companies non-competitive internationally. They are also not good for society: they have compromised U.S. consumer access to evolving products and affordable health care, raised the cost of goods and services, and undermined the notion of personal responsibility.

TORT LIABILITY LAW REFORM

Tort law reform is being increasingly called for to create a fair, common-sense system for both consumers and manufacturers, one that returns liability laws to moderate levels and original intended use - to spawn innovation in order to produce new, safer products. The right to sue and

seek recourse due to manufacturing defect along with business interests for international competitiveness should be sufficient to guarantee safe, high quality products which can only come about through constant improvement and innovation. As Lee Iaccoca said, 'We don't live in a risk-free world and never will'.

Reforms to the legal system may discourage frivolous suits, although there will still be no control over juries who deal out punishment for risk undertaken by the public depending on individual use of any product. The federal government could carry a greater role in absorbing more of the financial risks associated with new innovation to ensure that new technologies actually reach the U.S. marketplace, like it did in the 1970s energy crisis. More specifically, recommendations and measures for reform include *(3)*:

- Court defense. Federal approval of the defense claim that warning of dangers of a product was impossible due to non existent historical knowledge, as for example in the U.K.
- Establishment of Federal regulatory standards. A single, well defined set of federal defectiveness standards is needed. Currently each state has its own, many times conflicting, set of standards.
- Approval of aforementioned standards as statutory defense. Assuming product adherence, their approval as statutory defense can provide protection for manufacturers from at least liability claims, if not totally from punitive damages, as was done in New Jersey. This measure can also lead to more reasonable insurance premiums and coverages.
- State of Repose. Establish a period of time after which a manufacturer cannot be sued, as for example in the European Union where there is a 10-13 year limit.

- Insurance incentives. For insurers to cover new products.
- Liability assessment. Only for negligence.
- Abolishment of joint and market share liabilities (deep pockets mentality). Damage assignment should be based on defendant's share of negligence, not ability to pay. Damage liability based on responsibility would encourage safety improvements and innovation from defendant manufacturers.
- Caps. Should be established on punitive and non economic damages, contingency fees, pain and suffering, wage scales and lawyers' fees.
- No fault compensation systems. Greater governmental establishment on emergency, necessary items, for example vaccines.
- Adoption of the British cost practice. The losing party is required to pay its own costs as well as those of its opponents. This would discourage the filing of frivolous suits.
- Prior contract. A pre-set amount for victims and families of rare but catastrophic events, for example air crashes, would eliminate tort problems.
- Inclusion of collateral source payments. Allow the defendant to draw from any health, disability, workers compensation insurance into awards granted.
- Collateral Estoppel. Defendants should be allowed to use their product's proof of safety from successful prior lawsuits as statutory defense in current litigation, the same way plaintiffs are allowed to do.

The American Tort Reform Association (ATRA) was co-founded in 1986 by the American Medical Association and the American Council of Engineering Companies. It is a nonpartisan, nonprofit organization whose membership is diverse and includes nonprofits, small and large companies, as well as state and national trade, business, and professional associations.

It is the only national organization exclusively dedicated to reforming the civil justice system by bringing greater fairness, predictability and efficiency to it. Its efforts have resulted in the enactment of state and federal laws that make the system fairer for everyone.

ATRA publishes the Tort Reform Record each June and December to record the accomplishments of the latest legislative year. The ATRA agenda and the number of states that enacted each reform since 1986 are summarized below *(5)*:

Joint and Several Liability

Joint and several liability is a theory of recovery that permits the plaintiff to recover damages from multiple defendants collectively, or from each defendant individually. In a state that follows the rule of joint and several liability, if a plaintiff sues three defendants, two of whom are 95% responsible for the defendant's injuries, but are also bankrupt, the plaintiff may recover 100% of her damages from the solvent defendant that is 5% responsible for her injuries.

The rule of joint and several liability is neither fair, nor rational, because it fails to equitably distribute liability. The rule allows a defendant only minimally liable for a given harm to be forced to pay the entire judgment, where the co-defendants are unable to pay their share. The personal injury bar's argument in support of joint and several liability—that the rule protects the right of their clients to be fully compensated—fails to address the hardship imposed by the rule on co-defendants that are required to pay damages beyond their proportion of fault.

ATRA supports replacing the rule of joint and several liability with the rule of proportionate liability. In a proportionate liability system, each co-defendant is proportionally liable for the plaintiff's harm. For example, a co-defendant that is found by a jury to be 20% responsible for a plaintiff's injury would be required to pay no more than 20% of the entire settlement. More moderate reforms that ATRA supports include: (1) barring the application of

joint and several liability to recover non-economic damages; and (2) barring the application of joint and several liability to recover from codefendants found to be responsible for less than a certain percentage (such as 25%) of the plaintiff's harm.

Forty states have modified the rule of joint and several liability.

Collateral Source

The collateral source rule of the common law says that evidence may not be admitted at trial to show that plaintiffs' losses have been compensated from other sources, such as plaintiffs' insurance, or worker compensation. As a result, for example, 35% of total payments to medical malpractice claimants are for expenses already paid from other sources.

Twenty-four states have modified or abolished the collateral source rule. Two states have had reforms struck down as unconstitutional and have not enacted additional reforms.

Punitive Damages

Punitive damages are awarded not to compensate a plaintiff, but to punish a defendant for intentional or malicious misconduct and to deter similar future misconduct. While punitive damages awards are infrequent, their frequency and size have grown greatly in recent years. More importantly, they are routinely asked for today in civil lawsuits. The difficulty of predicting whether punitive damages will be awarded by a jury in any particular case, and the marked trend toward astronomically large amounts when they are awarded, have seriously distorted settlement and litigation processes and have led to wildly inconsistent outcomes in similar cases. ATRA recommends four reforms:

Establishing a liability "trigger" that reflects the intentional tort origins and quasi-criminal nature of punitive damages awards - "actual malice."

Requiring "clear and convincing evidence" to establish punitive damages liability.

Requiring proportionality in punitive damages so that the punishment fits the offense.

Enacting federal legislation to address the special problem of multiple punitive damages awards; This would protect against unfair overkill, guard against possible due process violations, and help preserve the ability of future claimants to recover basic out-of-pocket expenses and damages for their pain and suffering.

Thirty-two states have reformed punitive damages laws. One state had reforms struck down as unconstitutional and has not enacted additional reforms.

Noneconomic Damages

Damages for noneconomic losses are damages for pain and suffering, emotional distress, loss of consortium or companionship, and other intangible injuries. These damages involve no direct economic loss and have no precise value. It is very difficult for juries to assign a dollar value to these losses, given the minimal guidance they customarily receive from the court. As a result, these awards tend to be erratic and, because of the highly charged environment of personal injury trials, excessive.

ATRA believes that the broad and basically unguided discretion given juries in awarding damages for noneconomic loss is the single greatest contributor to the inequities and inefficiencies of the tort liability system. It is a difficult issue to address objectively because of the emotions involved in cases of serious injury and because of the financial interests of plaintiffs' lawyers.

Twenty-three states have modified the rules for awarding noneconomic damages. Four states have had reforms struck down as unconstitutional and have not enacted additional reforms.

Prejudgment Interest Payment

In the absence of an applicable statute or rule, the courts generally applied the traditional common law rule that prejudgment interest was not available in tort actions since the claim for damages was unliquidated. In an effort to compensate tort plaintiffs for the often-considerable lag between the event giving rise to the cause of action, or filing of the lawsuit, and the actual payment of the damages, many state legislatures have enacted laws that provide for or allow prejudgment interest in particular tort actions or under particular circumstances. In addition to seeking to compensate the plaintiff fully for losses incurred, the goal of such statutes is to encourage early settlements and to reduce delay in the disposition of cases, thereby lessening congestion in the courts. Although well-intended, the practical effects of prejudgment interest statutes can be inequitable and counter-productive. Prejudgment interest laws can, for example, result in over-compensation, hold a defendant financially responsible for delay it may not have caused, and impede settlement.

At a time when policymakers are attempting to lower the cost of the liability system in an equitable and just manner, prejudgment interest laws that currently exist and new proposals should be reviewed to ensure that they are structured fairly and in a way designed to foster settlement. At a minimum, the interest rate should reflect prevailing interest rates by being indexed to the Treasury bill rate at the time the claim was filed and an offer of judgment provision should be included.

Sixteen states have enacted prejudgment interest reforms.

Product Liability

Product liability law is meant to compensate persons injured by defective products and to deter manufacturers from marketing such products. It fails, however, when it does not send clear

signals to manufacturers about how to avoid liability or holds manufacturers liable for failure to adopt a certain design or warning even if the manufacturers neither know, nor could have anticipated, the risk.

Sixteen states have enacted laws specifically to address product liability. Three states have had reforms struck down as unconstitutional and have not enacted additional reforms.

Class Action Reform

Once considered a tool of judicial economy that aggregated many cases with similar facts, or similar complaints into a single action, class actions are now often considered a means of defendant extortion. Today, some class actions are meritless cases in which thousands, or millions, of plaintiffs are granted class status, sometimes without even notifying the defendant. In many of these cases, the victimized consumers often receive pennies, or nearly-worthless coupons, while plaintiffs' counsel receives substantial legal fees. State class action reform can more equitably balance the interests of plaintiffs and the defendant.

Nine states have reformed their laws pertaining to class actions.

Evidence shows that tort liability law reform has taken place to some extent, primarily at the state, and more sparsely at the federal level. Several Federal reforms were enacted, as congressional Acts, in direct and urgent response to the September 11, 2001, terrorist attacks. They are not directly related to promoting technological innovation, but are worthy of at least brief mention at this point in the discussion. The Acts were drafted to protect the industries most impacted by the attacks - air transportation and insurance - against subsequent liability issues. The highlights of the remedial measures include:

- Special federal funds for injury or death compensation to individuals

- Special federal funds for reimbursement (90%) to insurance companies for claims due to terrorism
- Caps on insurance claims due to terrorism
- Liability protection/limits of air carriers, manufacturers, security

Prior to September 11, 2001, key Federal reforms included the bird flu and childhood vaccine Acts in the mid 1970's and 1980's respectively. They were enacted in response to the national threat of the industry's collapse, due to insurance unavailability arising from expensive lawsuits. The Acts shifted the liability and compensation burden from the manufacturers to the federal government.

In the 1990's the General Aviation industry was revitalized, as outlined earlier in this chapter. In addition, AMTRAK liability protection was ensured through the related Act, which established caps and federal standards on awards.

However, what is somewhat disturbing is the fact that drastic reform required a massively catastrophic event for the mechanisms of the federal government to quickly and efficiently respond to the ramifications of tort liability laws. In addition, the reforms directly affected only a specific subset of U.S. businesses and consumers whereas many other industry sectors could benefit form similar reforms.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

DISCUSSION OF RESULTS

Employing new, lower-cost technology to detect trains at grade crossings has enjoyed an intuitive appeal that is reinforced by the number and array of sensor systems impacting our increasingly machine-aided lives. Automobiles, homes, offices – almost every walk of life – have become augmented with technologies designed to detect events, conditions or intrusions in a manner superior to that of the human being. The blind-spot object-detection radars included in some higher-priced cars is a case in point. This explosion of low-cost systems gives rise to the reasonable notion that something as large as a train ought to be detectable in a way that improves safety at passive grade crossings. This is in fact true; there are sensor systems that can reliably detect a train and this has been demonstrated in the current research.

The systems selected for testing, a radar system and an acoustic, train-horn detection system, were able to detect trains with 100 percent accuracy. That is to say that each time the track circuit-based system detected a train, the alternative systems did as well. This is not to say, however, that the trains were detected at the same times by each system. Variability in the advanced warning times and the release times proved problematic for the low cost systems and the variance was in many cases, extreme. The low-cost systems failed, however, in discriminating between trains and other features of the environment that would serve in their respective domains to trigger an indication of the presence of a train.

For the radar system this occurred, as detailed in the results section of the report, at roughly a 2:1 rate. For the acoustic system, which was ostensibly "tuned" to discriminate the

specific frequency combinations of train horns, this undesirable event inclusion exceeded a disastrous 16:1 ratio, making the system totally useless for grade crossing safety applications in its tested form. The research team has no idea what events were triggering the system indication of train activity, although in pretest conditions signals as varied as overhead air traffic and traffic noise were observed to cause this response. Thus, a fundamental conclusion of this work is that detecting a train is the easy part – detecting *only* trains in a complex environment is not easy and likely is not inexpensive.

The radar system, as has been discussed, may have suffered from detectable vehicle traffic on adjacent roadways. With additional site selection care and perhaps additional investment in equipment, these numbers might be reduced. This begs the question, however, of where a radar system can be reliably employed in a safety-critical role. If it can only be used in those settings where no adjacent activity is present, then the number of candidate locations will be vastly lower than the 62,000 we identified in our evaluation *(18)*. Additional instrumentation or more sophistication in the system itself could help with false positive readings, but the price of the hardware would increase accordingly.

The research team went to extraordinary lengths to provide the systems a fair test in a controlled and straight forward environment. More than six months were dedicated to site selection, communication with vendors, trial implementations, adjustments to equipment, and final installation with opportunities for calibration prior to the start of the data collection phase. This represents far more care than could be expected in a commercial setting where the equipment would be installed and expected to perform in its safety-critical role. The test was designed to compare each system to a track-circuit based traditional system as well as to compare each to the other. The tests were allowed to continue even after there were clear

indications that discrimination was going to be the down fall of the low-cost systems because to offer repeated opportunities for adjustment for one system would negate the comparative value of the evaluation and extend the testing beyond reasonable time limits. Further, once all systems were in place – low-cost detection systems, data collection systems, and communications equipment – the testing was automatic and incurred no additional cost to the research project.

MOTORIST DISREGARD FOR WARNING SYSTEMS THAT FAIL

Given the disappointing results of the current research, the issue that becomes predominant is that motorists learn to disregard and ignore a warning device that is as often wrong, as it is correct. This is often referred to as the "crying wolf" phenomenon and there is a large body of research that investigates the impacts of false alarms on the responses of human operators *(16)*. In grade crossing safety, false alarms are a recipe for trouble and the risk associated with this scenario for the tested systems is far more substantial than anticipated by either the research staff or by the NCHRP 3-76B Panel. Type I errors, or missed predictions, were a less severe problem with the tested systems than were the Type II errors – the false alarms. The research on false alarms suggests that there is a large amount of variability in the way individual humans respond to false alerts and there is added variability as a function of the degree to which a system provides false positive indications *(17)*. We believe that the rates exhibited by both tested systems would render them highly ineffective in a safety-critical role.

Importantly, in our current tort liability system, this well established learning propensity to disregard false alarms has the effect of helping to shift responsibility from the motorist to other parties. Even with the high degree of reliability associated with traditional track-circuit based systems, anything less than 100 percent reliability (i.e., zero false alarms) results in the argument that the occurrence of a false positive, teaches the motorist to disregard the warning

system and inadvertently places the driver who thinks the system is giving a false indication of train presence, in harms way.

This is also referred to as the "reliance effect." It further supports the proposition that errors in judgment can be induced by systems we learn to depend on. This is particularly true when fatigue or sensory overload is an additional factor. The motorist that automatically enters an intersection upon a green light without first checking cross-traffic is guilty of the same thing – relying on a system that does not guarantee the other motorist's compliance with the corresponding red signal to stop. Many red-light running accidents are of this nature.

An issue related to the false positive indication of train presence is that of fail-safe design. Fail-safe refers to design features that allow a system that is not operating properly to fail in the most restrictive or safest fashion possible. With a traditional warning system, if a component fails, the system automatically drops the gates and activates the warning lights, providing the motorist with a false positive as an indication of system failure. The systems tested in this research do not have design features that can indicate a self-detected inability to perform the function for which they have been installed. Obviously, this creates a potential circumstance where a system failure leads to a collision between a train and a motor vehicle. The results of the current research do not directly suggest that fail safe design is critical, since 100 percent of the train events were detected. However, extended operation of either system would ultimately make the lack of a fail safe capability both a safety issue and ultimately an issue to be dealt with in the courts.

CONCLUSIONS

The conclusions to be drawn from this research are twofold; first, low-cost technology offers the promise of reducing the cost of active grade crossing warning systems while

maintaining performance at a level sufficient to ensure improved safety at some of the thousands of passive grade crossings on our transportation system. However, this promise is as yet unmet with alternative technologies such as radar and acoustic systems, each of which showed a high degree of variability in when a train was detected and very limited capability to avoid false alarms – Type II errors. Perhaps the desire to test off-right-of-way systems increased the chances that the selected technologies would fall victim to Type II errors. Even so, alternatives that are on the right-of-way, such as magnetometer-based detection systems, are also subject to false alarms when presented with suitable objects like large trucks in proximity to the sensor.

The introduction of lower-cost and higher performance components and subsystems will likely find an impact first and foremost within the systems design for traditional track-circuit based systems – systems that do not suffer from the inability to discriminate trains from other events and thus do not register large numbers of false alarms. These improvements are in fact taking place already with solid state components and improved designs for relays.

Secondly, determining a path toward lessening the inhibiting effects of the tort liability system on technological innovation is fragmented and complex. Many states are making changes to their respective tort liability systems, but these changes will not, in the opinion of the authors, fundamentally alter the requirement that systems, particularly those employed in roles critical to public safety, operate reliably. It is difficult to envision changes to the tort liability system that would protect those installing warning devices that inadvertently induce the human to make errors in judgment. However, with railroads fulfilling a public safety role by maintaining active warning systems that are an integral part of their signaling system, tort reform should seek to alleviate the burden placed on these private companies whenever motorists create the conditions that lead to a grade crossing collision. If suitable tort reforms were made that

placed the responsibility squarely on the motorist rather than allowing juries to act out of sympathy for the injured or otherwise harmed plaintiff with largely misplaced notions of partial blame, then innovative approaches would be more fully explored and lower cost systems could be introduced. Further in this vein, tort reform must prohibit the adverse consequences associated with fault stemming from the omission-commission dilemma discussed in Chapter 4.

The notion that the railroads are inclined to explore alternative technology looks past the reality that they must maintain every system put in place *in perpetuity* – an expensive proposition for a private industry, particularly one that is as capital intensive as the railroad industry. Premium components that reduce maintenance requirements, yield highly reliable operations, and lower the life-cycle cost to the railroads are more expensive.

Asking public sector agencies to take on an expanded role for grade crossing safety beyond the financial role currently filled would likely be met with some resistance. At least two obstacles exist to making a fundamental shift in responsibility for grade crossing warning systems. First, public entities are risk averse and would have to have blanket immunity from liability before considering a larger role in grade crossing system selection, installation, and maintenance. Second, public entities are by definition budgeted at a level that provides just enough funding for them to accomplish their prescribed functions. A bigger public safety role would mean additional staff, additional physical infrastructure, and added training. More funding would have to be provided for these new activities through an enlarged tax base – a universally unpopular proposition.

Other developments in low-cost warning systems need to be considered as well since the immediate need for new technological solutions may be impacted. It seems likely that some of the changes taking place in response to NCHRP Report 470 – calling for the augmentation of

passive crossings with “Yield” and “Stop” signs – may alleviate some of the pressure to provide active warnings at passive crossings and do so in a cost-effective manner. These passive markings added to the Crossbuck take advantage of the fact that motorists recognize and are conditioned to respond to the Yield and Stop signs in a fashion that is consistent with improved safety at dangerous highway-rail intersections.

RECOMMENDATIONS

The implications for grade crossing safety that can be drawn from this research are clear, even given the poor performance of the systems evaluated – systems, we may add, that were considered the most promising off-right-of-way technologies available to test. The results of NCHRP 3-76B suggest that there are technologies that may offer lower-cost active warning options for passive grade crossings. The inability to demonstrate this with available systems however, attests to the need for an improved definition of the performance characteristics required to warrant serious consideration in this safety-critical application. Were the developers fully aware of the need to achieve both detection and discrimination at near 100 percent levels of reliability and to improve the consistency of advance warning time control, they could then design and test components with these goals in mind.

It is recommended that a request be submitted to the federal agencies responsible for grade crossings safety to establish a committee composed of a cross-section of professionals from industry and government to define the performance requirements for low-cost active warning systems. The committee could include representatives from:

- The Federal Highway Administration
- The Federal Railroad Administration
- Association of American Railroads

- TRB Grade Crossing Safety Committee AHB60
- National Committee on Uniform Traffic Control Devices
- National Highway Traffic Safety Administration

The standards committee, thus formed, could determine the minimum requirements for Type I and Type II errors as well as defining performance parameters for advance warning time under differing conditions, such as roadway volume and sight distance. The committee could also develop a draft of the fundamental changes to the tort liability system that would be required to provide immunity from liability for innovators, public agencies, and railroads from any adverse occurrences resulting from the use of new technologies at grade crossings.

In summary, while much has been accomplished over the last two decades in grade crossing safety, much work remains for those dedicated to lessening the hazards associated with passive grade crossings. With a resurgent rail industry setting new records for car loadings each month and highway traffic growth that appears to be a unabated, contention at highway-rail grade crossings will only increase. Many more passive grade crossings will see exposure levels that are problematic and, as long as motorists remain human, collisions will occur. Some passive grade crossings will be converted to active through respective warning systems, but far more will remain passive and present a hazard to drivers that are fatigued, distracted, or become complacent. As technology continues to advance and designers improve their systems, we must help create both legal and institutional conditions that allow innovation to be transferred from ideas to reality with the goal of reducing injuries and saving lives.

REFERENCES

1. Federal Railroad Administration Grade Crossing Statistics, 2002.
2. Manual of Uniform Traffic Control Devices.
3. Herbig, P. A., and Golden, J. E., Innovation and Product Liability, *Industrial Marketing Management*, 23, 245-255, 1994.
4. Magee, S., The Optimum Number of Lawyers: A Reply to Epp, *Law and Social Inquiry*, 17, 667-693, 1992.
5. American Tort Reform Association, http://www.atra.org. Accessed December 2006.
6. Lawsuit Abuse Reform Coalition, http://www.lawsuitabusereform.org. Accessed December 2006.
7. Castaing, F. J., How to Stifle Innovation, *Technology Review*, 98, 4, 72-73, 1995.
8. Bernstein, H. M., Tort Liability: Limiting U.S. Innovation, *Civil Engineering*, 62, 11, 6, 1992.
9. Gittings, G. L., and Bagby, J. W., *NCHRP Synthesis of Highway Practice 265: Managing Product Liability to Achieve Highway Innovations*, Transportation Research Board, National Research Council, Washington, D.C., 1998.
10. Lewis, R. M., *NCHRP Synthesis of Highway Practice 206: Managing Highway Tort Liability*, Transportation Research Board, National Research Council, Washington, D.C., 1994.
11. Hunter, D., Help for Innovation in the U.S., *Chemical Week*, 159, 11, 5, 1997.
12. Lienau, K. A., A Discussion of Liability Issues Associated with Automated Highway Systems. Texas A&M University, College Station, Texas, 1994.

13. Viscusi, W. K., Product Liability, Research-and-Development, and Innovation, Journal of Political Economy, 101, 1, 161-184, 1994.
14. Norfolk Southern Railway Co. v. Shanklin, Supreme Court Cases: The Twenty-first Century (2000-Present), 1, 2000.
15. Gardner, J. S., Federal Preemption of State Health and Safety Regulations: CSX Transportation Inc. v. Easterwood, *Harvard Journal of Law & Public Policy*, 17, 1, 273, 1994.
16. Pate-Cornell, M. E., Warning Systems in Risk Management, *Risk Analysis*, 6, 2, 223-234, 1986.
17. Zabyshny, A. A. and Ragland D. R., False Alarms and Human-Machine Warning Systems. Institute of Transportation Studies, Traffic Safety Center, University of California, Berkeley, California, 2003.
18. Highway-Rail Crossing Inventory Data, Federal Railroad Administration, Office of Safety Analysis, http://safetydata.fra.dot.gov. Accessed October 2006.

APPENDIX A

VENDOR COMMUNICATION LOG

RADAR SYSTEM

The radar system vendor was not available to visit the proposed test site locations during January or February, 2006. However, based on the relayed site photographs, he disqualified site alternative 1 on grounds of the high levels of auto traffic, and commented that site alternative 2 did not indicate any difficulties for the radar system to detect train activity. Based on his evaluation, TTI selected site alternative 2 as the test site.

On March 24, 2006, the radar system vendor met with TTI and visited the selected test site. He temporarily set up partial test system data collection equipment and collected test data during the visit.

On May 5, 2006, the radar system vendor visited the test site with a prepared system for installation and testing. However, it was found that additional work to the system was required by TTI before it would be ready for installation on the selected traffic light utility pole.

On June 28, 2006, TTI, radar system vendor representatives and the City of College Station Maintenance Department installed the radar system on the traffic light utility pole at the selected site. TTI together with the vendor representatives proceeded to calibrate and test the system over the next several days.

On June 30 and July 1, 2006, TTI relayed initial recorded data to the radar vendor that indicated the system was not detecting all trains. In several instances the radar system did not detect the passing train until well after it had entered the actual grade crossing. The vendor

indicated he would visit the test site on July 11 and 12, 2006, to make equipment modifications and correct the errors.

On July 10, 2006, the radar system vendor informed TTI that the planned (July 11) visit would be delayed because he needed to make additional system changes at his headquarters beforehand. He stated that he had determined the power supply of the installed system to be faulty and that replacement was necessary.

The radar system vendor visited the test site on July 19 and 20, 2006, to modify and replace the faulty equipment. TTI assisted him throughout the visit by providing tools and lift equipment. Over the next several days, collected data were transmitted to the vendor so that he would be able to evaluate the modified system performance. He found that the system was still performing in an unstable manner and stated that errors remained, still, that required yet additional evaluation. The vendor then performed additional testing at his facility, based on the transmitted data collected at the test site.

On July 31 and August 1, 2006, the radar vendor made on-site system modifications and observed the operation of his system during train passage and grade crossing occupancy.

On August 3 and 7, 2006, TTI provided both test system vendors with data collected by their respective equipment, as well as railroad-supplied traffic signal pre-emption data. The latter indicated the railroad grade crossing warning device status during warning device activations. The railroad-supplied data stream was initiated when a train was first detected by the grade crossing track circuit, and ended when the last car of the train departed the roadway crossover (cleared the crossing).

Throughout the week of August 7 through 11, TTI worked with both test system vendors to further calibrate their equipment. The vendors were encouraged to make any last minute changes or adjustments they deemed necessary. The vendors or their representatives finally indicated that they were not aware of any alterations that could substantially improve the operational capability of their installed test systems.

On August 14, 2006, at 5:00 pm CDT, data collection from both systems was officially initiated. On August 22, 2006, all data collected from the radar system since August 14 was transmitted to the vendor for review, at his own request.

ACOUSTIC SYSTEM

On January 4, 2006, the acoustic system vendor visited TTI to demonstrate the acoustic detection technology and review his system with the research team.

He visited the proposed test site locations, on January 20 and 23, 2006, respectively. He disqualified site alternative 1 because he considered the high levels of auto traffic activity at site alternative 1 to be too intrusive for the acoustic system to effectively discriminate between an approaching train horn and adjacent road traffic. On January 23, he visited site alternative 2, and also displayed a new filter element to TTI. He then proceeded to collect train horn data from trains approaching the grade crossing at his test site of choice (site alternative 2), in order to start populating the train horn 'library'.

On February 15, 2006, the acoustic vendor visited the test site to collect additional train horn data. TTI was informed of the visit, but was not present at the site since the vendor did not require TTI's assistance.

On March 13, 2006, TTI informed the acoustic system vendor that the operating requirements of the test necessitated the system be mounted on the utility traffic light pole at the corner of the intersection. The acoustic system vendor had already scheduled a trip to deliver the equipment on April 24, 2006. However, as a result of the new information, delivery was delayed until May 17, 2006.

On May 17, 2006, the acoustic vendor delivered approximately one half of the system, for TTI to prepare it for mounting on the traffic light pole. The delivered equipment included the radio receiver and power supply for the overall system. Further modifications to the train horn recognition portion of the system continued to be carried out by the vendor at his office until mid July 2006.

On July 31, 2006, the completed acoustic system was delivered to TTI, which consisted of the acoustic horn detection cabinet enclosing the horn recognition equipment, data processor computer, and the transmitter/receiver radio system. TTI mounted the acoustic cabinet on the traffic light pole and connected it to the power line. The vendor was provided assistance with system calibration and verification of data transmission throughout the day.

On August 3 and 7, 2006, TTI provided both test system vendors with data collected by their respective equipment, as well as railroad-supplied traffic signal pre-emption data. The latter indicated the railroad grade crossing warning device status during warning device activations. The railroad-supplied data stream was initiated when a train was first detected by the grade crossing track circuit, and ended when the last car of the train departed the roadway crossover (cleared the crossing).

Throughout the week of August 7 through 11, TTI worked with both test system vendors to further calibrate their equipment. The vendors were encouraged to make any last minute

changes or adjustments they deemed necessary. The vendors or their representatives finally indicated that they were not aware of any alterations that could substantially improve the operational capability of their installed test systems.

On August 14, 2006, at 5:00 pm CDT, data collection from both systems was officially initiated.

On August 22, 2006, all data collected from the acoustic system since August 14 was transmitted to the vendor for review, as a courtesy, since the radar system data was transmitted to its vendor.

APPENDIX B

DATA TABLES

Table B-1. Radar Activation Length – False Activation Data.

Radar Activation Length - False Activations		
Seconds (≤ Number shown)	Frequency	% Frequency
5	580	29.4%
10	690	35.0%
15	392	19.9%
20	195	9.9%
25	74	3.8%
30	25	1.3%
More	17	0.9%
Total	1973	100.0%

Table B-2. Radar Activation Length vs Rail Activation Length Data.

Radar Activation Length vs Rail Activation Length				
Seconds	**Radar**		**Rail**	
(≤ Number shown)	Frequency	% Frequency	Frequency	% Frequency
50	15	1.0%	15	1.0%
75	41	2.8%	46	3.1%
100	114	7.7%	203	13.7%
125	267	18.0%	294	19.8%
150	274	18.4%	305	20.5%
175	309	20.8%	274	18.4%
200	193	13.0%	149	10.0%
225	111	7.5%	84	5.7%
250	71	4.8%	49	3.3%
275	38	2.6%	28	1.9%
300	20	1.3%	11	0.7%
More	33	2.2%	28	1.9%
Total	1486	100.0%	1486	100.0%

Table B-3. Radar Activation Start after Rail Activation Start Data.

Radar Activation Start after Rail Activation Start		
Seconds (≤ Number shown)	Frequency	% Frequency
-50	6	0.4%
-20	175	11.8%
-15	100	6.7%
-10	98	6.6%
-5	127	8.5%
0	227	15.3%
5	183	12.3%
10	191	12.9%
15	178	12.0%
20	99	6.7%
50	97	6.5%
More	5	0.3%
Total	1486	100.0%

Table B-4. Radar Activation End after Rail Activation End Data.

Radar Activation End after Rail Activation End		
Seconds (≤ Number shown)	Frequency	% Frequency
-5	2	0.1%
0	145	9.8%
5	189	12.7%
10	285	19.2%
15	646	43.5%
20	86	5.8%
50	132	8.9%
More	1	0.1%
Total	1486	100.0%

Table B-5. Acoustic Activation Length – False Activation Data.

Acoustic Activation Length - False Activations		
Seconds (≤ Number shown)	Frequency	% Frequency
35	597	2.4%
40	619	2.5%
45	11498	46.7%
50	10045	40.8%
55	1310	5.3%
60	348	1.4%
65	42	0.2%
75	30	0.1%
More	119	0.5%
Total	24608	100.0%

Table B-6. Acoustic Activation Length vs Rail Activation Length Data.

Acoustic Activation Length vs Rail Activation Length				
Seconds	**Acoustic**		**Rail**	
(≤ Number shown)	Frequency	% Frequency	Frequency	% Frequency
50	49	3.3%	15	1.0%
75	109	7.3%	46	3.1%
100	210	14.1%	203	13.7%
125	289	19.4%	294	19.8%
150	309	20.8%	305	20.5%
175	245	16.5%	274	18.4%
200	124	8.3%	149	10.0%
225	70	4.7%	84	5.7%
250	44	3.0%	49	3.3%
275	21	1.4%	28	1.9%
300	6	0.4%	11	0.7%
More	10	0.7%	28	1.9%
Total	1486	100.0%	1486	100.0%

Table B-7. Acoustic Activation Start after Rail Activation Start Data.

Acoustic Activation Start after Rail Activation Start		
Seconds (≤ Number shown)	Frequency	% Frequency
-5	13	0.9%
0	230	15.5%
5	231	15.5%
10	597	40.2%
15	168	11.3%
20	102	6.9%
25	75	5.0%
30	44	3.0%
35	22	1.5%
More	4	0.3%
Total	1486	100.0%

Table B-8. Acoustic Activation End after Rail Activation End Data.

Acoustic Activation End after Rail Activation End		
Seconds (≤ Number shown)	Frequency	% Frequency
-5	13	0.9%
0	230	15.5%
5	231	15.5%
10	597	40.2%
15	168	11.3%
20	102	6.9%
25	75	5.0%
30	44	3.0%
35	22	1.5%
More	4	0.3%
Total	1486	100.0%