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VIDEO DETECTION OF TRAINS

Michael David Forsberg
University of Nebraska-Lincoln, mike.forsberg@hdrinc.com

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VIDEO DETECTION OF TRAINS

by

Michael David Forsberg

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Committee Member: Aemal J. Khattak

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VIDEO DETECTION OF TRAINS

Michael David Forsberg, M.S.

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Advisor: Elizabeth G. Jones

This thesis discusses the use of video detection as a means for train detection. It reviews works done to increase safety at and near Highway-Rail Grade Crossings (HRGCs), discusses existing and past forms of technology and methods used in train detection and arrival time prediction, and provides summaries of investigations of other detection technologies used for vehicle detection. It then goes into depth on the use of radar and video detection with Autoscope Machine Vision Processing for train detection. This thesis provides a methodology of data collection, data analyses, results, and conclusions of video detection for train detection.

Data analyses concluded that Autoscope video detection works for detecting trains and recovering acceptable data on their speeds. Data obtained by radar and Autoscope video detection can be used to reasonably predict train arrival times at HRGCs and alert motorists near HRGCs of upcoming train arrivals and departures. The conclusions reached with this research also identified future research needs that will assist in creating a robust system for detecting trains with video detection.

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CHAPTER 1. INTRODUCTION

The railroad is a major mode of transportation of goods and to some extent people throughout the United States. Many urbanized areas grew up around the railroad. As a consequence of the historic development of the railroads and urban areas, the United States has approximately 250,000 grade crossings with 150,000 of those being public highway-rail grade crossings (HRGCs) (FHWA 2005). Of these public crossings approximately 60% are passively controlled and the remainder are actively controlled. An actively controlled HRGC uses some type of electronically controlled warning device to warn approaching motorists of an approaching train. Common active warning devices use flashing lights, gate arms, or traffic signals. Passively controlled HRGCs have no electronically controlled warning devices and often contain cross-bucks and striping only.

HRGCs are considered by many to be a major safety issue due to the number of accidents and fatalities that occur at grade crossings each year. Studies show that over the last 36 years, the number of accidents and fatalities have an overall decreasing trend at HRGCs (FRA 2011). Figures 1 and 2 show the number of accidents and fatalities at HRGCs throughout the U.S. and Nebraska, respectively, from 1975 to 2010. Even though the data shows that safety at HRGCs has improved over the past 36 years (1975-2010), the number of accidents and fatalities over the past 10 years (2000 to 2010) has remained relatively steady..

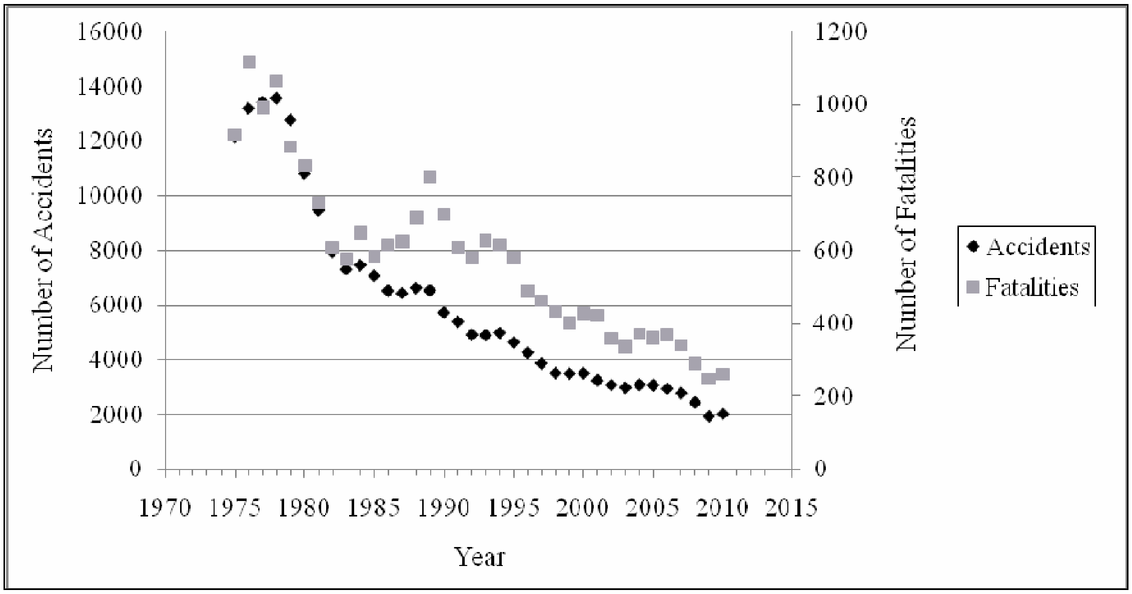


FIGURE 1 Accidents and Fatalities at HRGCs in the U.S. by Year (FRA 2011)

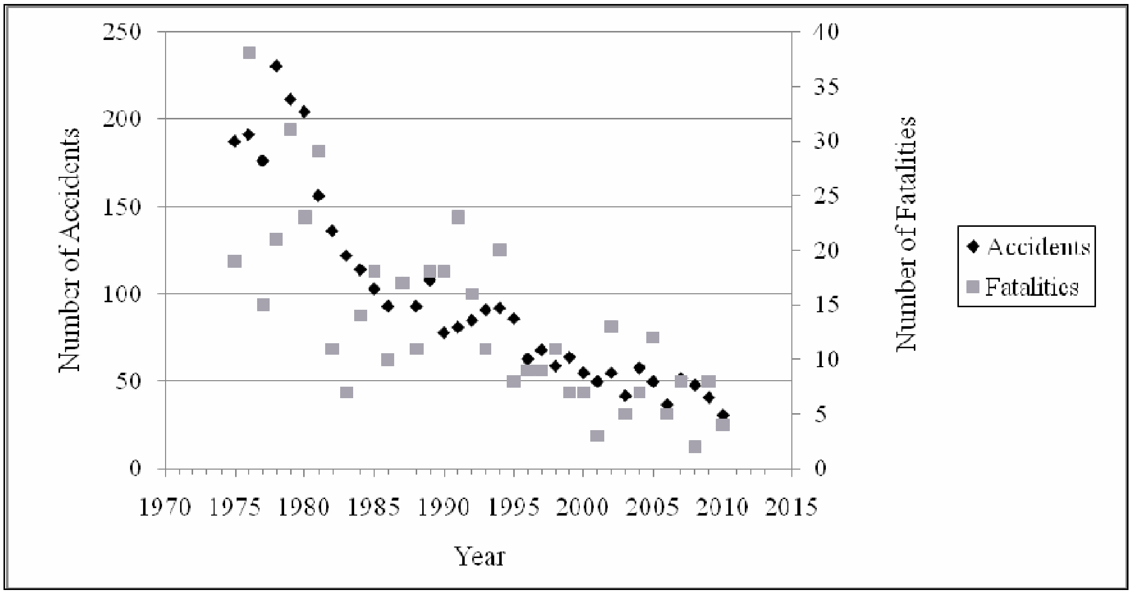


FIGURE 2 Accidents and Fatalities at HRGCs in Nebraska by Year (FRA 2011)

To further improve safety at HRGCs, much work has been done to incorporate newer technologies at HRGCs. One effort to improve safety at HRGCs has been to provide more reliable information about when a train is approaching so that the grade crossing can be closed to highway traffic in a safe manner for vehicles, pedestrians, and bicyclists, allowing trains to travel safely without interruption from highway traffic. With advancements in technology, several alternatives exist for detecting trains. These alternatives involve the use of equipment that can vary greatly in their level of sophistication by using first, second, and third generation technologies. The following section describes these technologies.

1.1 TRAIN DETECTION TECHNOLOGIES

The types of technology used for train detection can be classified as first, second, and third generation technologies. First generation is the least sophisticated and third generation is the most sophisticated. The following sections describe each.

1.1.1 FIRST GENERATION

Current technology primarily involves the use of first generation train detection equipment that are physically linked to the railroad track circuitry and provide a continuous uniform signal until a train is detected. The signal changes when a train crosses the detector, and this change indicates that a train is approaching and activates warning devices at the HRGC. These technologies can produce variable arrival times between the time that active warning devices are initiated and the time that a train arrives at a HRGC. This may lead to unsafe conditions at HRGCs where motorists may make poor decisions to cross the tracks while gate arms are down (Cho 2003-(1)).

One method using first generation technology is the fixed-distance warning time (FDWT) system (Figure 3). In this system, trains activate the warning devices with a detector at a fixed distance from the crossing. These systems are calibrated to alert the controller far enough in advance such that the fastest possible train would reach the crossing at least 20 seconds (minimum warning time) after the controller is notified. The Manual on Uniform Traffic Control Devices (MUTCD) specifies a minimum of 20 seconds of warning time for active warning devices at grade crossings (FHWA 1988).

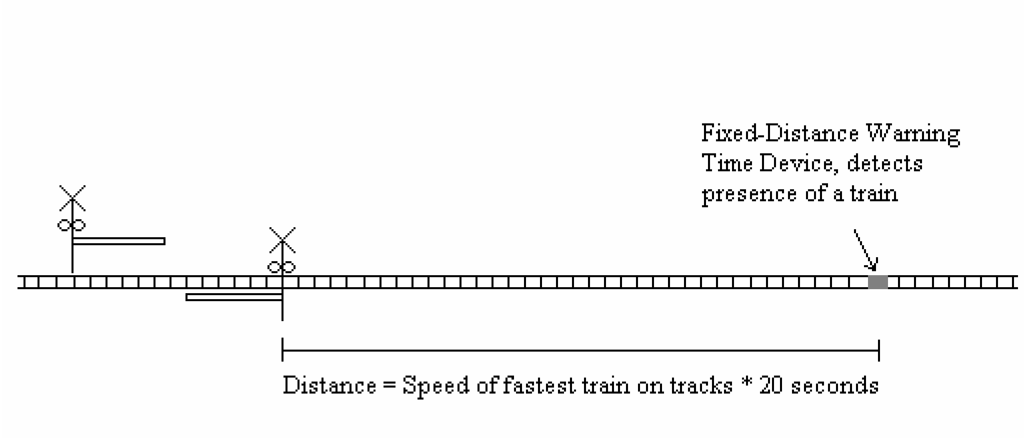


FIGURE 3 Diagram of Fixed-Distance Warning Time Device

Another type of train warning system using first generation technology utilizes constant warning time (CWT) devices (Figure 4). With CWT devices, train speeds are measured, and the distance from the intersection to the detector is fixed at a distance greater than or equal to the distance that the fastest train at the crossing would travel over the minimum warning time. The arrival time of the train is predicted based on the measured speed. The active warning devices are then activated accordingly to provide a constant warning time.

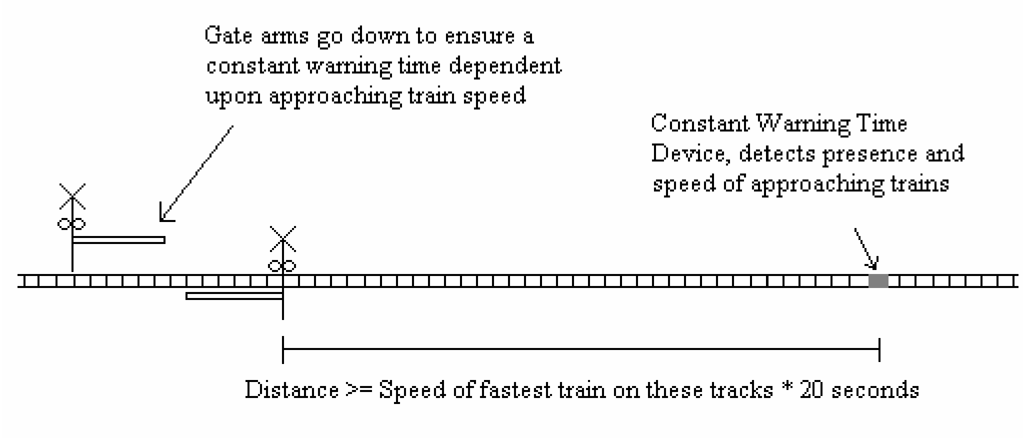


FIGURE 4 Diagram of Constant Warning Time Device

Some general conclusions can be made about the two first generation systems described. First, since the majority of trains travel at speeds slower than the fastest train, they will most likely create warning times longer than the 20 seconds provided for the fastest train in the FDWT system. This can lead to long warning times, which can increase delay for motorists and may prompt drivers to ignore the warning system and cross tracks in an unsafe manner. Second, CWT systems assume that trains do not accelerate or decelerate beyond the detected location. If the approaching train accelerates after triggering the CWT device, the required minimum warning time will not be given at a HRGC. Conversely, if the approaching train decelerates after triggering the CWT device, the warning time will be longer. Although a brief literature review of work using first generation technology is presented in the next chapter, other properties of first generation technologies have been well-documented and therefore will not be discussed in great detail (Tustin 1986, AREMA 2000-(1), and AREMA 2000-(2)).

Based on this brief summary of first generation systems, these commonly used train warning systems may potentially yield highly variable warning times. Therefore, a demand exists for an improved technology that is able to use more robust prediction models for train arrival at HRGCs. With the advancement in technology in recent years more sophisticated methods now exist for train detection. Some of these methods involve the use of second generation technology, which is discussed in the following section.

1.1.2 SECOND GENERATION

Second generation technologies, such as radar detection and video detection, use more advanced detector equipment, and consequently obtain more and better information on trains. For example, Doppler radar can provide a continuous stream of estimated train speed during the time that the train is detected, yielding a more accurate prediction of a train's arrival at a HRGC than first generation technologies. Additionally, second generation systems are able to be located outside of railroad right-of-way and their deployment is relatively inexpensive (Estes 2000).

Some limitations of second generation technologies have been identified. For instance, radar can have difficulty obtaining accurate measurements during rain events and during events where multiple trains exist at a location simultaneously. Also, video detection has been found to have difficulty due to snow blinding and sun glare. To account for these limitations, research has been conducted on data fusion of the two detection methods to reduce or eliminate error in detection.

Second generation technologies have been investigated through the TransLink Research Center at the Texas Transportation Institute (TTI) (Cho 2003-(1), Estes 2000 and, Cho 2002). The next chapter presents a literature review for research that has been performed with second generation technologies. Despite the efforts still being made to investigate second generation technologies, new research has begun on third generation technologies. The following section describes what some consider being an even higher form of technology than second generation technology, third generation technology.

1.1.3 THIRD GENERATION

Third generation technologies provide continuously updated train information that can be integrated into the operation and management of the railroad and traffic network, commonly through the use of Global Positioning Satellite (GPS) systems. This technology allows traffic management centers to know the current position, speed, length, and other information of trains within their network. Third generation technologies would however result in installation of GPS units on every train crossing a given HRGC to accurately predict train arrival times at that crossing. Additionally, these systems require consistent equipment on all trains and an integrated communication system that is integrated across modes.

An important component of Intelligent Railroad Systems (IRSs) is Intelligent Grade Crossings (IGCs) (Richards 1990-(1)). IGCs use information obtained from second generation technology systems and Positive Train Control (PTC) systems, all components of third generation technology systems, to provide information of train presence and arrival times to motorists and information on stalled vehicles in the middle of a grade crossing to railroad control centers. PTC systems control train movements safely, precisely, and efficiently through the use of integrated command, control, communications, and information systems. These systems combine multiple systems and equipment in an effort to monitor and control train operations. Such items integrated together include: digital communications networks, Differential Global Positioning Systems (DGPS), on-board train equipment and technologies, wayside interface units at switches and wayside detectors, and control center computers. The objective of PTC systems is to improve rail safety by significantly reducing the likelihood of an incident involving damage to pedestrians, property, and equipment. A review of works using third generation technologies is provided in chapter 2.

Advancements in intelligent transportation systems (ITS) technologies, such as second and third generation technologies, allows for information to be easily shared between rail and highway operations. This would increase the reliability of train arrival prediction times and is essential to reduce vehicular delay and improve safety at HRGCs. This thesis investigates the use of second generation technologies as a means to gather train information that would be able to be shared with equipment at nearby crossings and any other adjacent traffic control systems.

1.2 PROBLEM STATEMENT

Limited work has been done using second generation technologies at HRGCs. Similar technologies to those used in second generation systems are used in a highway environment to detect vehicles. One potentially useful second generation technology is video detection. Video detection has seen wide use in the highway area as it has several advantages. It is a non-intrusive detector that can be installed away from the area of interest for detection. It has proven to be a robust detection system that is flexible in terms of where detection is done within the field of view of the camera. It can collect a variety of data including presence of vehicles and vehicle speeds. The work presented in this thesis investigates the use of video detection to detect the presence of trains as well as train speeds through a series of field experiments.

If video detection can be used to detect trains and train speeds accurately, it would provide highway traffic engineers a relatively inexpensive tool for obtaining longer advanced warning of train arrivals at HRGCs over that of extended track circuitry. While positive train control (PTC) has the potential to perform a similar function, PTC information may not be readily available to highway traffic engineers for a variety of reasons. Since video detection can be installed off railroad right-of-way, it could be used by highway traffic engineers in situations where track circuitry and PTC are not available.

1.3 OUTLINE OF THESIS

Chapter 2 of this thesis presents a literature review of materials relevant to the topic of train detection at and near HRGCs. This review includes work done using first, second, and third generation technologies, studies to increase safety at HRGCs, and research of other non-intrusive technologies.

Once the literature review was performed, the next step was to collect data in the field. Chapter 3 presents the methodology and results of the field data collection. Field data collection consisted of collecting radar data of trains, video recordings of trains, and all necessary field measurements to properly calibrate equipment during field data processing.

After collection of data in the field, the data was processed in the traffic engineering lab in the Peter Kiewit Institute in Omaha, Nebraska and is described in

Chapter 4. Field data processing consisted of several steps used to accurately calibrate the radar data and the Autoscope video detection system. Field data processing also consisted of data collection with the Autoscope video detection system once calibrated.

Once field data processing in complete, data analyses were performed on the radar and Autoscope data. This involved statistical comparisons between the radar and Autoscope data. This is presented in Chapter 5

Finally, Chapter 6 presents the results and conclusions based on the findings of the research, data collection, and data analyses.

CHAPTER 2. LITERATURE REVIEW

Much work has been done to investigate several different forms of train detection technologies and increase safety at and near HRGCs. The following sections present a review of literature for works done using first, second, and third generation technologies as well as works done to increase safety at HRGCs.

2.1 FIRST GENERATION TECHNOLOGIES

Although much advancement has been made in detection technologies, equipment that is considered to be part of first generation technology continues to be widely used for train detection. The following presents a review of works using first generation technology for train detection at HRGCs.

2.1.1 WARNING TIMES AT GRADE CROSSINGS USING TRAIN PREDICTORS

The effects of train predictors with CWT on crossing safety and driver response measures were evaluated by Richards, Heathington, and Fambro (Richards 1990-(1)) in order to improve the overall safety of HRGCs. Constant warning time predictors attempt to provide a constant amount of warning time to drivers and pedestrians crossing an at-grade crossing regardless of a train’s speed. Performance data were collected at an existing active crossing with conventional detectors, and then again at the same crossing after predictors had been installed. Based on the results of the study, the length of the warning time period at active grade crossings is vital to crossing safety and traffic operations. Train predictors resulted in shorter and more consistent warning times.

Predictors were also concluded to significantly improve crossing safety and enhance motorist respect for the active traffic control systems. Finally, research also recommended that train predictors be installed at active crossings that have highly variable and long train warning times.

2.1.2 ALTERNATIVE DETECTION TECHNOLOGIES

The FRA, TTCI and the Volpe Center evaluated five technologies for their ability to detect trains and/or highway vehicles approaching and occupying HRIs (Reiff 2003, and Reiff 2001). Each system used first generation technology for train detection; although, higher forms of detection were used for vehicle and obstacle detection. “System 1” was evaluated as a train presence detection system only. This system uses a combination of magnetic anomaly and vibration detectors in a sensor module. “System 2” was evaluated as an integrated train and vehicle detection system. This system used double wheel sensors for train detection. A low power laser and video imagery system was used to detect highway vehicles. “System 3” was evaluated as a train detection system only. This system used a low power module with vibration and magnetic anomaly sensors to detect the approach and departure of a moving train. “System 4” was evaluated as an integrated train and vehicle detection system. This system utilized inductive loops placed between the running rails to detect the approach of a train. To detect vehicles within the HRI, “System 4” utilized a single radar unit placed on one side of the HRI. “System 5” was not evaluated. “System 6” was evaluated as a vehicle/obstacle detection system only. This system used a combination of passive infrared and ultrasonic detectors to indicate a vehicle/obstacle within the HRI.

“Systems 2 and 4” exhibited no train approach failures. “System 2” consistently matched the baseline system for accuracy in detecting train arrival and departure within the island limits. “Systems 2, 4, and 6” detected pedestrians and vehicles statically within the HRI. “Systems 2 and 6” interpreted all combinations of moving vehicles properly and were able to detect dropped loads. Furthermore, ITS findings concluded that “System 1” was able to provide train direction, speed, and length information. “System 2” was able to provide train direction and train speed information and “System 4” was able to provide train direction information.

2.2 SECOND GENERATION TECHNOLOGIES

Advancements in technology have allowed for a higher level of technology to be used for train detection. Much of the research performed with advanced technology has been done with second generation technology; research relevant to this thesis is reviewed in the following sections.

2.2.1 SAN ANTONIO ADVANCED WARNING TO AVOID RAILROAD DELAY (AWARD)

The Texas Department of Transportation (TxDOT) tested a system called Advanced Warning to Avoid Railroad Delay (AWARD) (Venglar 2000-(1), Engelbrecht 1999, Jacobson 1999, and Venglar 2000-(2)) for train detection, traffic management, and traveler information. This system used sonar detectors to monitor the low-speed trains traveling inside the city and predict their arrival times at important grade crossings. The prediction information was displayed on variable message signs near the crossing, advising motorists of the blockage. Sensors detected the presence, speed, and length of an approaching train, and the length of time in blockage was calculated. VMS upstream of the crossing informed drivers to take alternate routes. The TransGuide traffic management center included information on delay. Also, emergency vehicles used the delay information to plan their alternate routes. Due to the low frequency of situations where the system could be activated, the impact of the system on network performance measures could not be measured. However, the researchers estimated that if approximately 45% of drivers changed their route based on the VMS message, travel time delay would decrease by 19%.

2.2.2 IN-VEHICLE WARNING

An in-vehicle warning system was designed, installed, and tested by Raytheon Company (U.S. DOT 2001). The devices are used to detect trains and activate train warnings and send a signal to the in-vehicle receiver to let the driver know when an oncoming train is approaching. The in-vehicle warning system can act in visual mode, audio mode, or audio/visual mode. Findings showed that the system made improvements in making drivers more aware of on-coming trains near his/her relative location.

The Minnesota DOT partnered with 3M Corporation and Dynamic Vehicle Safety Systems (DVSS) to develop an in-vehicle warning system and a passive train detection system (U.S. DOT 2001). Wireless vehicle and roadside communication antennas that were built into the cross-bucks sent a message to the in-vehicle warning systems of nearby vehicles. The in-vehicle display warned drivers by means of both visual and audible signals. Since the scope of deployment was so small, the impact of the system on network performance measures could not be measured directly. The passive train detection system was set to detect internal radio frequency communications called Head-Of-Train (HOT), which coordinated braking between the front and rear of the train. These HOT passive train detectors were installed onto school buses. The results from the passive train detection system showed that only 15% of bus drivers reported altering their driving behaviors due to the system.

2.2.3 ADVANCED PREDICITON OF TRAIN ARRIVAL AND CROSSING TIMES AT HRGCs USING DOPPLER RADAR

Estes and Rilett looked at developing a model using second generation technologies to produce algorithms used in train arrival and crossing times at HRGCs (Estes 2000). The advantage of second generation technology is that it is relatively inexpensive to deploy. Four different types of data were collected: speed, presence, direction, and still pictures. Doppler microwave radar detectors were mounted on traffic-signal poles near three grade crossings. A speed profile variation was created to cluster the different values of acceleration into four groups. A sensitivity analysis, as well as stepwise regression, confirmed that roughly one speed reading every 10 s was significant in predicting train arrival times. Models/algorithms were then created using single linear-regression of the most recent recorded speed, multiple linear-regressions of speeds recorded every 10 s, and a modular approach using the clustered data of the speed profile variation along with multiple linear-regression. The statistical analysis of train data using a modular approach was able to accurately predict the arrival times of trains. The modular method was able to predict the arrival time of a train to within + or – 20 s of its true arrival time, whereas early predictions had an accuracy of + or – 60 s. The researchers also mentioned that this information could be utilized as a supplemental method of predicting the arrival of trains at a HRGC and should not be considered as a replacement for the current safety systems at grade crossings.

2.2.4 RAILROAD GRADE CROSSING MONITORING SYSTEM

Research was conducted by Goolsby et al. to examine how detection, communication, and information systems can be integrated to monitor the movements of trains in a corridor to reduce conflicts and delays created by HRGCs (Goolsby 2003). This project developed a system primarily oriented for use by fire and police personnel to minimize conflicts and delays while on emergency runs. Two systems for monitoring train movements were considered in the evolution of the deployed project. Functionally, the two concepts were very similar with the primary difference being the technology used for train detection, e.g., transponders (Automatic Vehicle Identification - AVI) and Doppler radar. Each technology could detect presence, direction, speed, and length of trains. Both concepts also included the monitoring of trains at crossings adjacent to signalized intersections. Research concluded that from these tests, to successfully utilize the currently available AVI technology for monitoring trains, a distance of 25 feet or less from antenna to tag is necessary. This requirement makes it necessary to set up the monitoring system on railroad right of way–something that could not be agreed upon between Union Pacific Railroad (UPRR) and TxDOT. In addition, system costs are higher than for a Doppler radar system. The Doppler radar-based system developed in Sugar Land, TX has evolved into a very stable, reliable operating system for detecting trains and projecting the movements in the corridor. City fire, police, and public works personnel find the system to be useful in making emergency runs and for verifying the status of crossing protection equipment.

2.2.5 FORECASTING TRAVEL TIMES WITH ARTIFICIAL NEURAL NETWORKS

Cho and Rilett investigated the use of modular Artificial Neural Networks (ANN) to forecast train arrival times at HRGCs (Cho 2003-(1), Estes 2000, and Cho 2002). The existing prediction methods assume that the train's speed at the time of detection will remain constant. The authors used second generation technology which included a Doppler radar detector for measuring train speed, direction, and length, as well as video cameras to record train events. Two models used for detection were standard ANN, see Table 1, and modular ANN.

TABLE 1 Comparison of Computing Approaches

Characteristics	Traditional Computing (Including Expert Systems)	Artificial Neural Networks
Processing style	Sequential	Parallel
Functions	Logically (left brained) Via Rules Concepts Calculations	Gestault (right brained) Via Images Pictures Controls
Learning Method	By rules (didactically)	By Example (Socratically)
Applications	Accounting Word Processing Math Inventory Digital Communications	Sensor Processing Speech Recognition Pattern Recognition Text Recognition

Research found that the current method of detection used produced the greatest amount of error in arrival times. The results from the modular ANN approach were combined with multiple regression to form arrival models/algorithms. The ANN approach greatly reduced the error, and the modular ANN further reduced the error. Therefore, the modular ANN approach is suitable for forecasting train arrival times at sites where a wide range of train speed profiles exist (Cho 2002).

2.2.6 LONG ISLAND RAILROAD INTELLIGENT GRADE CROSSING

The New York State Department of Transportation developed an IGC that used a combination of first generation technology to detect trains approaching the crossing and second generation technology for vehicle detection at the crossing. The IGC incorporated ITS technologies including CWT detectors, VMS, and presence detectors at the crossing, to perform many functions in order to improve railroad crossing safety and minimize driver inconveniences (U.S. DOT 2001). The IGC provided a constant 30-second warning time to drivers, regardless of the train's speed or type. The IGC also used Transient Gate Control, which left gates down when a second train entered the crossing shortly after another. It was also capable of letting an equipped emergency vehicle through the crossing if a train's speed and distance allowed for it. The IGC minimized gate down times, used VMS to inform drivers of various situations, and was able to detect vehicles stalled or stopped on the tracks. This system was taken out of operation to pursue development of an enhanced system that would include train location using GPS.

2.3 THIRD GENERATION TECHNOLOGIES

The latest form of train detection to emerge has been through the use of third generation technology. As described before, third generation technology allows for the use of GPS to locate and gather data on trains. The following presents a review of research performed using third generation technology.

2.3.1 POSITIVE TRAIN CONTROL AND INTELLIGENT GRADE CROSSING

The FRA and the railroad industry worked on the development of IRSs (Ditmeyer 2001) that would incorporate new technologies to increase the safety and serviceability of railroads. Two of the new technologies that will help with safety at at-grade railroad crossings are PTC and IGCs. PTC systems are integrated command, control, communications, and information systems using DGPS for controlling train movements with safety, precision, and efficiency. IGCs use information obtained from PTC systems to provide information of train presence and arrival times to motorists and information on stalled vehicles in the middle of a grade crossing to railroad control centers. The FRA believes that these technologies will prevent collisions and improve safety.

2.3.2 FOUR-QUADRANT GATE WITH AUTOMATIC TRAIN STOP

Testing was done on a four-quadrant gate system with an obstruction detection function that interfaces with Amtrak's in-cab signaling system (U.S. DOT 2001). Third generation technology was used for the interface with the Amtrak in-cab signaling system in determining train position relative to the crossing. This provided the locomotive engineer with a notice to stop the train safely before it reached the crossing. Findings from this analysis revealed that risky behavior of drivers decreased significantly following the upgrade at the crossing from conventional two-quadrant gates to four-quadrant gates with automatic train stop.

2.4 SAFETY AT HIGHWAY-RAILROAD INTERSECTIONS

Between 1973 and 1989, over $2.3 billion in federal and state funds were spent to improve HRGC safety (Richards 1990-(1)). A major problem existing with HRGCs is the interaction of the train system with the traffic system (U.S. DOT 1994, Tustin 1986, AREMA 2000-(1), and AREMA 2000-(2)). This includes the safety implications of train-traffic vehicle collisions as well as traffic vehicles queuing back at HRGCs into nearby traffic intersections. To counter these problems, ITS seeks to more intelligently operate traffic near HRGCs. The Federal Railroad Administration (FRA) and the railroad industry worked on the development of Intelligent Railroad Systems (IRS) that would incorporate new sensors, computers, and digital communication technologies to increase the safety and serviceability of railroads (U.S. DOT 2002, and U.S. DOT 2001). Studies have been performed by researchers to observe driver behavior and to increase safety at these intersections. The following sections summarize the need to increase safety and safety related issues at HRGCs.

2.4.1 DRIVER WARNING TIME NEEDS

Research conducted by Richards and Heathington assessed the effects of warning time on driver behavior and safety at HRGCs with active traffic control (Richards 1990-(2)). The goal of this research was to minimize the number of vehicles crossing during the warning period and promote driver credibility for the active control devices. Research suggested that minimum warning times range from 20-35 seconds depending on the width and grade of the crossing. Based on study results, warning times in excess of 30-40 seconds caused many more drivers to engage in risky crossing behavior. Research also concluded that if more than 10 percent of the warning times exceed 40 seconds for flashing light signals or 60 seconds for gates with flashing light signals, then the installation of motion sensors for trains or train predictors, such as constant warning time devices, is strongly recommended.

2.4.2 SECOND TRAIN WARNING

The benefits for installation of a train-activated sign to warn pedestrians when two or more trains are approaching an HRGC were investigated (Khawani 2001, and TCRP 2002) for the Los Angeles County Metropolitan Transportation Authority and the Maryland Mass Transit Administration. From the analysis of before and after video data, research found that the warning sign was effective in increasing pedestrian safety.

2.4.3 PREDICTION OF HAZARDS

Faghi and Demetsky applied the principles of reliability and risk assessment in a model for the problem of measuring hazardous instances at HRGCs (Faghri 1988). A reliability-based model was compared to five other models [The Department of Transportation (DOT), Peabody-Dimmick (P-D), NCHRP 50, Coleman-Stewart (C-S), and New Hampshire (N.H.)] to provide probabilistic concepts of reliability and risk assessment. The reliability-based model showed improvements over the other models due to its probabilistic nature.

2.4.4 DRIVER APPROACH SPEED

Moon and Coleman analyzed data to statistically determine whether the observed speed profiles of drivers were a constant speed approach or speed reduction approach (Moon 1999). The findings were that drivers do reduce their speed on approach to highway-rail intersections. The data gathered on driver speed selection was used to adjust four-quadrant-gate timing to avoid vehicle entrapment.

2.4.5 CONTROL DEVICES AT RAILROAD-HIGHWAY GRADE CROSSINGS

Two active traffic control devices for use at HRGCs were examined by Heathington et al. (Heathington 1990) as a means to improve safety for the traveling public at railroad crossings. The two systems examined were a four-quadrant gate system with skirts and flashing light signals and a highway traffic signal system with white bar strobes in all red lenses. Both systems proved to decrease the number of motorists that crossed in front of oncoming trains. Conclusions stated that as these systems are implemented and placed under additional field conditions, modifications may be needed.

2.4.6 VEHICLE PROXIMITY ALERT SYSTEM

The Volpe National Transportation Systems Center (Volpe Center) investigated the FRA’s coordinated field-testing of Vehicle Proximity Alert System (VPAS) technologies (Carroll 2001-(1)) as part of a comprehensive research program for improving safety at highway-railroad grade crossings. VPAS technologies can transmit in-vehicle visual and audible warnings to motorists in the vicinity of a grade crossing when a train is approaching. Three different prototypes were tested: a three-point system by SmartStops Unlimited, Inc., a one-point system by Custom Automated Plastic System Inc. – the Early Alert Response System (EARS), and a two-point system by Dynamic Vehicle Safety Systems (DVSS). The SmartStop system appeared to be the best candidate due to the minimal number of misses by the system. The EARS system had several misses, and the DVSS system triggered alarms in vehicles that were not near crossings. The Transportation Technology Center, Inc. (TTCI) concluded that the concept of VPAS for warning priority vehicles of the approach of a train to a grade crossing is feasible, though none of the systems as tested was suitable for further testing. TTC also concluded that radio frequency systems appeared to be more suitable for a warning system than do acoustic systems.

2.4.7 PASSIVE RAILROAD CROSSINGS

The Transportation Research Board (TRB) tried to determine whether any innovative or nonstandard Traffic Control Devices (TCDs) could be recommended as improvements to safety at passive (no flashing lights or automatic gates) HRGCs (TRB 2002). The report evaluated the shortcomings of current practice and the potential benefits of alternative devices through a variety of activities. The work identified key requirements that a TCD system for passive HRGCs should meet. A desire existed to identify relatively low-cost improvements to TCD practice at passive grade crossings. Studies show that existing TCD practice may not be providing the driver with the information required. Research found that preference for the combined use of a cross-buck mounted together with a regulatory sign was high. One conclusion was that drivers need to be made aware that they are approaching a passive crossing and that the decision to stop or proceed rests in their hands. The research concluded that advance warning signs and cross-bucks only convey the general idea of "railroad crossing," which is not regarded as highly as they should be by drivers, but these signs could be made more effective through the use of supplementary plaques.

Work was conducted on Passive Warning Signs (PWSs) that have no lights or electrical connections, but are designed to light up and have 'an active look' as a train locomotive approaches the grade crossing (Russell 1997). The sign was evaluated in many adverse environmental conditions and conclusions confirmed that the PWS sign was effective under all conditions when illuminated by the train's headlights.

2.4.8 PHOTO ENFORCEMENT

The use of photo enforcement was investigated to increase the safety at public crossings (Carroll 2002). This technology observes and records driver and pedestrian behavior, since driver behavior is at the base of the crossing safety problem. The results of the investigations by Carroll and Warren at six sites in the United States showed positive results in reducing violations in the range of 34% to 92%.

2.4.9 FREIGHT CAR REFLECTORIZATION

Demonstration tests were conducted by FRA to establish the durability of a developed microprismatic material used for retroreflectors on freight cars (Carroll 1999). These reflectors are used to reduce the number of collisions at HRGCs where train visibility is a contributing factor. Results from this research indicated that a uniform, recognizable pattern of reflectorized material can generate recognition of a freight car. Conclusions stated that the microprismatic material tested could sustain adequate intensity levels for up to 10 years with maintenance.

2.4.10 NEW TECHNOLOGIES FOR IMPROVING LIGHT-RAIL GRADE CROSSING SAFETY

ITS technologies were evaluated for Light-Rail Transit (LRT) systems (Meadow 1997). Operation of LRT systems in shared right-of-way presents an opportunity for collisions. Many safety problems are the result of failure of motorists and pedestrians to obey or accurately understand warning devices and traffic controls. New technologies, such as those of ITS, are being applied to improve safety at railroad grade crossings in Los Angeles County on the Metro Blue Line (MBL), a 22-mi (35-km) light-rail line. The Los Angeles County Metropolitan Transportation Authority (MTA) has demonstrated that photographic enforcement can assist in reducing the number of traffic accidents. Another ITS technology being used on the MBL is the Autoscope video detection system. This system is being used to detect vehicles making illegal left turns across the MBL tracks, which triggers the photographic enforcement camera to take pictures of violators. For MBL grade crossings, camera equipment is activated by vehicles running under or around crossing gates or making left turns against red-turn arrows. On a seven month demonstration project in the city of Compton, the number of violations recorded by the equipment dropped off dramatically from one violation per hour to one violation every 12 hr. In downtown Los Angeles, where motorists make left turns on red-arrow signals in front of the train, a demonstration project using photographic enforcement has resulted in a 34% reduction in violations.

2.4.11 BALTIMORE LIGHT RAIL TRANSIT SECOND TRAIN COMING

Testing was done by the Maryland Mass Transit Administration (MTA) on a second train warning system (U.S. DOT 2001) that warns drivers and pedestrians, by means of VMS, when a second train is arriving shortly after another train has left the crossing. The devices used to detect trains and activate train warnings identify when a second train is approaching and relay information to the VMS. Videotaped observation at the crossing showed that risky behavior of drivers decreased by 36% after installation of the system.

2.5 MISCELLANEOUS RESEARCH FOR HIGHWAY-RAIL GRADE CROSSINGS AND NON-INTRUSIVE VEHICLE DETECTION

Much research has been performed on train detection as previously presented. In addition to that research, a lot of other research has been performed that is relative to the topic of train detection near HRGCs. Also, much research has been done on detection using non-intrusive equipment. This equipment, typically used for vehicle detection, may also be a means of train detection as research of second generation technology for the use of train detection continues. The next sections present research relative to train detection near HRGCs and non-intrusive detection equipment.

2.5.1 AUTOMATED HORN WARNING SYSTEM

Gent et al. determined the effectiveness of the automated-horn system in reducing the annoyance levels for nearby residents and determined the overall safety at the crossings with the new automated-horn warning system (Gent 2000). The new automated-horn system was placed at the crossing gates to minimize the affected area. The automated-horn system proved to be effective in reducing the noise level in surrounding areas, and the project found no evidence to suggest that the automated horns are less safe than the current practice of using train-mounted horns.

2.5.2 EFFECT OF VMS ON TRAFFIC-FLOW OPERATIONS

The impacts of train operations and Variable Message Signs (VMS) on traffic-flow operations were studied by Sivanandan et al. using simulation scenarios with various train-crossing durations, levels of traffic demand, and levels of vehicle response to the VMS system (Sivanandan 2003). Only marginal benefits were found from the use of the VMS system. While little network improvements were obtained, the analysis showed the capability of the INTEGRATION software in analyzing certain scenarios and the profit that exiting freeway traffic may experience from the VMS system.

2.5.3 PREEMPTION CAPABILITIES OF TRAFFIC SIGNAL CONTROLLERS

Marshall and Berg examined and compared the preemption capabilities of a number of currently marketed actuated traffic signal controllers based on the National Electrical Manufacturers Association standard (Marshall 1990) to determine whether modern controllers allow practical and reasonable preemption design. They found that some of the features included on individual controllers are excellent and should be included on all controllers, while other features are inappropriate. The research concluded that further work was needed concerning the capabilities of the track circuit hardware as it relates to traffic signal preemption.

2.5.4 INTERSECTIONS NEAR CROSSINGS

TRB reviewed the state-of-the-practice operation of traffic signals at intersections located near HRGCs (TRB 1999). Research showed that practices relative to traffic signal operations near HRGCs vary widely throughout North America. A lack of coordination between rail crossings and nearby intersections in certain areas was found to be a common problem. Research also showed that potential conflicting movement occurs when motor vehicles queue back across the tracks at a HRGC due to red traffic signal indications at the adjacent intersection. One solution offered was the use of pre-signals, signals upstream of crossings that function to control traffic entering the HRGC. To provide an adequate level of safety, conclusions stated that state-highway agencies need to synchronize the timing sequence of the highway traffic signals with the train detection system as well as the HRGC warning devices.

2.5.5 TRANSITIONAL PREEMPTION STRATEGY

Venglar investigated the use of a logic algorithm known as the Transitional Preemption Strategy (TPS) to preempt traffic signals at signalized highway intersections located near HRGCs (Venglar 2000-(1)). Traffic signals located near HRGCs are interconnected with active warning devices and were programmed to preempt their regular timing sequence and present a green signal to motorists on the intersection approach that crosses the tracks. The results indicated that intersections within 200 ft of a HRGC should be considered for preemption. TPS was design to provide the advanced detection time required to preempt a traffic signal without affecting vehicular and pedestrian phasing. A simulation test indicated the potential of the TPS logic to alleviate phase abbreviation problems, but revealed controller interface issues between the TPS logic and the signal controller unit. The research concluded that the TPS could only be considered a developing concept that was not ready for field implementation.

Subsequent work was conducted by Cho and Rilett that expanded the TPS concept to explicitly include the variability of the forecast train arrival times, traffic delay, and amount of advanced warning within the preemption strategy (Cho 2004-(1), Cho 2004-(2), and Cho 2003-(2)). The improved TPS algorithm was tested using a calibrated VISSIM model of the traffic network where the traffic signal logic was encoded using a Vehicle Actuated Programming (VAP) language (Verkehr 2000). Empirical train and traffic delay was collected in a test bed using direct observation, Autoscope cameras, and second generation train detection technology. The logic of the EPAC 300 actuated controller was used to control the traffic signals (Eagle 1997). Research showed that by using a greater advanced preemption warning time and explicitly considering the variability in the predicted arrival time, the safety could be increased while simultaneously reducing delay.

2.5.6 SIGNAL OPTIMIZATION UNDER RAIL CROSSING SAFETY CONSTRAINTS (SOURCAO)

An approach, named “Signal Optimization Under Rail Crossing sAfety cOnstraints” (SOURCAO), was proposed by Zhang and Hobeika for the traffic signal control near a HRGC (Zhang 2000, and Zhang 1999). SOURCAO’s two objectives are HRGC safety improvement and highway traffic delay reduction. By integrating artificial intelligence and optimization technologies, the independent simulation evaluation of SOURCAO by

TSIS/CORSIM demonstrated that the objectives are reached. The research suggested that the proposed system be tested on other cases to further validate the software. Finally, the sensitivity tests demonstrated that SOURCAO works efficiently under light and heavy traffic conditions, as well as a wide range of HRGC closure times.

2.5.7 PREEMPTED TRAFFIC SIGNALS

The technological advances of preempted traffic signals near active railroad grade crossings were investigated by the TRB (ITE 1997). The report included a phasing sequence for pre-signals and elaborated on the operational characteristics of pre-signals. It also provided operational discussions on interconnected, preempted traffic signals near active HRGCs.

2.5.8 PRE-SIGNALS

TCRP Report 69 discussed pre-signal design similar to the current practice in the state of Illinois (TRB 2000). In addition, this report illustrated the effectiveness of pre-signal based on the before and after analysis of two Chicago metropolitan signals. The report's appendix materials summarized the use of pre-signals as a state standard in Michigan and South Carolina.

2.5.9 INTRUSION DETECTION TECHNOLOGIES

Methods for detection of objects on railway tracks where they are crossed by a roadway were evaluated by Zaworski and Hunter-Zaworski (Zaworski 2003) both in the laboratory and in the field. The focus of this research was the evaluation of two existing technologies, a video detection system and a microwave detection system. The two technologies showed good results in the laboratory, but had shortcomings when tested in the field. The research deemed it possible to improve the technologies to a point where they would perform at an acceptable level. However, research suggested that the full range of possibilities that exist for intrusion detection be re-explored. Two previous studies that were conducted on this topic were a 1997 study by the Oregon DOT (Bell 1997), which took a comprehensive look at possible grade crossing treatments for a potential high speed rail corridor, and a 1998 study by Carroll that focused on the issue of what constitutes an intruder or obstacle that needs to be detected (Carroll 2001-(2)).

2.5.10 NON-PAVEMENT INVASIVE DETECTORS

Non-pavement invasive detectors, detectors that do not require construction with concrete, non-pavement invasive detectors, were discussed in the 1996 edition of the Traffic Control Systems Handbook (U.S. DOT 1996). These detector types included radar/microwave detectors, sonic detectors, video image processing systems (VIPS), and infrared detectors. Research found that all four technologies could provide vehicle counts, presence of vehicles, vehicle speeds, and vehicle occupancy. However, the ability to detect presence and occupancy of vehicles by the radar/microwave detector is dependant on the design of the specific unit, and the sonic detectors yield poor accuracy in speed determination of vehicles. The infrared detectors' measuring capabilities and accuracy of all four parameters listed also is dependant on the design of the specific unit. Conclusion stated that each technology has various advantages and disadvantages pertaining to environmental, geometric, and economical effects.

2.5.11 FIELD TEST OF NONINTRUSIVE TRAFFIC DETECTION TECHNOLOGIES

The results of a two-year field test of nonintrusive traffic detection technologies were presented by Bahler et al. (Bahler 1998). Seventeen devices representing the following eight technologies were evaluated: passive infrared, active infrared, magnetic, radar, Doppler microwave, pulse ultrasonic, passive acoustic, and video. The devices were tested in a variety of environmental and traffic conditions at both intersection and freeway test sites. Emphasis was placed on urban traffic conditions, such as heavy congestion; locations that typify temporary counting situation, such as 48-hour or peak hour counts; and performance in the wide variety of weather conditions found in Minnesota. The evaluation also focused on the ease of system set-up and general system reliability. The results show that nonintrusive technologies are capable of performing as well as conventional methods in some, but not all, situations. At the freeway test site, most nonintrusive devices counted within three percent of baseline data. At the intersection test site, however, congested stop-and-go traffic hindered the performance of the majority of the devices. Weather and other environmental variables were found to have minimal impact on the majority of devices.

Conclusions were made for each of the eight different technologies. The passive infrared technologies were found to have good potential for detecting traffic at both intersection and freeway applications. The active infrared technology was only tested at the freeway, where it also exhibited good potential for vehicle detection.

The passive magnetic technology mounted in a conduit under the pavement has the potential for accurately detecting traffic; however, reliability problems were encountered during testing of the devices. This was probably due to the specific device tested or to cabling problems, not the technology itself. The installation of the magnetic probes under the freeway was much more involved than installation of the above-ground devices tested.

Radar technology was only tested at the freeway test site, where it showed good results for detecting traffic and measuring vehicle speed. The technology also has the advantage of monitoring multiple lanes when mounted from a side fire location, perpendicular to the direction of traffic. The Doppler microwave technology has good potential for detecting traffic and measuring the speed of moving vehicles at the freeway test site. Data collection performance at the intersection test site was found to be poor.

Pulse ultrasonic technologies have good potential for detecting traffic at both intersection and freeway applications. The passive acoustic technologies gave moderate results for detecting traffic at the intersection and freeway test sites.

Finally, the video detection was found to require extensive installation and set-up time and performed irregularly at times. However, the technology has the advantage of side fire mounting, multiple lane detection, and surveillance information, and it offers a wide variety of traffic data in addition to live video feeds of current traffic conditions.

2.5.12 DESIGN AND OPERATIONAL ISSUES RELATED TO VIDEO DETECTION SYSTEMS AT SIGNALIZED INTERSECTIONS

Some commonly encountered issues that are related to video detection system applications at signalized intersections were investigated by Tian (Tian 2003). The issues addressed reflected various aspects of occlusion; see Figure 5 for an illustration of occlusion. Occlusion in video detection systems can result in missed detections, false detections, and increased detector presence time, and thus may affect intersection operations under actuated control.

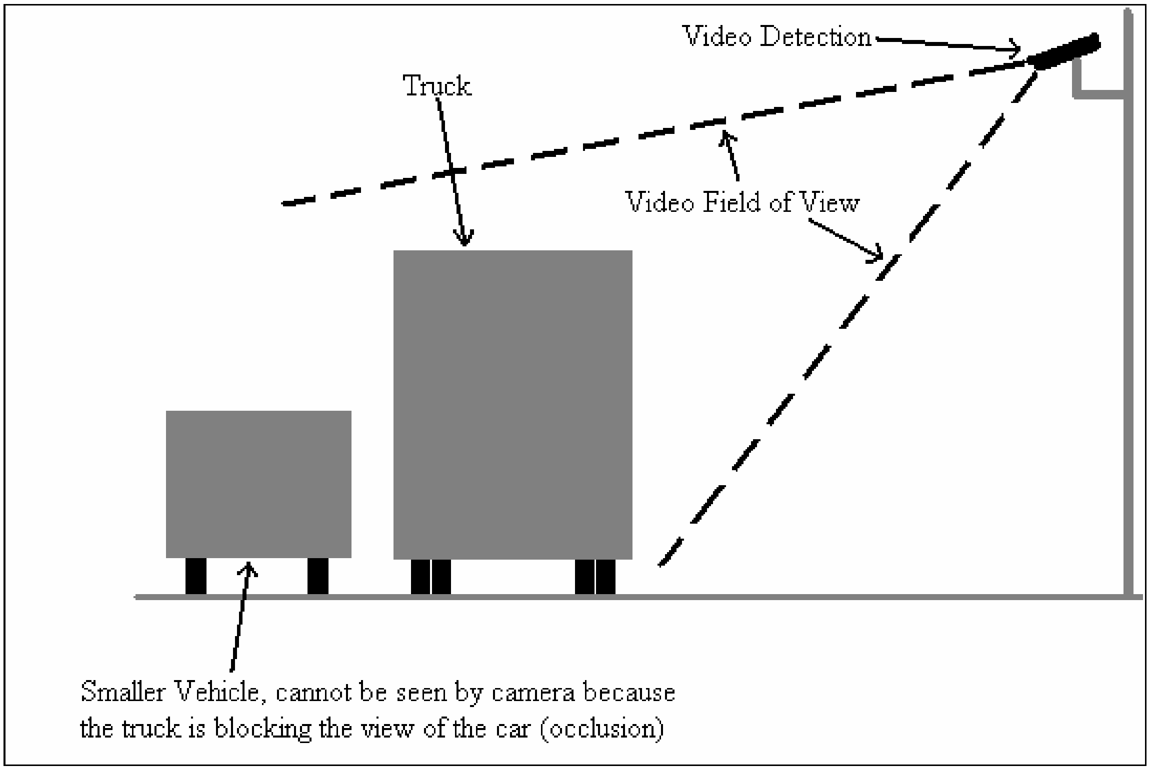


FIGURE 5 Illustration of Occlusion

Various models were developed to address these issues and quantitative evaluations were presented. Missed detections due to occlusion of following vehicles were generally less than 10% when the approach volume is less than 600 vph. At this traffic volume level, additional phase extension time caused by occlusion was generally less than four seconds. Conclusions stated that to minimize false detections due to occlusion of adjacent lanes, the camera is better positioned to the division line between the lanes. Also, it would require a much higher mounting position if the camera is located outside the travel lanes.

2.5.13 VIDEO DETECTION WITH THE AUTOSCOPE SOLO SYSTEM

Several video detection systems are available for traffic control and management. These systems include Econolite's Autoscope system, Iteris' Vantage system, and Traficon's system. Only the Autoscope system is covered, as this is the system employed at the University of Nebraska-Lincoln's Nebraska Transportation Center's (NTC's) ITS Lab. Other systems likely operate in similar fashion to the Autoscope system, but would require comparisons between the different technologies.

The Autoscope Solo™ Wide Area Video Vehicle Detection System (Autoscope Solo System and Autoscope System) is described in the Autoscope Solo User Guide (Econolite 2005-(1)) as a sophisticated traffic monitoring system. Both the Autoscope Solo System and the Autoscope System use machine vision processor (MVP) technology to yield traffic measurements. Autoscope has the ability to detect presence, speed, and counts of vehicles as well as several other parameters that pertain to these types of detection (i.e., traffic queues, stalled vehicles, or other incidents). With this technology, Autoscope can be implemented at intersections and interfaced with traffic control devices to detect vehicles and then be used for actuated control of traffic signals. Also, Autoscope can be used for incident detection on freeways which can be used in combination with other ITS to inform drivers of such incidents.

2.5.14 EVALUATION OF UDOT'S VIDEO DETECTION SYSTEM

The Civil and Environmental Engineering department at the University of Utah evaluated the performance of the Utah DOT's video detection system in various test conditions (University of Utah 2004). They found that video detection performed best under day and dusk conditions, recording approximately 87% correct detection of vehicles. The researchers observed that this rate declined in inclement weather, and produced the worst results at night, approximately 73% correct detection. On average, the video detection system recorded 83% correct detection. Research concluded that close attention to detail must be made during the installation of video detection systems. This includes placement of cameras, sufficient background lighting, focus settings, field of view calibration, and placement of detectors. The study also recommended that vendors be employed for the initial installation of video detection at each intersection. Finally, the researchers determined that video detection works well as a means of vehicle detection, and has the potential to work even better if the proper measures are taken into account during the installation process.

2.6 SUMMARY OF LITERATURE REVIEW

Much research has been done for train detection with an array of different technologies and methods. Advancements in technology have led to research using higher forms of technology, second and third generation, than what are typically used today. This research in turn has presented several solutions for train detection and arrival time prediction. In addition, much of the research performed at HRGCs has been to increase safety. This research has shown many alternatives to standard practice at HRGCs that can increase safety at these locations. Finally, much more research has been done on other topics relative to train detection near HRGCs. This research includes affects of traffic on street networks and at intersections near HRGCs as well as the study of non-intrusive detection equipment that may be used for train detection.

From this literature review, it can be seen that an extensive amount of research has been done to improve train detection, increase safety at HRGCs, improve signalization at intersections near grade crossings, and search for other means of detection that may improve the overall conditions at and near HRGCs. Results from these studies have helped to save lives and manage train and vehicular traffic. Continuing advancements in ITS and roadway vehicle detection technologies are likely to provide more technologies that may be useful in developing second generation HRGC control systems.

The next step to conducting research for video detection of trains after performing a thorough literature was to gather data. A methodology for data collection with second generation technologies is described in Chapter 3.

CHAPTER 3. FIELD DATA COLLECTION

To assess how well second generation technologies perform in measuring train speed and acceleration, data using these technologies must be collected. Two second generation technologies will be explored. These are Doppler radar and video detection.

Data collection was performed in the field and in the Nebraska Transportation Center's (NTC) Intelligent Transportation Systems (ITS) lab at the Peter Kiewit Institute in Omaha, NE. Field data collection consisted of radar data collection, video recordings, and field measurements. In-lab data collection consisted of manual data collection and Autoscope video data collection. The following describes data collection locations and data collection methodologies both in the field and in the lab.

3.1 DATA TO BE COLLECTED

To determine how well second generation technologies determine train speed and acceleration, data were first collected in the field and then through data extraction of field collected data. Field data collection consisted of video recordings, collection of Doppler radar data, and field measurements needed for calibration. Videos of trains were recorded so that various Autoscope detector setups could be used to collect train data during the data extraction process. These videos were also used to determine train speed and acceleration manually as a means of comparison and calibration of radar data. Radar data were collected so that results from Autoscope video detection could be compared to results from a documented accurate form of train data collection. Finally, field measurements were recorded at each site so that the camera locations with respect to the cameras' field of view could be established. These filed measurements were needed to calibrate both the radar and video detection.

3.2 DATA COLLECTION SITES

The research sites for the project were located in Nebraska. Nebraska is an excellent place to study HRGCs due to the large number of at-grade crossings: 6219 total crossings (40% private and 60% public), with approximately 75% of the public crossings passively controlled and the rest actively controlled (FRA 2011). Another reason to perform this research in Nebraska is because central Nebraska contains the highest volume of rail freight train traffic in the world. The mainline of the Union Pacific Railroad (UPRR) between North Platte and Gibbon, NE carried approximately 135 unit trains per day in 2005 (UPRR 2005). The Burlington Northern Santa Fe (BNSF) Railroad also has mainlines crossing Nebraska, with approximately 70 unit trains per day (Craig 2005). The UPRR and BNSF mainlines in Nebraska, the locations used for data collection, as well as other significant railroad areas in Nebraska are shown in Figure 6.

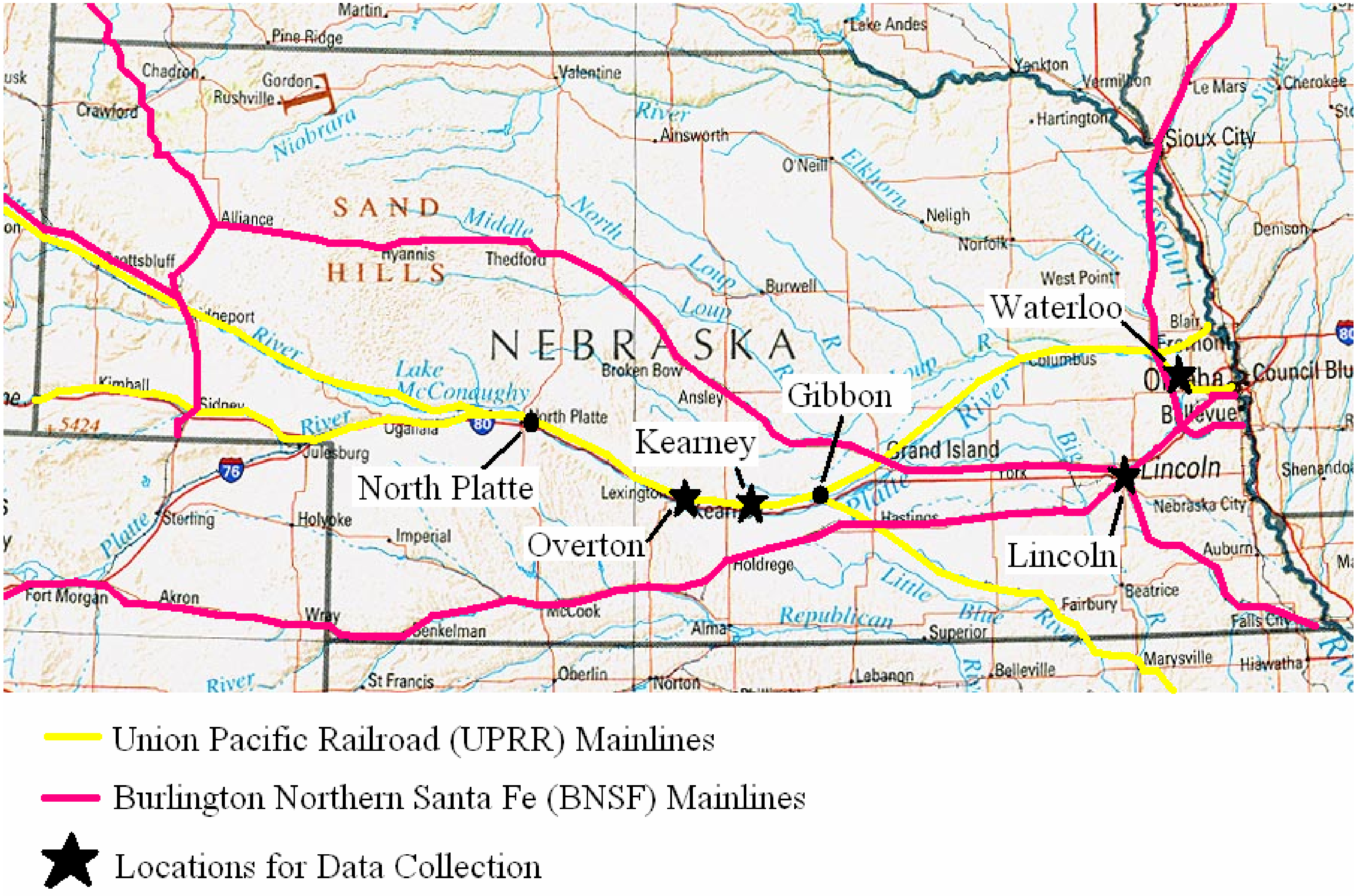
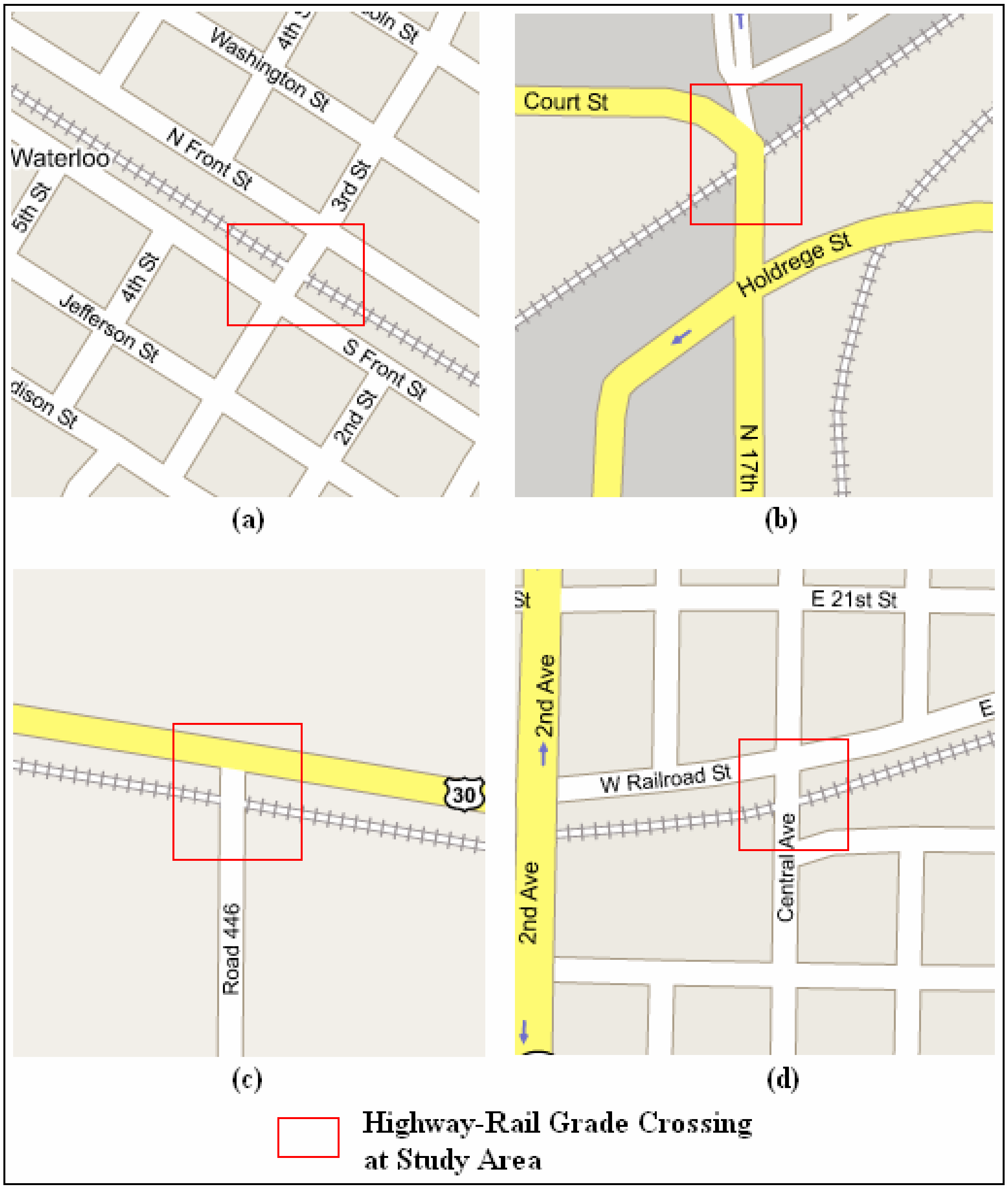


FIGURE 6 Mainlines of UPRR and BNSF in Nebraska with Data Collection Sites Shown

Data and video were collected at four different locations in Nebraska: Waterloo, Lincoln, Overton, and Kearney. Each site had different constraints from one another, and each contained a HRGC. Detailed views of the four specific locations used for data collection are presented in Figure 7. Descriptions of each site follow.



(a) (b) (c) (d)

FIGURE 7 Data Collection Sites (Google Maps 2005): (a) Waterloo, NE near corner of 3rd St and N Front St, (b) Lincoln, NE near corner of N 17th St and Holdrege St, (c) Rural NE, approximately 1.5 miles East of Overton, NE on U.S. Hwy 30, and (d) Kearney, NE, near corner of W Railroad St and Central Ave

Waterloo

Waterloo is just northwest of Omaha, NE. The data collection location in Waterloo, NE is located in the downtown area near the intersection of 3rd and North Front Streets, approximately half a mile south of Nebraska Highway 64 (West Maple Road of Omaha, NE). Approximately 90 trains pass through this location daily on two mainline tracks of the UPRR. The crossing at the location is an active HRGC with flashing lights and two-quadrant gate arms (one gate arm on each side of the tracks restricting vehicle movements across the tracks). The crossing street is a local road with one lane in each direction. This site was chosen due to its proximity to the Peter Kiewit Institute in Omaha, NE, the amount of train traffic at the site, and the observed speeds of the trains, which appeared to be 50 mph or higher.

Lincoln

In Lincoln, NE, the data collection site is just north of the University of Nebraska-Lincoln Main Campus and just southeast of the Bob Devany Sports Complex near the intersection of 17th and Holdrege Streets. Approximately 70 trains pass through this location daily on two mainline tracks. The crossing at the location is an active HRGC with flashing lights and two-quadrant gate arms. The crossing street is a local road with two lanes in each direction. Note that this crossing is now permanently closed. This crossing was selected because of its location in an urbanized environment causing trains to travel at speeds slower than at the Waterloo site.

Overton

Overton is approximately 20 miles west of Kearney, NE in central Nebraska. The site at Overton, NE is approximately 200 feet south of U.S. Highway 30 and 1.5 miles east of Overton. Approximately 135 trains pass through this location daily on three mainline tracks. The crossing at the site is a passive HRGC with cross-bucks only. The crossing street is a paved rural road with one lane in each direction. The Overton location was used as a data collection location due to its location in a rural setting, the high amount of train traffic, and the potential for multiple trains to pass the location at the same time.

Kearney

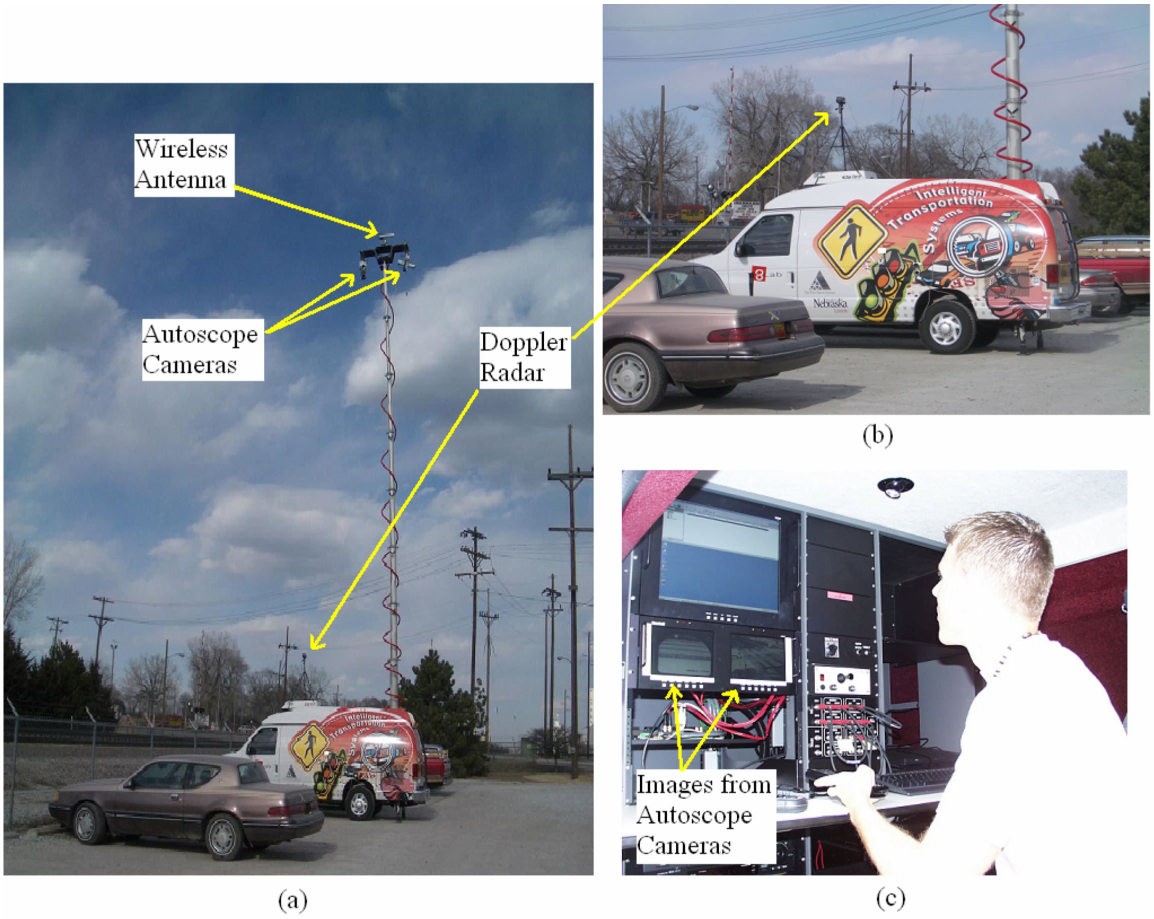
The location in Kearney, NE is approximately 1.75 miles north of Interstate 80, two blocks east of the 2nd Avenue viaduct, and in the southern portion of the downtown area near the intersection of West Railroad Street and Central Avenue. Approximately 135 trains pass through this location daily on three mainline tracks. The crossing at the site is an active HRGC with flashing lights, two-quadrant gate arms, and an automated horn warning system. The crossing street is a local road with two lanes in each direction. The site in Kearney was chosen because it exists in a fairly urbanized area, like Lincoln, and has good potential to produce occasions where multiple trains pass the location at the same time.

3.3 DATA COLLECTION PROCESS

Data collected in the field were the base for all data collected in the NTC ITS lab through a data extraction process. Field data collection consisted of video recordings, data collection with radar, and field measurements. Before field data collection could begin, a series of steps was taken to properly set up equipment at each site. The following section details the setup process of the data collection van.

3.3.1 SET-UP OF VAN

A portable intelligent transportation system was used for data collection, see Figure 8. The van is equipped with two Autoscope Solo Pro II cameras (Model 704120) (see Figure 9a), two remote controlled pan/tilt units, a 43-foot high locking mast, a computer, LCD screens for each camera and the computer, an Autoscope interconnect panel, two VCRs, a portable Stalker ATS radar gun (see Figure 9b), and other necessary cables and power connections. The computer was equipped with Autoscope Software (version 8.10) and was used for control of the detector files, video calibration, and data collection from the radar. The two VCRs were used to record analog video of each camera for post-processing.



(a) (b) (c)

FIGURE 8 Intelligent Transportation System Van: (a) Fully Extended Locking Mast and Mounted Autoscope Solo Pro II Cameras, (b) Tripod Mounted Radar Detection Unit on top of Van, and (c) Interior of Mobile Intelligent Transportation System Van

(a) (b)

FIGURE 9 Data Collection Equipment: (a) Autoscope Solo Pro II Machine Vision Processor (Model 704120) (Autoscope 2005) and (b) Stalker ATS Radar (Stalker 2005)

During a typical day of data collection, it was first necessary to find an appropriate location for the data collection van at a chosen site. Placement of the van was desired such that it was close enough to the tracks and the HRGC at the site so that the Autoscope cameras would have as steep of an angle as possible to the tracks. A steep angle was desired because the general rule for accurate data collection from Autoscope is to have the object being detected no more than three feet out from the camera location for every foot the camera is above the object (Econolite 2005-(1)).

Once an appropriate site was located and the van parked there, power was turned on for all of the electronic equipment in the van, stabilizer jacks were lowered, Autoscope cameras were mounted onto the pan/tilt units on the mast, and, after testing to see if the cameras were operating correctly, the mast was raised. Once these set-up procedures were performed for the van, the set-up of the Autoscope video detection cameras was performed. The following section discusses the field set-up of the video detection equipment.

3.3.2 SET-UP OF CAMERAS

After the mast was raised on the van, the cameras were aimed to desired locations, such as views of the site HRGC and the view perpendicular to the tracks. Note that these views are from off of the railroad right-of-way and are not from above the tracks. The view of the HRGC provided a skewed view of the trains and allowed for data collection of any hazardous events from motorists as the crossings. The perpendicular view allowed for the largest view of headway between rail cars. The camera zooms were adjusted so that approximately one and a half railcars were in the view of the perpendicular view and approximately three to four railcars were in the view of the HRGC (skewed view). These zoom settings were chosen based on the size of the detectors placed over the image during Autoscope video detection[1].

Autoscope was also utilized to place a time-stamp over the recorded video images. This was important for future data collection and train indexing during the data extraction process. Once all of the appropriate steps were taken to set up the video detection equipment, videotapes were used to record videos of the two fields of view with the two VCRs in the van. Once tapes had neared their capacity new tapes were inserted while no trains were present.

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[1] However, the research determined during data extraction of field data that a zoom showing more railcars in the perpendicular view may be better for video data collection. This is due to optimum detector placement for the detection of headway between railcars.

The recorded videos were later used during the video detection process during data extraction. Field measurements were necessary for video detection and were also collected during the field data collection. Measurements used for video detection included the height of the cameras above the track elevation and down-track and cross-track distances. These measurements were necessary for video calibration. More discussions of these measurements and their use in calibration is found in Chapter 4.

Once the cameras were set up to record video of trains, the portable radar unit was set up to record train data. The following section outlines the process of setting up the radar detection unit and radar data collection.

3.3.3 SET-UP OF DOPPLER RADAR

After the van was set up and the cameras were ready to record videos of the trains at the location, the Doppler radar unit was set up for data collection. The radar unit was set up on a tripod that was placed on top of the van and placed near the tracks. It was aimed at a position on the tracks where the angle between the tracks and the radar's line-of-site could be minimized, yet at a position that was within the limits of the radar unit. This placement and orientation of the radar unit was critical because of the way that the radar unit collects data. The speeds collected by the radar unit are the speed of an object as it approaches the radar unit along the line-of-site for the unit. To determine an object's speed along the object's path, an adjustment needs to be made based on the angle between the objects path and the radar unit's line-of-sight. By minimizing this angle, a smaller adjustment factor needed to be applied to the raw data collected by the radar. This angle was estimated to vary between 25 and 30 degrees at each site. An example of the comparison of the object path, radar line of sight and the adjustment angle is shown in Figure 10. Note that the placement on top of the van allowed for a small vertical angle to the trains' elevation on the tracks at the sites. This allowed for the calibration of the radar's vertical angle to be omitted from future calculations. Calibration of the radar data is further discussed in Chapter 4.

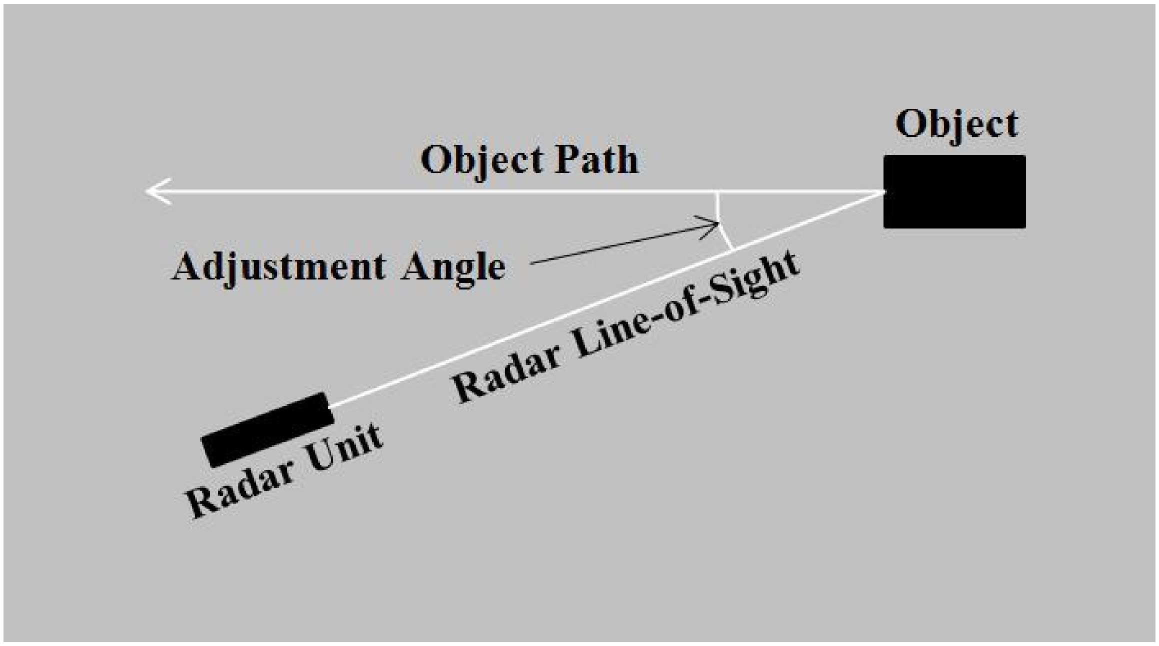


FIGURE 10 Radar Line-of-Sight Compared with Object Path

The radar was powered by a power strip plugged into the top of the van. The radar unit was connected to the computer in the van via a serial port cable that was run down the side of the van and through a cable access port on the side of the van. To begin data collection, the radar unit was put into 'transmit' mode by pressing the 'transmit' button on the unit. The recording of train data from the radar had to be initiated by the computer in the van. Once a train approached the location on the tracks where the radar unit had been aimed, the recording of data was started with the computer. The maximum allowable time for recording data with the radar was five minutes; this was a limitation of the software. Once the train had passed the location on the tracks where the radar was aimed or the five minute capacity was reached, which ever came first, the radar unit had to be reset. To reset the radar unit, it had to be taken out of 'transmit' mode by physically pressing the 'transmit' button on the radar unit. Once the unit was no longer in transmit mode the data was compiled on the computer. The radar unit had to be put back into 'transmit' mode before data could be collected for another train. The radar unit recorded a speed reading approximately 33 times every second and recorded the values into a text format. The text file also contained a time stamp; however this was the time at which the file was saved, not the time that the file began.

In addition to the estimated angle between the tracks and the radar's line-of-sight, the orthogonal distance between the radar and the tracks was also recorded in the field. This was a required measurement in determining the time-stamps for the radar files.

3.4 DATA COLLECTION

Data were collected at four different sites. These sites included the same set-up process previously described. Some locations allowed for more extensive data to be collected. The following sections detail the data collected at each site.

3.4.1 WATERLOO

Data collection at this site was performed on May 9, 2005 during the day from 1:00 – 2:30 PM. Data for a total of three trains were collected during the data collection time interval. Video data collection at this site consisted only of the view of the HRGC. Data was also collected with the radar unit during the above mentioned times. The angle between the tracks and the radar's line-of-site was approximated to be 30 degrees. Field measurements were recorded for video and radar calibration during the data extraction process.

3.4.2 LINCOLN

Data collection at the Lincoln site was performed on May 14, 2005 during the day from 1:45 – 4:15 PM. Data for four trains were collected during the data collection time interval. Video data collection at this site consisted of a view of the HRGC and the view perpendicular to the tracks. Data from the radar unit was also collected during the times mentioned. The angle between the tracks and the radar's line-of-sight was approximately 30 degrees. Also, field measurements were recorded for video and radar calibration during the data extraction process.

3.4.3 OVERTON

Data collection at the location near Overton was performed on May 24, 2005 from 5:30 – 8:15 PM. During this time, data for 12 trains were collected. Video data collection at this location consisted of a view perpendicular to the tracks and a skewed view of the tracks to the east. Radar data was collected during the mentioned time interval, and the angle between the tracks and the radar's line-of-sight was approximately 25 degrees. Field measurements were also recorded at the site to be used during the data extraction process for video and radar calibration. Two instances involving multiple trains on multiple tracks at the same location and time occurred during the data collection at this site.

3.4.4 KEARNEY

Data collection at the Kearney site was performed on May 25, 2005 from 11:45 AM – 10:30 PM. During this time, data were collected for 59 trains. Video data collection at the Kearney site consisted of the view including the HRGC and a perpendicular view to the tracks. Radar data was also collected at the site, and the angle between the tracks and the radar's line-of-sight was approximately 25 degrees. Field measurements were recorded to be used for video and radar calibration during the data extraction process. During the data collection time interval at the Kearney site, seven instances occurred where multiple trains were on multiple tracks at the same location and at the same time. Also, data collection of the last seven trains occurred at night providing low visibility for the camera views.

3.5 FIELD DATA COLLECTION CONCLUSIONS

Data collection in the field was a rigorous process that required careful set-up at each site to obtain all the information and data needed to later extract the data and perform analyses on it. Keeping a detailed record of all of the data collected was also important in being able to accurately extract and analyze the train data. The data collected from the field can be found in Appendix A.

Once the field data collection process was complete, the field data was extracted in the NTC ITS lab in the Peter Kiewit Institute. Extraction of data included manual data collection of train speeds, radar data adjustment, and Autoscope video data collection. The next chapter discusses the processing of data from the field data to be used for data analyses.

CHAPTER 4. LAB DATA COLLECTION

Before the data collected in the field can be used to analyze how well video detection works for measuring train speeds, additional data needs to be extracted from the video collected in the field. In this stage of the research the field data are used to compile manual train speed measurements, adjust data collected by radar, and collect calibrated Autoscope video detection data of train speeds. The majority of in-lab data collection was performed for trains at the Kearney, NE site. This was due to the large amount of trains passing through the location and recorded with video and radar at Kearney compared to the other three sites.

4.1 MANUAL SPEED MEASUREMENTS

Manual speed measurements were collected to adjust the data obtained from the radar in the field. By determining an adjustment factor for the radar data at a given site using a small sample of trains, that adjustment factor could then be applied to the radar data obtained for the remaining trains at that site. This allowed for an accurate prediction of train speeds without having to manually calculate speeds for every train. The adjusted radar data would then be used as a comparison to the data collected through Autoscope video detection. The following sections provide the methodology for obtaining manually measured train speeds and the results from this process.

4.1.1 METHODOLOGY FOR DETERMINING MANUAL ESTIMATE OF TRAIN SPEED

Manual data collection was performed using recorded videos of trains, the Car and Locomotive Cyclopedia (Simmons-Boardman 1997) and a stopwatch. The goal of this procedure was to collect a series of train speeds during different portions of a train event to create a speed profile of the train.

Video tapes of recorded train events were played back, and the time for five railcars to pass a specific point on the screen was recorded with the stopwatch. Note that the choice of five railcars could have been some other value, such as ten; however, five railcars seemed to be adequate based on the typical number of railcars in a train for the purpose of determining train speed. The time at the beginning of the first locomotive was recorded (always set at time 0), the time of the first railcar beyond the locomotives was recorded and then the time of the beginning of every fifth railcar thereafter was recorded. This was performed three times for a given train and the times were averaged to provide more accurate times.

The length of each five-railcar segment was then determined. Railcar lengths (between couplers) were obtained from the Car and Locomotive Cyclopedia (Simmons-Boardman 1997). The Car and Locomotive Cyclopedia breaks up the different types of railcars into groups, such as open top hoppers, gondolas, and articulated well cars. For each of these groups, the Cyclopedia gives geometric measurements for different railcars. To obtain the speed for each segment of railcars being measured, the railcars in the segment were identified using the Cyclopedia. Because of the variety of railcars provided in the Cyclopedia it is possible that a railcar selected from the Cyclopedia to match a railcar from the video was selected incorrectly. For this reason, sensitivity analyses for trains were performed to determine the differences in speeds by using the shortest possible and longest possible railcar lengths for similar railcars to each railcar in a train. An example of this sensitivity analysis is provided in Table 2. Each railcar segment consists of five railcars whose lengths are defined in the table. The "shortest" columns use the shortest probable lengths for the railcars; the "most likely" columns use lengths for the railcars that appeared to be the closest match to those being viewed; and the "longest" columns use the longest probable lengths for the railcars. This example shows approximately an 8% difference in average speeds from the "most likely" average speed. Although the sensitivity analysis shows that actual train speeds may occur within a range of values, all manual data collection was based on the assumption that results using the "most likely" railcar lengths were accurate.

TABLE 2 Example Table for Sensitivity Analysis of Manually Calculated Speeds

Segment	Average Measured Travel Time (sec)	Lengths of Railcar Segments (ft)			Calculated Estimate of Speed (mph)		
		Shortest	Most Likely	Longest	Shortest	Most Likely	Longest
1	3.9	243.5	265.4	285.2	42.9	46.8	50.3
2	3.9	243.5	265.4	285.2	42.9	46.8	50.3
3	3.9	243.5	265.4	285.2	42.6	46.4	49.9
4	3.9	243.5	265.4	285.2	42.6	46.4	49.9
5	3.9	243.5	265.4	285.2	42.6	46.4	49.9
6	3.9	243.5	265.4	285.2	42.6	46.4	49.9
7	3.9	243.5	265.4	285.2	42.2	46.0	49.4
8	4.0	243.5	265.4	285.2	41.9	45.6	49.0
9	4.0	243.5	265.4	285.2	41.9	45.6	49.0
10	4.0	243.5	265.4	285.2	41.9	45.6	49.0
11	4.0	243.5	265.4	285.2	41.9	45.6	49.0
12	4.0	243.5	265.4	285.2	41.9	45.6	49.0
13	4.0	243.5	265.4	285.2	41.9	45.6	49.0
14	4.0	243.5	265.4	285.2	41.5	45.2	48.6
15	4.0	243.5	265.4	285.2	41.5	45.2	48.6
16	4.0	243.5	265.4	285.2	41.5	45.2	48.6
17	4.0	243.5	265.4	285.2	41.5	45.2	48.6
18	4.0	243.5	265.4	285.2	41.2	44.9	48.2
19	4.1	243.5	265.4	285.2	40.8	44.5	47.8
20	4.0	243.5	265.4	285.2	41.2	44.9	48.2
21	4.1	243.5	265.4	285.2	40.8	44.5	47.8
22	4.1	243.5	265.4	285.2	40.5	44.1	47.4
23	4.1	243.5	265.4	285.2	40.5	44.1	47.4
24	4.1	243.5	265.4	285.2	40.5	44.1	47.4
25	4.1	243.5	265.4	285.2	40.5	44.1	47.4
Average =					41.7	45.4	48.8
Absolute Difference =					-3.7	0.0	3.4
Percent Difference =					**-8.2%**	0.0%	**7.5%**

Note: Shortest = 48’ –8 ½” / Car;
Most Likely = 53’ – 1” / Car;
Longest = 57’ – ½” / Car

The speed of the train at the point where railcar times were recorded was calculated using the recorded times and segment length. It was assumed that the calculated speed of each segment occurred at the midpoint of each railcar segment and that the calculated speed for a given railcar segment represented the speed of the entire train at that point in time. Table 3 presents an example for manual data collection and calculation of train speeds, and the following set of equations demonstrate the manual data collection process.

- The "Time From Beginning of Train to Beginning Car in Segment Measurement" as labeled in Table 3 is the measured time from when the front of the train crosses a specific point to when the front of the first car in a given five-railcar segment crosses the same specific point. For the first recorded five-railcar segment, this measurement is recorded with a stopwatch. "Time From Beginning of Train to Beginning Car in Segment Measurement" for railcar segments beyond the first segment are calculated based on the measured time between the beginning of railcar segments. "Time From Beginning of Train to Beginning Car in Segment Measurement" for each segment beyond the first segment is calculated by using Equation 1.

$$T_n = T_{n-1} + \bar{t}_{n-1} \tag{1}$$

T_n = "Time From Beginning of Train to Beginning Car in Segment Measurement" for a given five-railcar segment (segment n)

T_{n-1} = "Time From Beginning of Train to Beginning Car in Segment Measurement" for the railcar segment before segment n

$\bar{t}_{n-1}$ = "Average" of the "Measured Travel Times" for the railcar segment before segment n

Equation 2 shows the calculation for "Time From Beginning of Train to Beginning Car in Segment Measurement" of segment 2 listed in Table 3.

$$T_2 = T_1 + \bar{t}_1 = 2.6 + 4.5 = 7.1 \tag{2}$$

- The "Time from Beginning of Train to Average Time that Calculated Speed Occurred" as labeled in Table 3 is assumed to be the time that the calculated average speed for a given railcar segment occurred. "Time from Beginning of Train to Average Time that Calculated Speed Occurred" is calculated by using Equation 3.

$$\overline{T}_n = T_n + \frac{\bar{t}_n}{2} \tag{3}$$

$\overline{T}_n$ = "Time from Beginning of Train to Average Time that Calculated Speed Occurred" for a given five-railcar segment (segment n)

$\bar{t}_n$ = "Average" of the "Measured Travel Times" for a given five-railcar segment (segment n)

Equation 4 shows the calculation for "Time from Beginning of Train to Average Time that Calculated Speed Occurred" of segment 2 listed in Table 3.

$$\overline{T}_2 = T_2 + \frac{\bar{t}_2}{2} = 7.1 + \frac{4.5}{2} = 9.3 \tag{4}$$

- The “Length of Railcar Segment” is the summation of the distance from coupler to coupler of each railcar in the segment. For example, a standard coal car length from coupler to coupler is 53’ – 1”, therefore, the “Length of Railcar Segment” for a segment consisting of five coal cars is equal to 265 feet 5 inches or 265.4 feet.
- The “Calculated Estimate of Speed” is simply the calculated estimate of speed for a given railcar segment. “Calculated Estimate of Speed” is calculated by using Equation 5.

$$\hat{S}_n = \frac{L_n}{\bar{t}_n} \tag{5}$$

$\hat{S}_n$ = “Calculated Estimate of Speed” for a given five-railcar segment (segment n)

L_n = “Length of Railcar Segment” for a given five-railcar segment (segment n)

Equation 6 shows the calculation for “Calculated Estimate of Speed” of segment 2 listed in Table 3.

$$\hat{S}_2 = \frac{L_2}{\hat{t}_2} = \frac{265.4 \quad ft}{4.5 \quad \sec} = 58.98 \quad \frac{ft}{\sec} = 40.5 \quad mph \tag{6}$$

TABLE 3 Example Table for Manual Data Collection and Calculation of Train Speeds

Segment	Time from Beginning of Train to Beginning Car in Segment Measurement (sec)	No. of 1^{st} Car in Segment	No. of Last Car in Segment	Measured Travel Times (sec)				Time from Beginning of Train to Average Time that Calculated Speed Occurred (sec)	Length of Railcar Segment (ft)	Calculated Estimate of Speed* (mph)
				Trial 1	Trial 2	Trial 3	Average			
1	2.6	3	8	4.4	4.5	4.5	4.5	4.8	265.4	40.5
2	7.1	8	13	4.5	4.5	4.5	4.5	9.3	265.4	40.2
3	11.6	13	18	4.4	4.5	4.4	4.4	13.8	265.4	40.8
4	16.0	18	23	4.5	4.5	4.4	4.5	18.2	265.4	40.5
5	20.5	23	28	4.4	4.3	4.4	4.4	22.7	265.4	41.4
6	24.8	28	33	4.4	4.4	4.4	4.4	27.0	265.4	41.1
7	29.2	33	38	4.4	4.4	4.3	4.4	31.4	265.4	41.4
8	33.6	38	43	4.4	4.4	4.4	4.4	35.8	265.4	41.1
9	38.0	43	48	4.4	4.4	4.4	4.4	40.2	265.4	41.1
10	42.4	48	53	4.4	4.4	4.4	4.4	44.6	265.4	41.1
11	46.8	53	58	4.4	4.4	4.4	4.4	49.0	265.4	41.1
12	51.2	58	63	4.4	4.3	4.4	4.4	53.4	265.4	41.4
13	55.6	63	68	4.3	4.3	4.3	4.3	57.7	265.4	42.1
14	59.9	68	73	4.3	4.2	4.3	4.3	62.0	265.4	42.4
15	64.1	73	78	4.3	4.4	4.3	4.3	66.3	265.4	41.8
16	68.5	78	83	4.3	4.3	4.3	4.3	70.6	265.4	42.1
17	72.8	83	88	4.2	4.3	4.3	4.3	74.9	265.4	42.4
18	77.0	88	93	4.3	4.3	4.3	4.3	79.2	265.4	42.1
19	81.3	93	98	4.3	4.3	4.3	4.3	83.5	265.4	42.1
20	85.6	98	103	4.2	4.3	4.3	4.3	87.8	265.4	42.4
21	89.9	103	108	4.2	4.2	4.2	4.2	92.0	265.4	43.1
22	94.1	108	113	4.2	4.2	4.3	4.2	96.2	265.4	42.7
23	98.3	113	118	4.2	4.2	4.2	4.2	100.4	265.4	43.1
24	102.5	118	123	4.2	4.2	4.2	4.2	104.6	265.4	43.1
25	106.7	123	128	4.1	4.2	4.2	4.2	108.8	265.4	43.4
26	110.9	128	133	4.2	4.2	4.2	4.2	113.0	265.4	43.1

* Speed was calculated based on the Average Measured Travel Times and the lengths of the railcar segments (5 car segments). All railcars for this train were coal cars with standard length from coupler to coupler of “Most Likely” 53’ 1” (Simmons-Boardman 1997)

This procedure was completed for four different trains, containing different types of railcars, from the Kearney site. By using different types of trains, an average adjustment factor determined for the radar data from the manual measurements could be assumed to encompass the various types of trains for which data had been collected. For instance, if manual measurements had only been collected for a single type of train, the adjustment factor developed for the radar data may be biased for that particular type of train. This would be the case if the radar device returned slightly different results for different surfaces. An average adjustment was possible since the radar unit was in the same location and position during data collection at the site. The four trains included two trains consisting solely of coal railcars, one train consisting solely of automotive transport railcars, and one train that consisted of articulated and unarticulated well cars that varied in length and cargo. Using railcars and well cars that varied in length and surface allowed for a wide variety of railcars that minimized the dependence of the adjustment of the radar data based on the type of railcar. Trains were numbered based on the site where their data was obtained (i.e. WA for Waterloo, LD for Lincoln, OV for Overton and KE for Kearney) and the number in which data was collected. The four trains from the Kearney site used to calibrate the radar were KE7, KE23, KE30 and KE36.

4.1.2 RESULTS OF MANUAL ESTIMATE OF TRAIN SPEED

Upon completion of collecting train speeds manually, the data is tabulated as shown in Table 3. This data can then be plotted to view the speed profile for the train. Figure 11 shows an example speed profile for the manually collected data presented in Table 3.

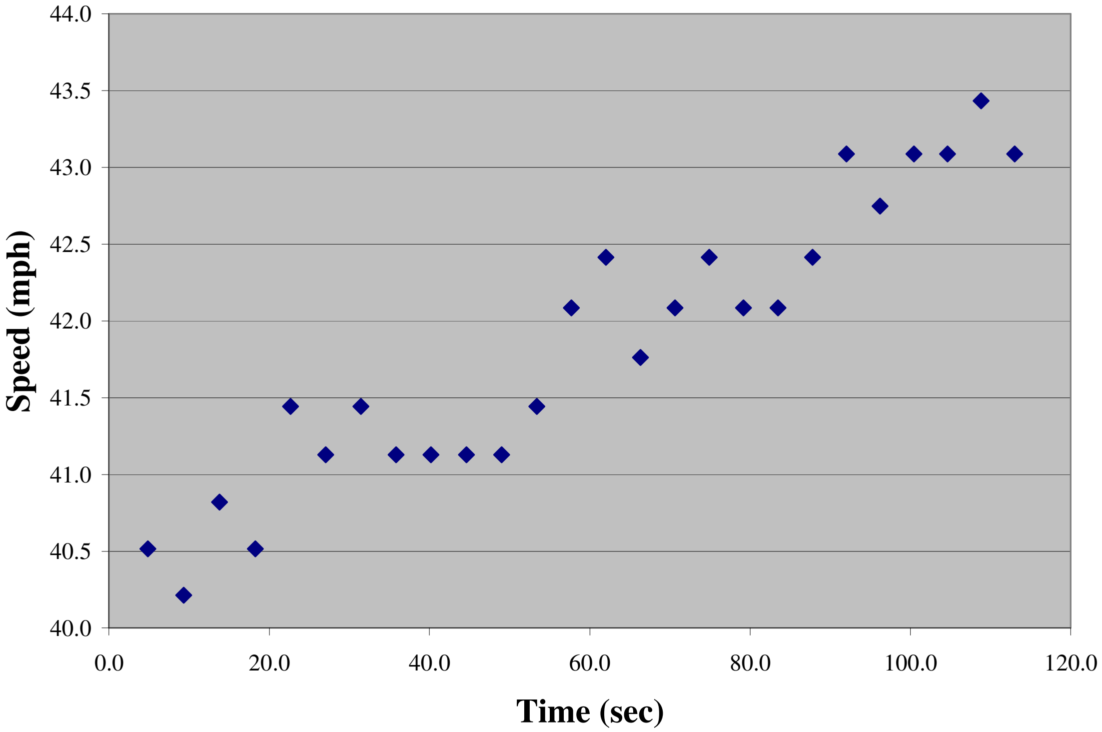


FIGURE 11 Example Speed Profile for Manually Collected Data

Once the data obtained through the manual data collection process is tabulated and organized it can be used to adjust the radar data during the calibration process as previously described. The calibration process for the Doppler radar data is described next.

4.2 CALIBRATION OF DOPPLER RADAR

The next step is to calibrate the raw radar data collected in the field. The following sections present the methodology for calibrating the radar data.

4.2.1 METHODOLOGY FOR CALIBRATING RADAR DATA

Calibrated radar data was used as the base comparison for all Autoscope Speed Detector data. For this comparison to be made accurately, several steps were performed with radar data to ensure the most accurate data possible. These steps are contained within radar data time stamp determination and radar calibration presented in the following sections.

4.2.1.1 Radar Data Time Stamp Determination

After field data collection was completed, it was determined that the time stamp recorded in the radar file was actually the time that the file was saved, and not at the start of the data collection by the radar gun. The time stamps for the radar were determined by the following four factors: the estimated time in the data set that the radar begins recording actual train speeds, the distance downstream/upstream from the radar location to where the train is being detected, the initial speed of the train, and the time stamp of the video detection used for the camera view perpendicular to the tracks, which is also the approximate perpendicular location of the radar unit from the tracks.

By viewing a plot of the raw speed data obtained by the radar, the approximate beginning time of actual train detection by the radar can be established. Many plots have a portion of speeds that increase uniformly for a period of time before the train is at the location of actual detection. For example, the estimated begin time of actual detection for the train data shown in Figure 12 is 8.8 seconds into the data file. After the beginning time of the train detection is established, an estimate of the train’s initial speed can be calculated by using Equation 7.

$$S_o = \frac{\bar{s}}{\cos(\theta)} \tag{7}$$

S_o = Estimate of train's initial speed

$\bar{s}$ = Average speed of train during the first second of train detection

θ = Approximate angle between the tracks and the radar line-of-sight

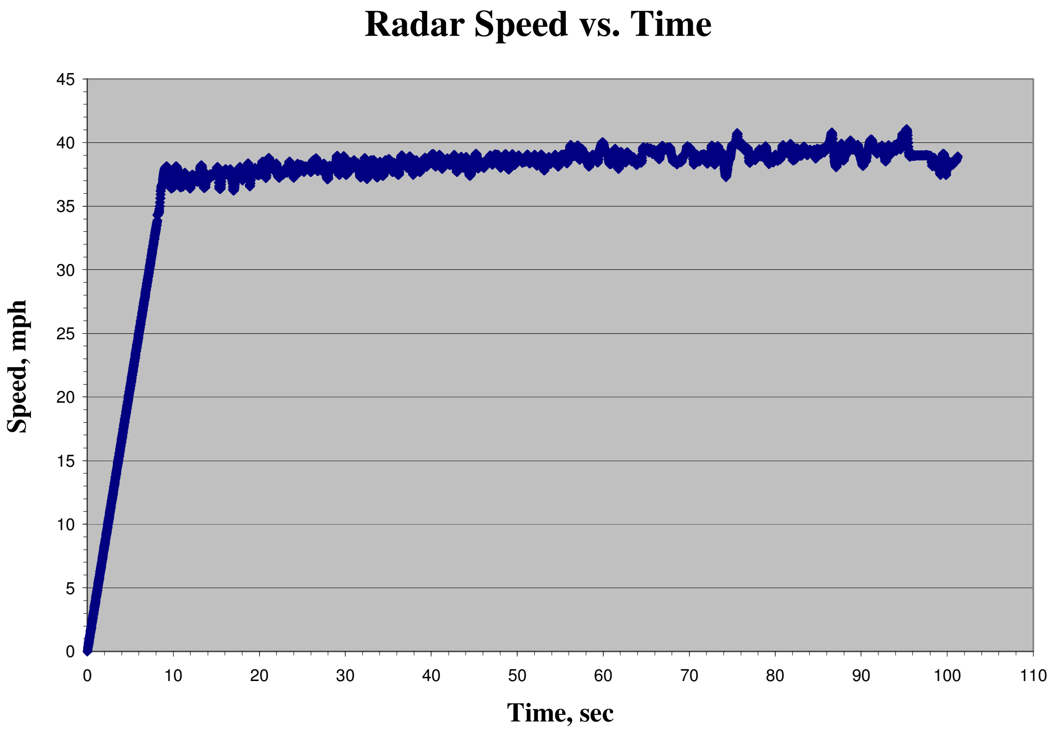


FIGURE 12 Example of Speed Profile from Radar Raw Data

Using the train's initial speed along with the distance downstream/upstream from the radar location where the train was being detected, the time that it takes the train to travel between the location of the radar unit perpendicular to the tracks and the location where train detection is occurring can be calculated. Figure 13 and Equation 8 describe how to calculate the time differential described.

$$T_R = \frac{X_R}{S_o} \tag{8}$$

T_R = The time differential between points in time when the train's position is at the "Perpendicular Train Position" and "Location of Train Detection" as shown in Figure 13 (this value is positive for trains traveling away from the radar detector and is negative for trains traveling toward the radar detector)

X_R = The distance between the "Perpendicular Train Position" and "Location of Train Detection" as shown in Figure 13

Adding the T_R values to the corresponding time stamp of the beginning of the train for the camera with the view perpendicular to the tracks yields the approximate radar data time stamp for the beginning of the train. Once this time is established, the speeds from the radar can be compared to the speeds calculated manually. The following section describes the methods used to calibrate the radar data by using the manually calculated estimate of train speeds.

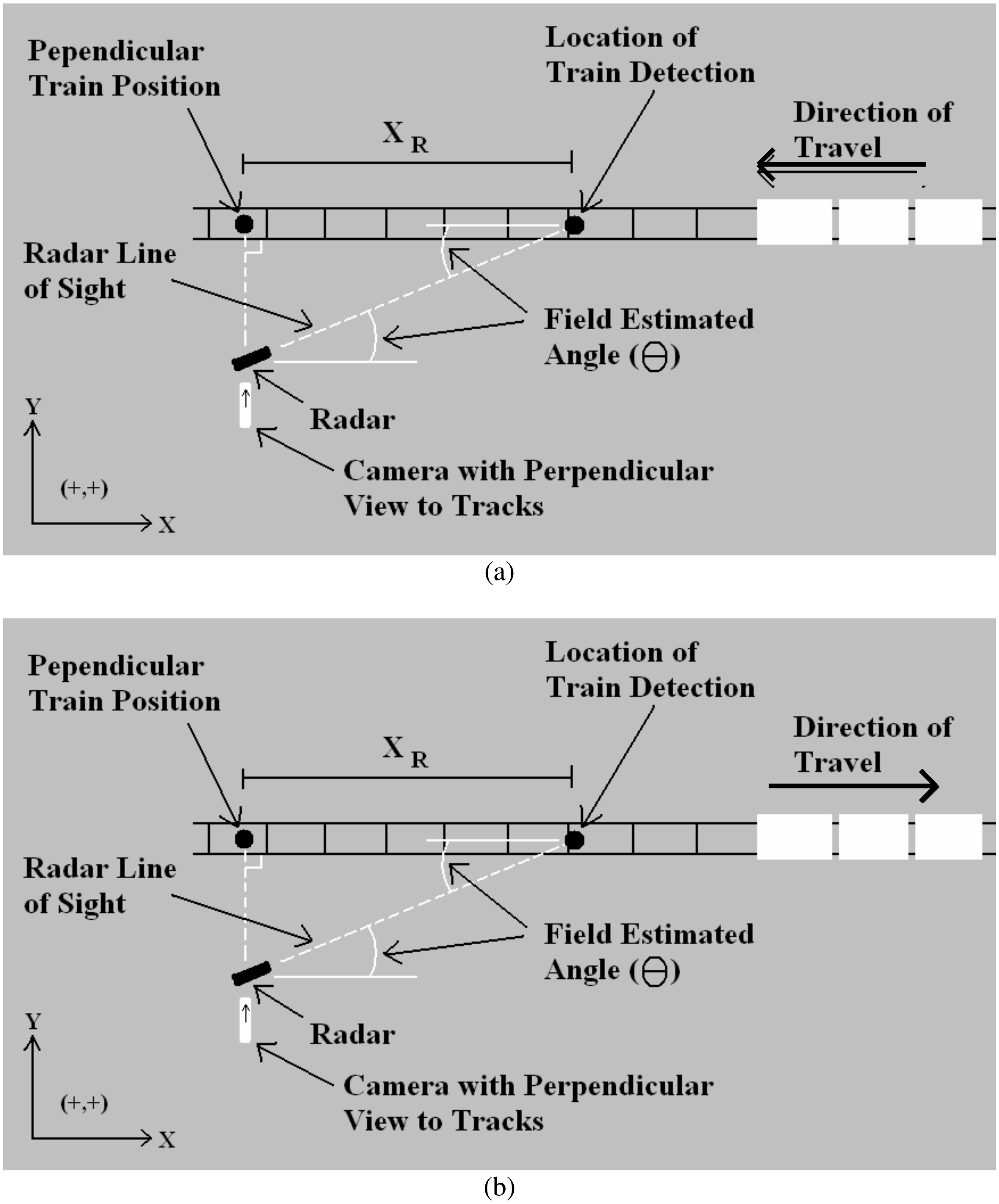


FIGURE 13 Plan View of Radar Set-up: (a) Trains Travelling Towards Radar Unit, and (b) Trains Travelling Away From Radar Unit

4.2.1.2 Calibration of Radar Speed Data

The first step in calibrating the radar data is to determine the average raw radar speed for each of the five-railcar segments that were defined in the manually collected information. This was a challenge based on the limitations of the radar unit data collection software to provide an actual time stamp that the data was being collected, as described in Section 4.2.1.1. A "best estimate" was used to determine the start of the train speed data detection by the radar unit and the time stamp was estimated as described in Section 4.2.1.1. Results (shown later) concluded that the changes in speed throughout a train event based on the "best estimate" of the data collection start time provided reasonable comparisons to the changes in speed of the manually collected data. It was concluded that there is a need to resolve the time stamp issue related to collecting radar data. This would likely involve using a different radar unit, different data collection software or a different collection method of the data.

It was assumed that a given five-railcar segment had the same speed at the perpendicular view location and at the upstream/downstream location that the radar data was being collected. This would mean that the train had zero acceleration between the perpendicular camera view and the point on the tracks in the radar's line-of-sight. This was necessary to compare the radar collected speed for a given set of railcars to the manually calculated estimate of speed for the same set of railcars. The calibration of the radar speed data is performed by using an adjustment angle (the angle between the tracks and the radar line-of-sight). The method for determining the radar adjustment angle using the manually calculated estimate of speeds is discussed below.

Radar Adjustment Angle

The method for adjusting the radar speeds involves matching the average of the adjusted radar speeds for all railcar segments equal to the average of the manually calculated estimates of speed for all railcar segments. Table 4 shows the adjusted radar speeds for each railcar segment by using the determined adjustment angle. The adjusted radar speed for each railcar segment is calculated by using Equation 9.

$$S'_{R_n} = \frac{S_{Rn}}{\cos(\theta)} \tag{9}$$

S'_{R_n} = The adjusted average radar speed for a given railcar segment (segment n)

S_{R_n} = The raw average radar speed for a given railcar segment (segment n)

θ = The adjustment angle determined by Method 1

Microsoft Excel was utilized to calculate S'_{R_n} for each railcar segment in Table 4. First, Equation 9 is input into the "Adjusted Radar Speed" column for each railcar segment. The cell containing the adjustment angle is initially left blank. Next, the "Goal Seek" tool is used to set the average of the "Adjusted Radar Speed" column equal to the average of the "Manually Calculated Estimate of Speed" column by changing the adjustment angle. The resulting adjustment angle is the radar adjustment angle. The calculation for the "Adjusted Radar Speed" for segment 2 using the determined radar adjustment angle is shown in Equation 10.

$$S'_{R_2} = \frac{S_{R2}}{\cos(\theta)} = \frac{36.50}{\cos(25.71^\circ)} = 40.51 \tag{10}$$

TABLE 4 Radar Adjustment Angle

Segment	Manually Calculated Estimate of Speed (mph)	Raw Radar Speed (mph)	Adjusted Radar Speed (mph)
1	40.51	36.20	40.18
2	40.21	36.50	40.51
3	40.82	36.60	40.62
4	40.51	36.80	40.84
5	41.44	36.60	40.62
6	41.13	36.80	40.84
7	41.44	37.10	41.18
8	41.13	37.00	41.07
9	41.13	37.50	41.62
10	41.13	37.50	41.62
11	41.13	37.50	41.62
12	41.44	37.50	41.62
13	42.09	37.80	41.95
14	42.41	37.90	42.06
15	41.76	38.10	42.29
16	42.09	37.90	42.06
17	42.41	38.20	42.40
18	42.09	38.40	42.62
19	42.09	38.30	42.51
20	42.41	38.30	42.51
21	43.09	38.40	42.62
22	42.75	38.50	42.73
23	43.09	38.50	42.73
24	43.09	38.50	42.73
25	43.43	38.90	43.17
26	43.09	38.90	43.17
Average =	41.84	37.70	41.84
Adjustment Angle = 25.71°			

Site Adjustment Angle Determination

To ensure optimum calibration, adjustment angles were determined for the four trains at Kearney that manually calculated data had been collected. These angles, shown in Table 5, and the average of the four angles were then applied to the raw radar data for each of the four trains, producing five sets of adjusted radar speeds for each of the four trains. Paired t-tests showed that the adjustment angle calculated for one of the trains (KE36) yielded the highest values for the t-statistic in the other three trains, see Table 5.

For this reason, the adjustment angles for only the remaining three trains (KE7, KE23, and KE30) were averaged together to obtain the adjustment angle for the radar at the Kearney location, 25.7 degrees.

TABLE 5 Paired t-test for Radar Adjustment Angles

Train	Optimum Radar Adjustment Angle	Manual vs. Radar(#)$_n$*	Critical t-value for α=0.05	Σd_i	Σd_i^2	Standard Deviation of the Differences, s_D	Absolute value of t-statistic
KE7	25.71	Radar(KE7)$_{KE7}$	2.060	-0.008	3.373	0.367	0.004
		Radar(KE7)$_{KE23}$	2.060	-0.663	3.391	0.367	0.354
		Radar(KE7)$_{KE30}$	2.060	0.432	3.379	0.367	0.231
		Radar(KE7)$_{KE36}$	2.060	-12.972	9.868	0.369	**(6.902)**
		Radar(KE7)$_{ave}$	2.060	-3.216	3.776	0.368	1.716
KE23	25.78	Radar(KE23)$_{KE7}$	2.262	0.158	1.680	0.432	0.116
		Radar(KE23)$_{KE23}$	2.262	0.000	1.676	0.432	0.000
		Radar(KE23)$_{KE30}$	2.262	0.264	1.686	0.432	0.193
		Radar(KE23)$_{KE36}$	2.262	-2.971	2.534	0.428	(2.194)
		Radar(KE23)$_{ave}$	2.262	-0.617	1.709	0.431	0.452
KE30	25.66	Radar(KE30)$_{KE7}$	2.064	-0.366	35.902	1.223	0.060
		Radar(KE30)$_{KE23}$	2.064	-0.917	35.993	1.224	0.150
		Radar(KE30)$_{KE30}$	2.064	0.004	35.856	1.222	0.001
		Radar(KE30)$_{KE36}$	2.064	-11.269	42.336	1.246	(1.809)
		Radar(KE30)$_{ave}$	2.064	-3.064	36.584	1.228	0.499
KE36	27.08	Radar(KE36)$_{KE7}$	2.080	13.058	9.352	0.276	**10.082**
		Radar(KE36)$_{KE23}$	2.080	12.399	8.588	0.276	**9.575**
		Radar(KE36)$_{KE30}$	2.080	13.501	9.887	0.276	**(10.422)**
		Radar(KE36)$_{KE36}$	2.080	0.008	1.586	0.275	0.007
		Radar(KE36)$_{ave}$	2.080	9.829	5.988	0.276	**7.598**

* μ(Manual) - μ(Radar$_n$) is interpreted as "Difference Between Average Manually Calculated Speed and Average Adjusted Radar Speed based on Optimum Adjustment Angle for Train n"

* μ(Manual) - μ(Radar$_{ave}$) is interpreted as "Difference Between Average Manually Calculated Speed and Average Adjusted Radar Speed (Adjustment based on the Average of the Radar Adjustment Angles, 26.06 degrees)"

(###) - Largest value of t-statistic for the corresponding train

Bold - t-statistic exceeds critical t-value for α=0.05

Once the adjustment angle for the radar was determined for the Kearney site, post-processing of the video data obtained with Autoscope could be performed. The first step to performing the post-processing of the video data was to calibrate the Autoscope system for the recorded video. The following sections discuss the calibration steps for the Autoscope system.

4.3 AUTOSCOPE

The next steps are to calibrate the Autoscope video detection system and collect train speed data with the Autoscope video detection system. Once complete, the data collected with the calibrated video detection system is compared to the calibrated radar data to determine the accuracy of the video detection system as a means of train detection. Calibrated radar data was used as a comparison to the data from the calibrated video detection system because of the availability of radar data for all trains at a given site and the unavailability of manually collected speeds without going through the time consuming process described in Section 4.1.1. Additionally, radar is widely accepted as a means to collect speeds, evident from the literature review provided in this thesis. Since the radar unit was calibrated to the manual measurements, comparing the data from the calibrated video detection system to the adjusted radar data should be approximate to manual measurements, had they been collected. As another means of checking the accuracy of the video detection system, the data collected by the calibrated video detection system could also have been compared to the manually collected speed information for trains which manually collected data had been collected. The following sections present the methodologies for calibrating the Autoscope system and collecting Autoscope data.

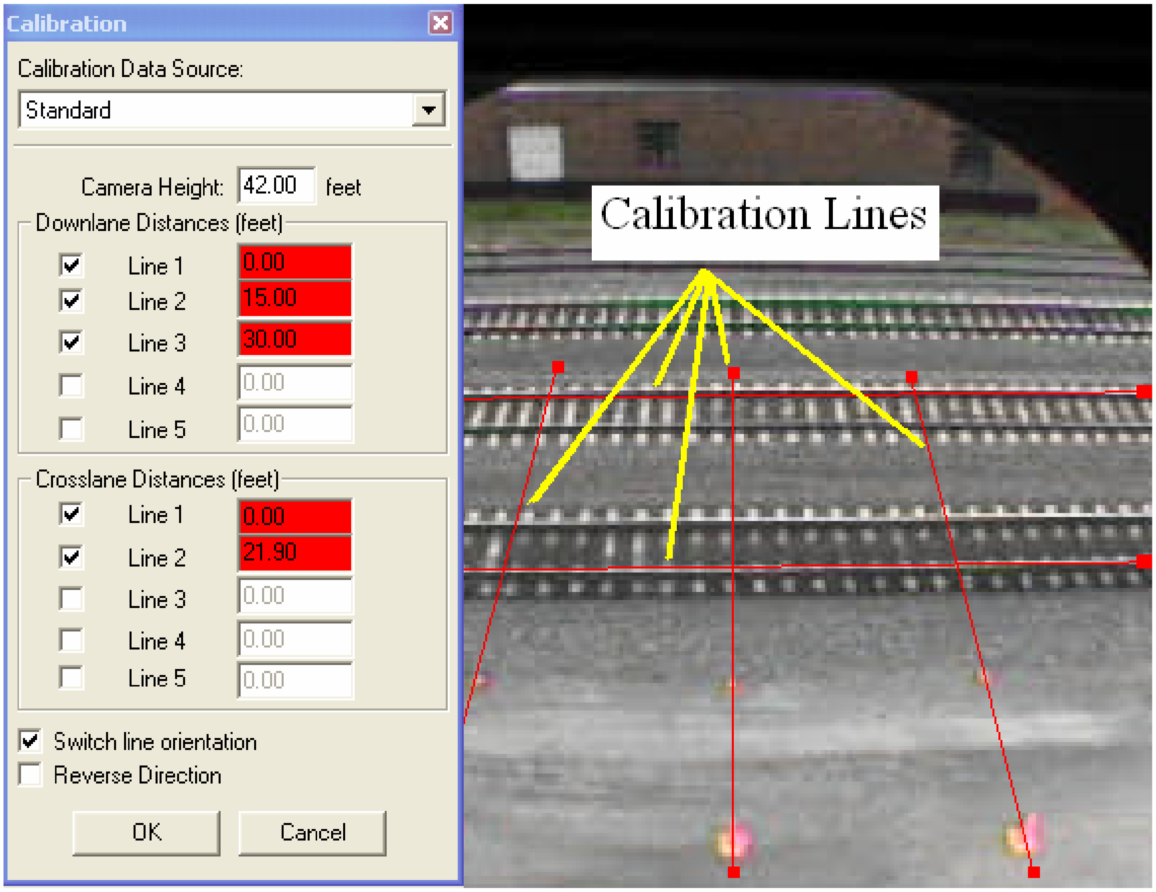
4.3.1 METHODOLOGY FOR CALIBRATING THE AUTOSCOPE SYSTEM AND AUTOSCOPE DATA COLLECTION

The process of calibrating the Autoscope video detection system involves calibrating the Autoscope system for the field of view, collecting data, and determining the Autoscope adjustment factor based on comparison to calibrated radar data. The following sections describe the steps to accurately calibrate the Autoscope video detection system.

4.3.1.1 Calibrating Autoscope for the Field of View

To collect accurate data during the video post-processing, the position of the cameras' views relative to the area in their field of view needs to be recorded. Parameters to accurately calibrate the cameras include the field measurements previously described in the Field Data Collection section. This information can then be used to calibrate the field of view for each video being post-processed.

The calibration is done by incorporating the real world distances into images obtained from the Autoscope cameras, see Figure 14. The calibration and placement of speed detectors in Autoscope is critical in recovering accurate data. Objects and markings that are clearly visible through Autoscope and produce parallel and perpendicular lines forming a grid of at least five total lines should be used in the calibration of the camera. If enough visible markings are not present to calibrate the camera properly, objects producing a high contrast with the picture relayed to Autoscope should be placed at fixed distances in the field of view in order to calibrate the camera to acceptable measures, see Figure 15. The input line distances are the distances from Line 1 to the line in question. The camera height is the height of the camera above the field of view.



Calibration Data Source:
Standard

Camera Height: 42.00 feet

Downlane Distances (feet)
☑ Line 1 0.00
☑ Line 2 15.00
☑ Line 3 30.00
☐ Line 4 0.00
☐ Line 5 0.00

Crosslane Distances (feet)
☑ Line 1 0.00
☑ Line 2 21.90
☐ Line 3 0.00
☐ Line 4 0.00
☐ Line 5 0.00

☑ Switch line orientation
☐ Reverse Direction

FIGURE 14 Typical Calibration of Autoscope Camera

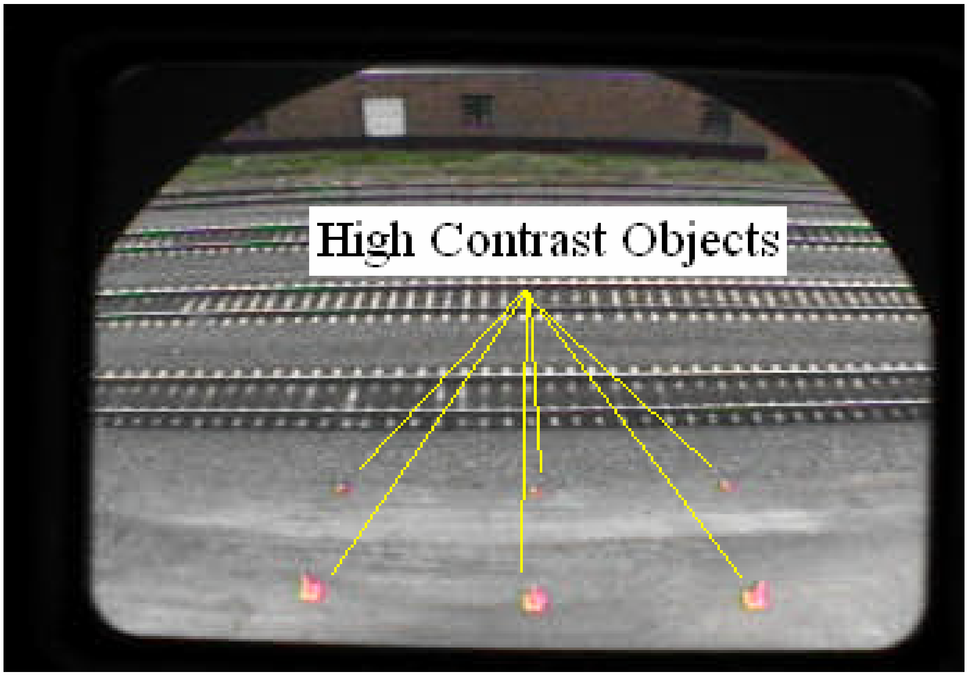


FIGURE 15 Image for Calibration with High Contrast Objects

4.3.1.2 Autoscope Data Collection

Once the dimensions have been put into Autoscope to calibrate its positions in space relative to the area in the field of view, data can be collected. Autoscope video data collection was performed by utilizing Autoscope's RackVision Machine Vision Processor (MVP) shown in Figure 16. The Autoscope RackVision acts almost the same as an Autoscope Solo Pro camera. The difference between the Autoscope Solo Pro camera and the Rack-Vision is that the Solo Pro camera integrates the MVP with the camera whereas the Autoscope Rack-Vision uncouples the camera and the MVP allowing for cameras other than Autoscope cameras to be used as long as they meet the specifications required by the MVP. Using the RackVision to collect data as opposed to the Solo Pro cameras in the field allow for processing of pre-recorded video as opposed to live video. This allows for an easier process of extensive data collection, such as changing the detector file in Autoscope several different times for a single train event. RackVision also allows for a several sets of data to be collected for a single train event if desired. Data are collected from the detectors defined by the user through the Autoscope software's data collector. These detectors and the manner in which data was collected are discussed in the following section.

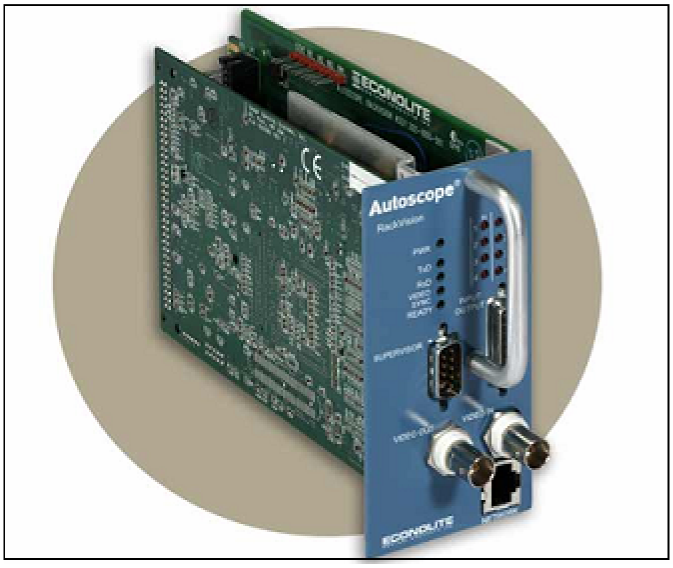


FIGURE 16 Autoscope RackVision Machine Vision Processor (Simmons-Boardman 1997)

4.3.1.3 Data Collection Detectors

The primary variable of interest during data collection was train speed. Autoscope allows for speed to be collected using two types of detectors: Speed Detectors and Detector Stations.

Speed Detectors are used to collect speed readings of trains as they pass through the detector. They contain perpendicular bars (Count Detectors) at the downstream end of the detector where the speeds are recorded. The speed of an object passing through the Speed Detector is measured as it passes from the upstream end of the detector to the downstream end of the detector, where the Count Detector is located. Speed Detectors are placed parallel to the direction of travel and in the path of the object being detected. Data recorded by Speed Detectors is based on “State On / State Off”, where speed values are recorded every time the detector is triggered on and off. They also allow for input of an adjustment factor that can increase or decrease recorded speeds by multiplying speeds by a specified factor. This factor was determined through comparisons of collected data from Autoscope with calibrated radar data, discussed further in the next section.

Placement of Speed Detectors is critical in collecting accurate and abundant data. It is good practice to have a portion of the Speed Detector over the background image even while an object is being detected (Dave Candey of Econolite, “Unpublished Data”). For this reason, it is best to have the placement of the Speed Detector toward the closest rail for a given track since the heights of railcars vary and a position including the background in the detection zone at all times anywhere else would be difficult to obtain.

During trial activations of the Speed Detector, using the recorded train video, it was determined that the Speed Detector performed best when the headway between railcars was most visible. Since the perpendicular camera view exposed the headway between railcars more apparently than the skewed view, it was determined that the video recorded from the perpendicular camera view would be used for all video data collection. Since the railcar headway was larger in the image for trains on the closest track to the camera and Speed Detectors appeared to activate with more ease by using a steeper angle looking down onto the trains, it was decided to only focus on trains travelling on the closest track to the camera. An example placement of a speed detector is shown in Figure 17. This placement was verified by observing several trains pass through and activate the detector. During trial activations of the Speed Detector, the view moved slightly, frequently, due to wind rocking the extended mast that contained the cameras mounted at the top. A more rigid mount would alleviate some of this movement described.

Detector Stations collect a variety of data by linking them to other detectors in the detector file. They collect a summary of data over a specified time interval with 1 second being the smallest retrieval interval. Placement of this detector does not affect any results from data collection. The junction between a Detector Station and Speed Detector is shown in Figure 17.

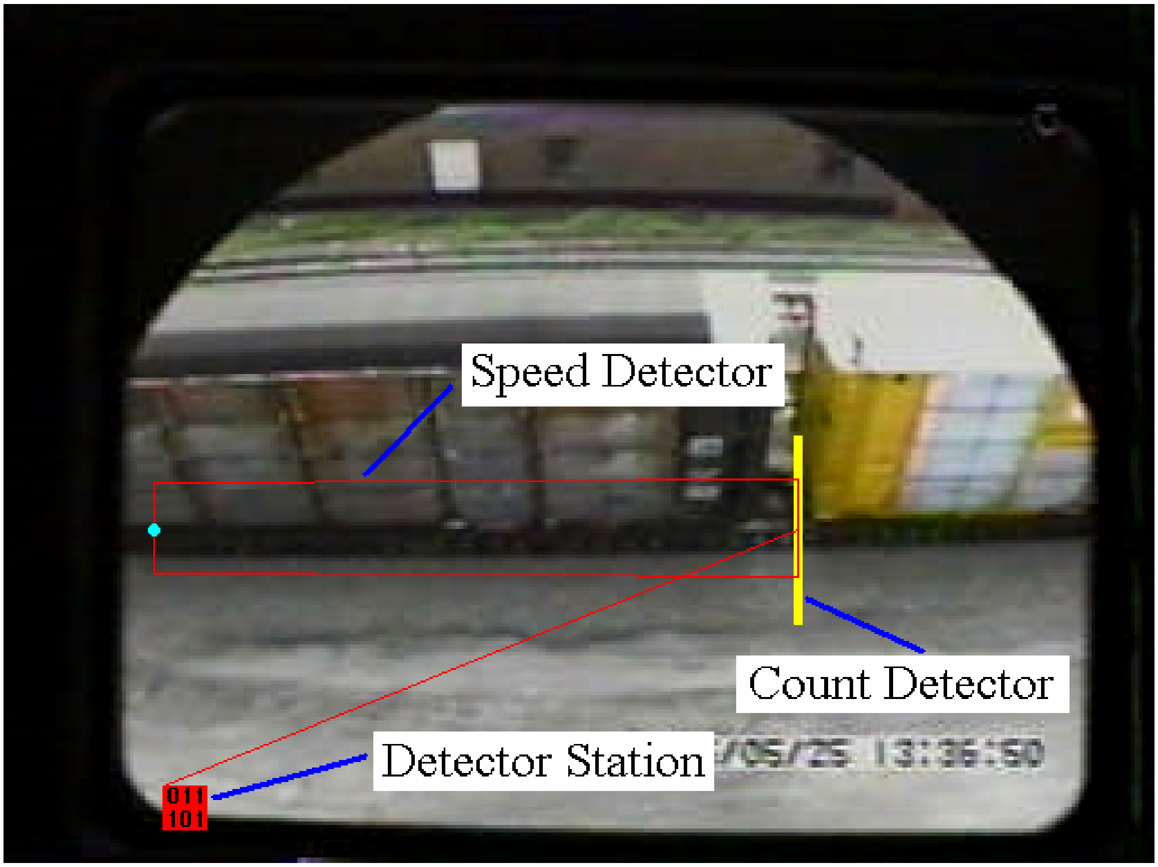


FIGURE 17 Autoscope Detectors and their Locations

Upon reviewing data obtained by both a Speed Detector and a Detector Station for a train, the Detector Station was found to give inaccurate results. The Detector Station, when linked to a Speed Detector and polling the average speed, reports the average speed recorded by the Speed Detector over the specified retrieval interval for a past portion of time. This results in the reported speeds corresponding to a previous point in time, thus being inaccurate. The Speed Detector, however, reported speeds at the times that the detector was triggered on and off. This conclusion resulted in all further data to be collected from the Speed Detector.

To collect data from the Autoscope Speed Detector, Autoscope's Data Collector was utilized. Data was polled directly from the Autoscope Speed Detector and saved as a text file to be viewed later for data analyses.

4.3.1.4 Autoscope Data Collection Location

As mentioned before, data from the Kearney site was more abundant than at the other three sites. In addition, the perpendicular camera view from the Kearney site had the steepest angle looking down onto the train than at the other three sites, which yields the benefits described above. For these reasons, Autoscope data were collected for all but two of the trains on the closest track to the camera at the Kearney site using the perpendicular camera view. All trains on the closest track to the camera traveled westbound, with the exception of two trains traveling eastbound. Data for the two trains traveling eastbound were not collected due to a separate set of analyses required to determine the Autoscope adjustment factor for the Speed Detector.

4.3.1.5 Autoscope Adjustment Factor

As previously mentioned, the Autoscope Speed Detector allows for an input of an adjustment factor that adjusts the recorded speeds based on the input factor. To determine this adjustment factor, unadjusted speeds collected from Autoscope were compared with calibrated radar speeds. Speeds for the calibrated radar and Autoscope comparisons were averaged over every five seconds, an arbitrarily chosen value. Speeds from Autoscope were collected for all four trains that had been used for manual data collection from the Kearney site. The average of the Autoscope speeds for each train were set equal to the average of the calibrated radar speeds for each train by multiplying the average Autoscope speed by a determined factor. Table 6 shows this adjustment for one of the four trains.

TABLE 6 Adjustment Factor for Autoscope Speed Detector, Train KE7

Time into Train Event (sec)		Average Speed (mph) from Time X1 to X2	
X1	X2	Calibrated Radar	Autoscope
0	5	40.23	40.40
5	10	40.31	39.75
10	15	40.68	38.60
15	20	40.89	39.25
20	25	40.68	39.83
25	30	40.86	39.50
30	35	40.98	39.50
35	40	41.40	39.00
40	45	41.80	39.50
45	50	41.58	39.33
50	55	41.50	40.80
55	60	41.90	39.75
60	65	41.94	40.50
65	70	42.22	40.25
70	75	42.28	40.20
75	80	42.52	41.25
80	85	42.48	41.50
85	90	42.63	41.60
90	95	42.61	41.50
95	100	42.68	41.40
100	105	42.70	40.60
105	110	43.22	42.50
110	115	43.18	41.80
115	120	43.82	42.33
Average Speed =		41.88	40.44
Adjustment Factor =			**1.04**
Adjusted Average Speed =			41.88

Train KE23 occurred on the center track in Kearney, whereas the other three trains all occurred on the close track. This resulted in a separate Speed Detector being used to collect speeds for train KE23, which may yield a different adjustment factor for the Speed Detector than for that of the detector used to collect speeds for the other three trains. For this reason, the adjustment factors for only the other three trains (KE7, KE30, and KE36) were used in determining the overall adjustment factor for the Speed Detector used for video data collection of trains at the close track. The adjustment factor for the Speed Detector was calculated by averaging the adjustment factors for trains KE7, KE30, and KE36. Some discrepancy between the calculated adjustment factors for the three trains existed; however, no justifications could be made to exclude any of the values. When averaging the three adjustment factors, the overall adjustment factor was calculated to be 0.98. Data from trains KE7, KE30, and KE36 used to determine the overall adjustment angle can be viewed in Appendix B. This factor was input into the Speed Detector parameters, and data was collected for all of the trains at the Kearney site on the closest track to the camera, in the perpendicular view, and traveling westbound.

In order to collect data for the two trains traveling eastbound on the closest track to the camera, a separate Speed Detector would need to be used. This would create the need to calculate a separate adjustment factor for this Speed Detector from the one used in the Speed Detector for trains traveling westbound. Having only two trains traveling eastbound is not enough to calculate an adjustment factor for the Speed Detector and collect adjusted data without the data being biased.

Note to the reader, from here on, all mention of data collected from the Autoscope Speed Detector refers to data collected after the input of the adjustment factor unless otherwise specified.

After data had been collected with Autoscope for single train events during daytime conditions, it was desired to test the abilities of Autoscope to collect train data for an event involving multiple trains on multiple tracks and an event of a train at night. The following sections describe the results of these investigations.

4.3.1.6 Multiple trains on Multiple Tracks

A major advantage of using video detection is its ability to detect multiple trains on multiple tracks at the same location and at the same time. Figure 18 shows a detector file set-up for multiple trains occurring at the same location and time. Figure 19 shows the same detector file with the absence of trains. This figure shows how far apart the Speed Detectors need to be in order to detect trains while trains on the close track and middle track at the same time.

The site at Kearney was chosen for investigation of multiple trains on multiple tracks because it contains three sets of tracks, which increased the rate of multiple trains at the same location and time, and the camera was located closer to the tracks than at the other site containing three sets of tracks located at Overton, which minimized the space between Speed Detectors used for different tracks.

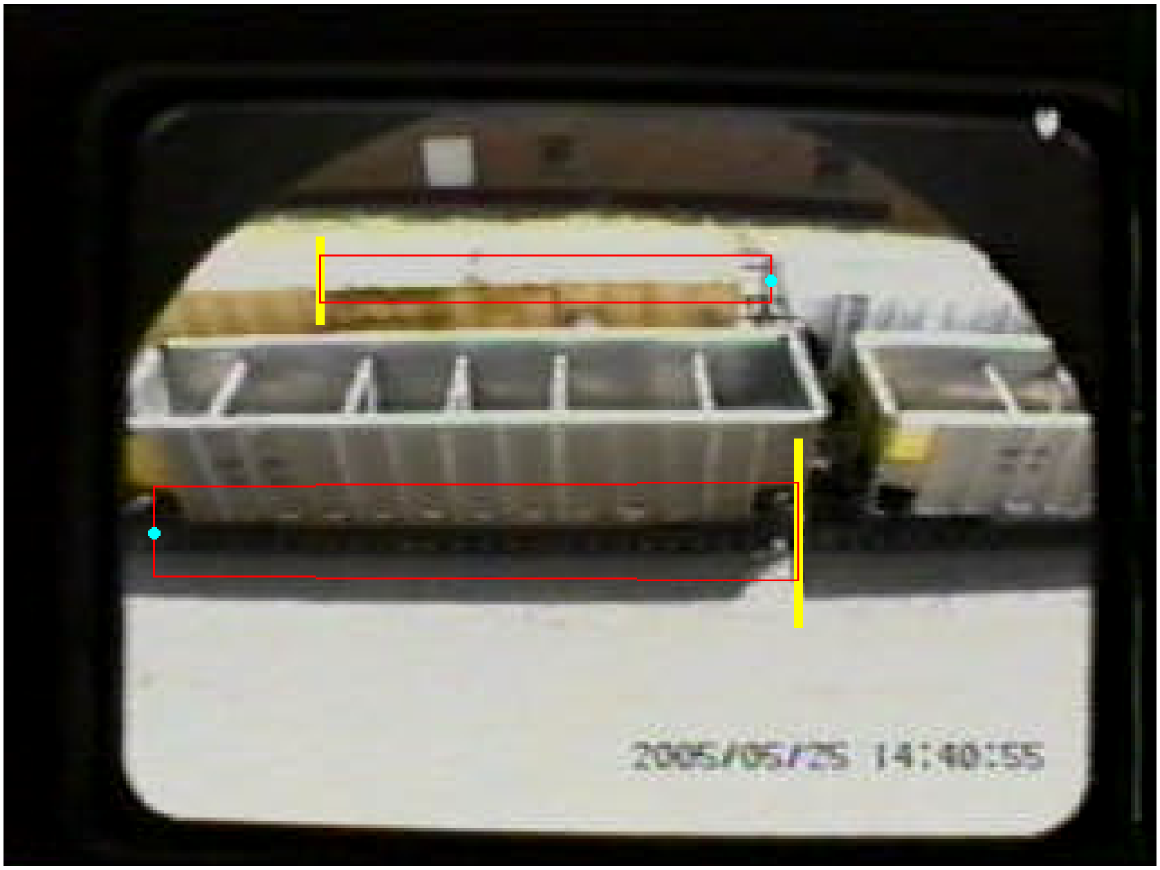


FIGURE 18 View from Camera with Speed Detectors at Multiple Track Location During Multiple Train Events at the Same Location and Time in Kearney, NE

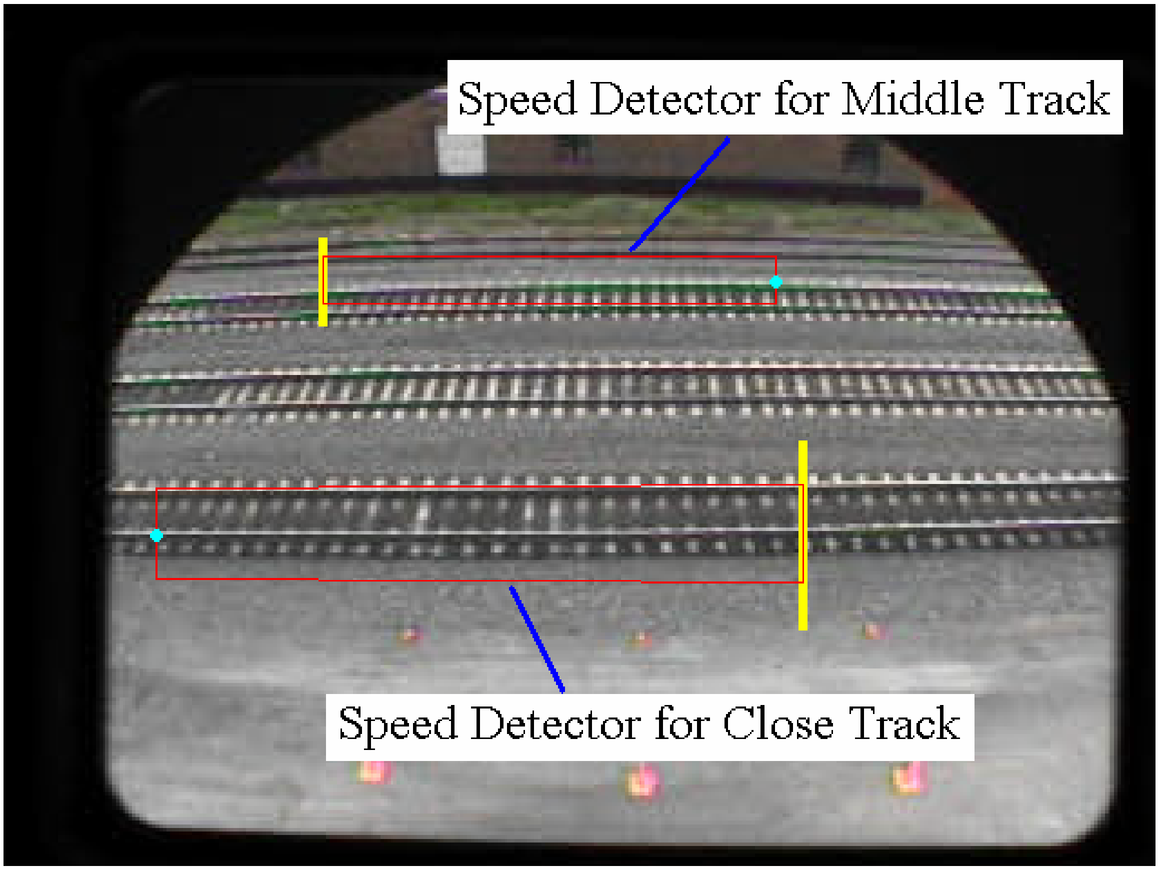


FIGURE 19 View from Camera with Speed Detectors at Multiple Track Location in Kearney, NE

From Figure 15 it can be seen how the effect of occlusion could affect the performance of Speed Detectors for multiple tracks. To conduct analyses for multiple trains on multiple tracks, research determined that either multiple cameras must be used or a steep downward angle toward the tracks must be available for the camera. Such a steep angle, as discussed here, would most likely require the location of video detection to be on the railroad right-of-way and was not available as part of this research. For this research, the investigation of detecting multiple trains on multiple tracks at the same location and time was unable to be fully analyzed due to the availability of cameras and their necessary placement as described before.

4.3.1.7 Video Detection at Night

To determine if Autoscope could be used for video detection at night, video of a train event at night in Kearney, NE was investigated. Figure 20 shows the Speed Detector from Autoscope being activated by the headlights on the front of the train engine when the Autoscope time stamp label is at 21:48:44. Note that the speed value of 22 mph shown in the figure is from some other object's motion previously recorded and that the speed of the train would be displayed when the Speed Detector transitions to an "Off" state.

FIGURE 20 Autoscope Video Detection of a Train Event at Night, Activation of Speed Detector by Headlights of Train

Figure 21 then shows the same train event just one second later, 21:48:45. The speed detector has obtained a value of 60 mph for the train from the initial reading by the speed detector but is no longer being activated due to the low level in contrast of the obtained images. Street lights were present at this location but did not provide enough light for Autoscope to detect the train after the first engine with the headlight had passed. This shows that the Autoscope Machine Vision Processor cannot detect a train at night with the setup used in this research.

FIGURE 21 Autoscope Video Detection of a Train Event at Night, Recorded Train Speed and Lack of Activation of Speed Detector

4.3.2 RESULTS

To conduct analyses for multiple trains on multiple tracks, research determined that either multiple cameras must be used or a steep downward angle toward the tracks must be available for the camera. Such a steep angle, as discussed here, would most likely require the location of video detection to be on the railroad right-of-way. If equipment cannot be used or installed this close to the tracks, multiple cameras, possibly on both sides of the tracks, would be required due to the shallower angle of the camera and the occlusion of trains on the far tracks by other trains on the closest set of tracks blocking them from the camera's view. This was determined through setting up a detector file in Autoscope for multiple tracks in Kearney, NE and playing recorded video of multiple train events on multiple tracks at the same time for this location through Autoscope Rack-Vision.

Investigation of video detection at night with Autoscope showed that the Autoscope Machine Vision Processor cannot detect a train at night with the setup used in this research. The setup used in this research would likely need either much brighter lights aimed at the tracks or lights placed on the railcars in order to collect data. Further investigation using a camera with "night vision" capabilities would also be another avenue of research for collecting train data at night with video detection.

Once calibration had been completed for the radar data and the Autoscope system and Autoscope data had been collected, analysis was performed to determine the accuracy of the data collected by the Autoscope system relative to the calibrated radar data. The next chapter presents the data analysis.

CHAPTER 5. DATA ANALYSES

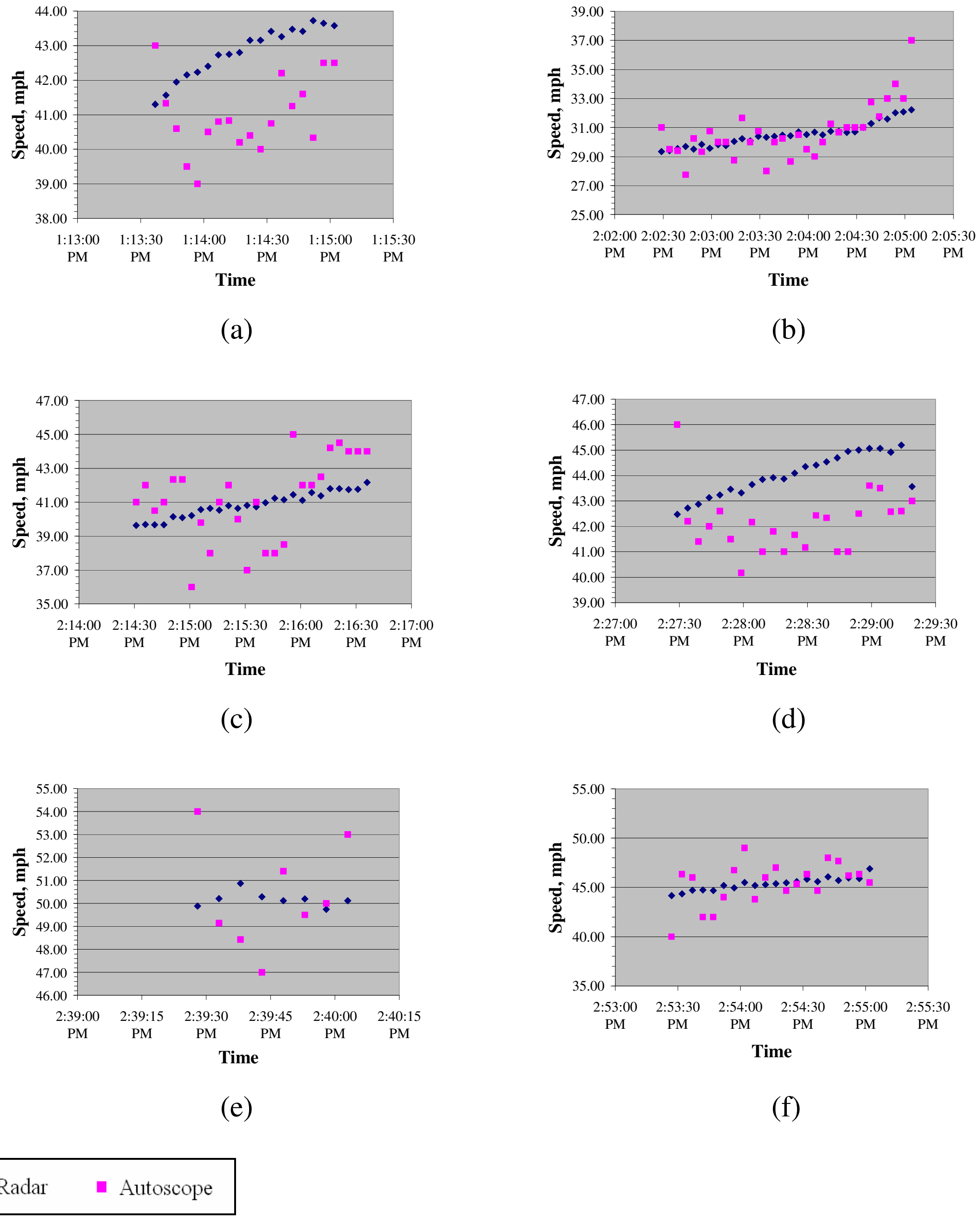
Data analyses were performed for video (Autoscope) data using calibrated radar data. The data analyses sections for video data present the processes and results for comparing data collected with an Autoscope speed detector to calibrated radar data. The following sections present the data analyses for data collected via the video detection system.

5.1 SPEED DATA ANALYSES

Speed data were the primary focus of the data analyses. Video data analyses included analyses for all of the trains at the Kearney site on the closest track to the camera, in the perpendicular view, and traveling westbound for reasons previously explained in section *4.3.1.3 Data Collection Detectors*. Trains KE7, KE30, and KE36 were omitted from the video data analyses due to their bias from determining the Autoscope speed detector adjustment factor. Also, trains KE6, KE18, and KE42 were omitted from data analyses because the radar time stamps were unable to be determined based on the available data. Data analyses of trains KE12, KE24, and KE44 were performed for only portions of the trains due to incomplete data sets from radar.

Once adjusted data were collected from the Autoscope speed detector, the data were compared with the calibrated radar data. Speeds for the calibrated radar and Autoscope pairs were averaged over every five seconds, an arbitrarily chosen value. Occasionally, during the five second period, the speed detector did not record any values. During these intervals, the value from the last interval to have recorded speeds was used to replace the void in the data set.

First, plots were developed for the calibrated radar speeds vs. speeds from the Autoscope speed detector for all the trains analyzed. These plots are shown in Figures 22 through 24. These figures show that Autoscope values of speed vary about the calibrated radar values. At times, the Autoscope values are close to the calibrated radar values, some times the Autoscope values are greater than the calibrated radar values, and at other times the Autoscope values are less than the calibrated radar values.



(a) (b)

(c) (d)

(e) (f)

FIGURE 22 Radar and Autoscope Speed Profiles Plots for Trains: (a) KE5, (b) KE8, (c) KE9, (d) KE11, (e) KE12, and (f) KE14

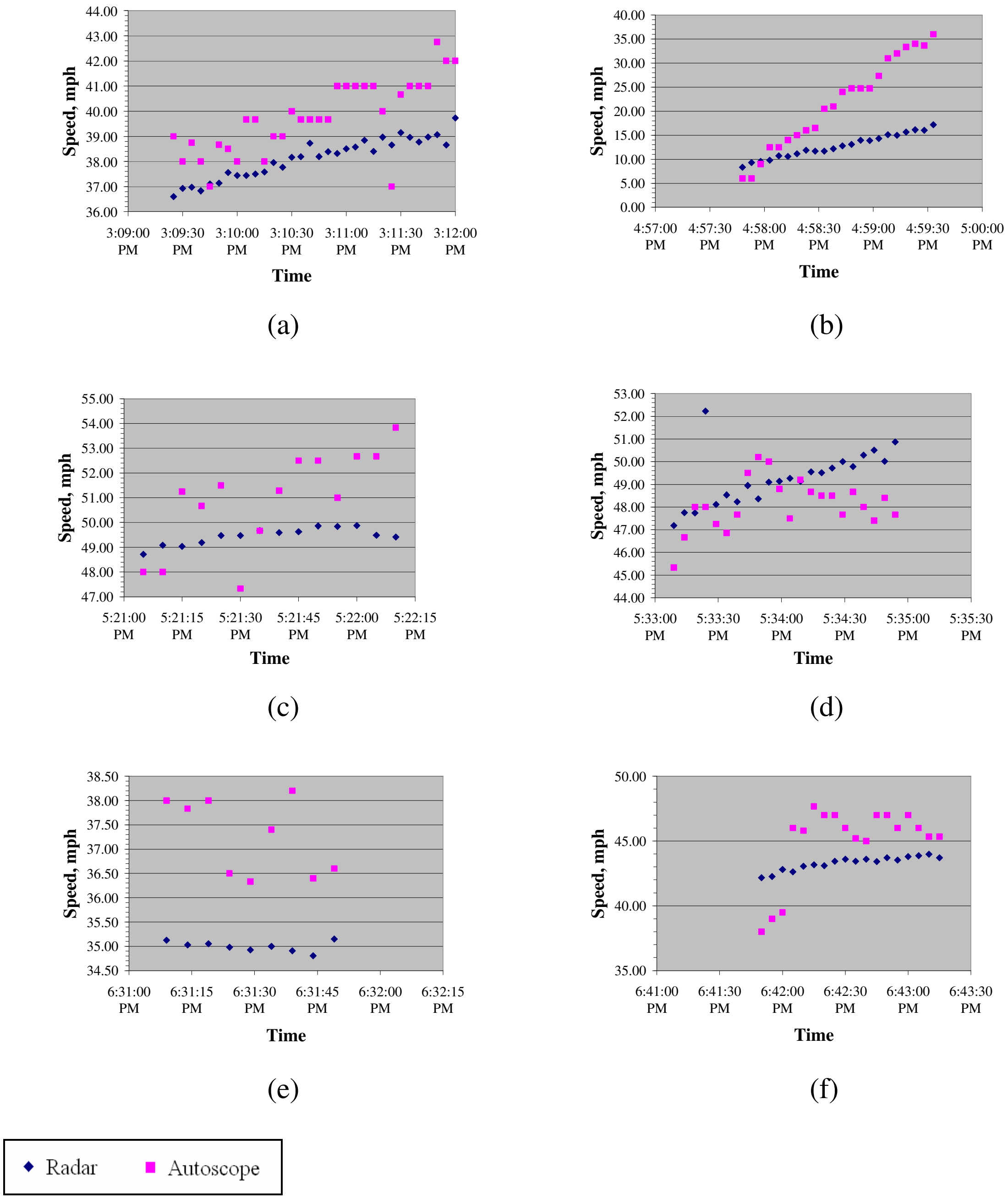
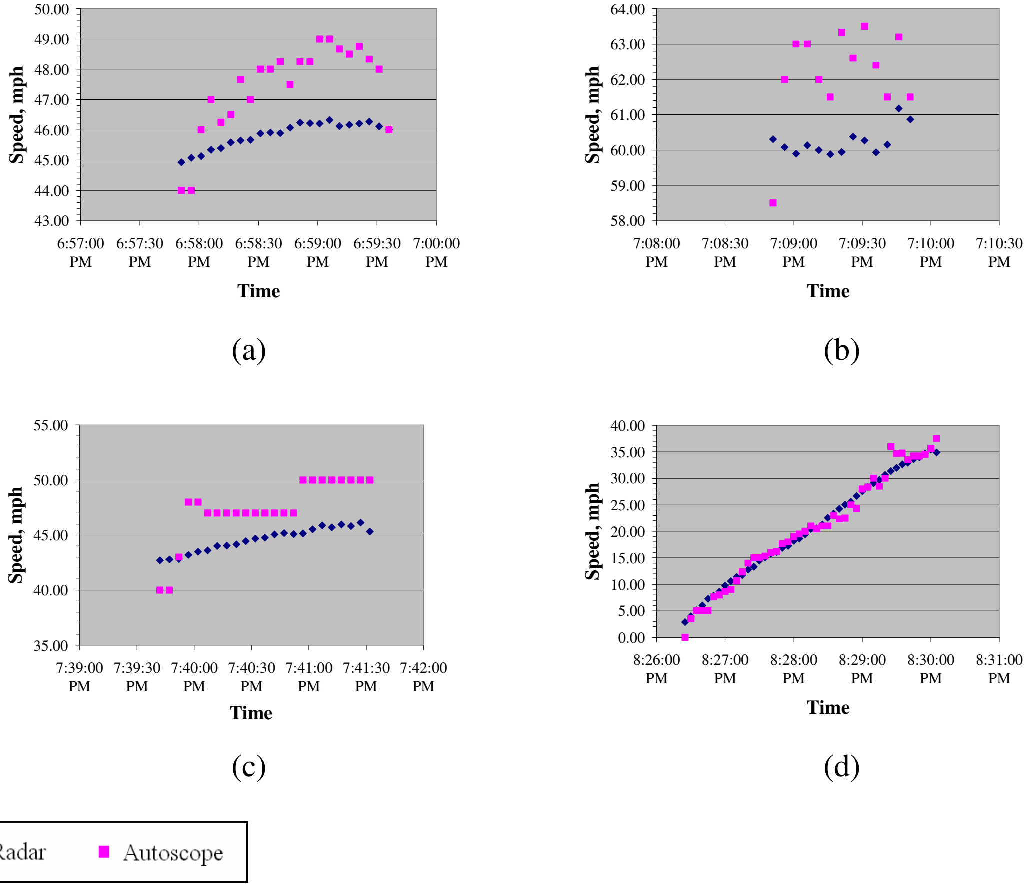


FIGURE 23 Radar and Autoscope Speed Profiles Plots for Trains: (a) KE15, (b) KE19, (c) KE24, (d) KE27, (e) KE31, and (f) KE32



(a)

(b)

(c)

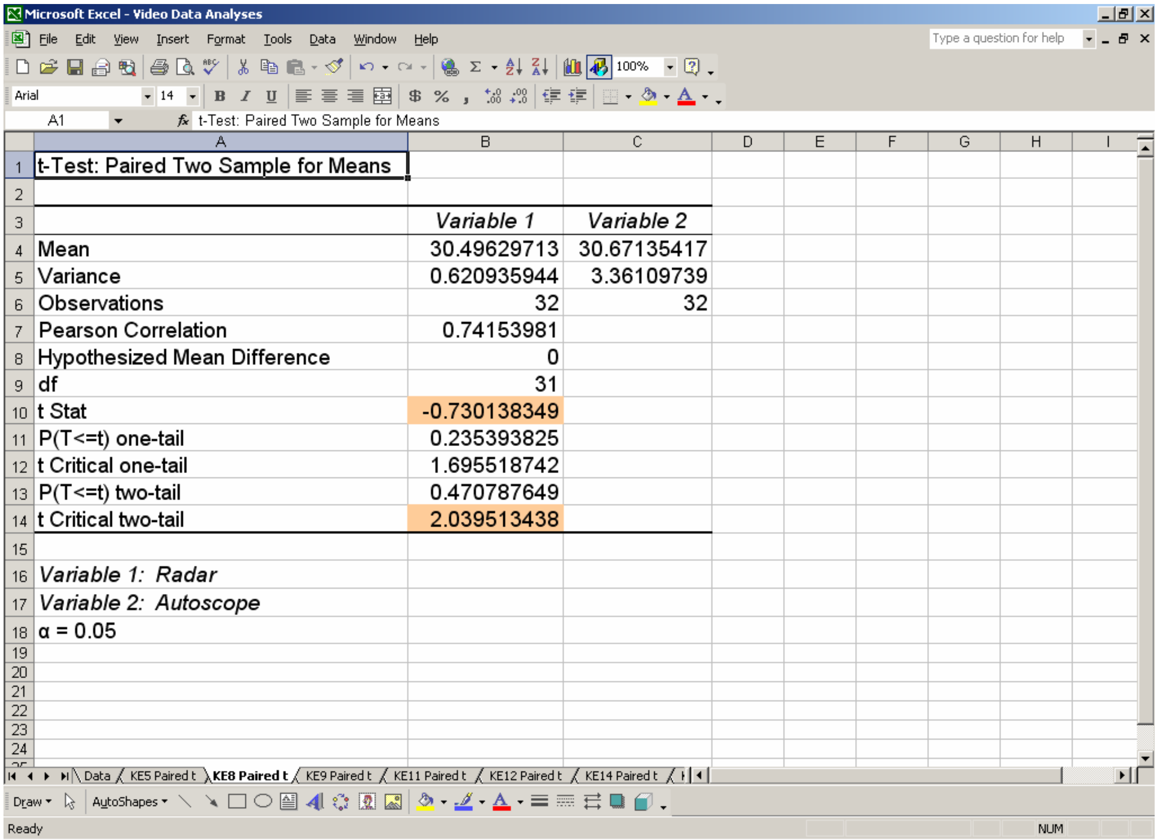
(d)

FIGURE 24 Radar and Autoscope Speed Profiles Plots for Trains: (a) KE33, (b) KE34, (c) KE38, and (d) KE44

Next, a statistical paired t-test was performed on each pair of speeds from the calibrated radar and Autoscope speed detector. Table 7 shows the calibrated radar speeds paired with speeds collected from the speed detector for train KE8. Figure 25 and Table 8 shows the analysis results for the paired t-test performed on the paired data for train KE8. For the paired t-tests; H_o: "The mean difference between radar and Autoscope = 0" and H_a: "The mean difference between radar and Autoscope $\neq 0$". The results in Table 8 show that the t-statistic equals approximately -0.73, and the critical t-value for a two-tale test, where $\alpha = 0.05$, equals approximately 2.04. Tables showing the calibrated radar speeds paired with speeds collected from the speed detector and figures showing the output for the paired t-tests performed on paired data for all 16 trains analyzed can be found in Appendix B. A summary of paired t-test results for the 16 trains analyzed is presented in Table 9.

TABLE 7 Autoscope Speed Detector Data paired with Calibrated Radar Data, Train KE8

Time		Average Speed (mph) From Times X1 to X2 Inclusively	
X1	X2	From Calibrated Radar	From Autoscope Speed Detector
2:02:29 PM	2:02:33 PM	29.34	31.00
2:02:34 PM	2:02:38 PM	29.41	29.50
2:02:39 PM	2:02:43 PM	29.56	29.40
2:02:44 PM	2:02:48 PM	29.69	27.75
2:02:49 PM	2:02:53 PM	29.51	30.25
2:02:54 PM	2:02:58 PM	29.84	29.33
2:02:59 PM	2:03:03 PM	29.57	30.75
2:03:04 PM	2:03:08 PM	29.83	30.00
2:03:09 PM	2:03:13 PM	29.76	30.00
2:03:14 PM	2:03:18 PM	30.04	28.75
2:03:19 PM	2:03:23 PM	30.22	31.67
2:03:24 PM	2:03:28 PM	30.08	30.00
2:03:29 PM	2:03:33 PM	30.39	30.75
2:03:34 PM	2:03:38 PM	30.33	28.00
2:03:39 PM	2:03:43 PM	30.39	30.00
2:03:44 PM	2:03:48 PM	30.46	30.25
2:03:49 PM	2:03:53 PM	30.44	28.67
2:03:54 PM	2:03:58 PM	30.70	30.50
2:03:59 PM	2:04:03 PM	30.51	29.50
2:04:04 PM	2:04:08 PM	30.67	29.00
2:04:09 PM	2:04:13 PM	30.50	30.00
2:04:14 PM	2:04:18 PM	30.74	31.25
2:04:19 PM	2:04:23 PM	30.74	30.67
2:04:24 PM	2:04:28 PM	30.66	31.00
2:04:29 PM	2:04:33 PM	30.70	31.00
2:04:34 PM	2:04:38 PM	31.00	31.00
2:04:39 PM	2:04:43 PM	31.27	32.75
2:04:44 PM	2:04:48 PM	31.66	31.75
2:04:49 PM	2:04:53 PM	31.57	33.00
2:04:54 PM	2:04:58 PM	32.02	34.00
2:04:59 PM	2:05:03 PM	32.08	33.00
2:05:04 PM	2:05:08 PM	32.21	37.00



t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	30.49629713	30.67135417
Variance	0.620935944	3.36109739
Observations	32	32
Pearson Correlation	0.74153981	
Hypothesized Mean Difference	0	
df	31	
t Stat	-0.730138349	
P(T<=t) one-tail	0.235393825	
t Critical one-tail	1.695518742	
P(T<=t) two-tail	0.470787649	
t Critical two-tail	2.039513438	

Variable 1: Radar

Variable 2: Autoscope

α = 0.05

FIGURE 25 Paired t-test Output from Excel for Train KE8

TABLE 8 Paired t-test Analysis for Train KE8

	Doppler Radar	Autoscope
Mean	30.496	30.671
Variance	0.621	3.361
Observations	32	32
Pearson Correlation	0.742	
Hypothesized Mean Difference	0	
df	31	
α	0.05	
t-statistic	-0.730	
P(T<=t) one-tail	0.235	
t Critical one-tail	1.696	
P(T<=t) two-tail	0.471	
t Critical two-tail	2.040	

TABLE 9 Summary of Paired t-test Results

Train	t-statistic	Critical t-value (Two-tale, α = 0.05)	Statistically the same?
KE5	6.34	2.11	No
KE8	-0.73	2.04	Yes
KE9	-0.76	2.06	Yes
KE11	5.97	2.07	No
KE12	-0.15	2.36	Yes
KE14	-0.07	2.09	Yes
KE15	-9.08	2.04	No
KE19	-5.92	2.08	No
KE24	-2.98	2.16	No
KE27	3.84	2.08	No
KE31	-8.92	2.31	No
KE32	-2.79	2.11	No
KE33	-6.80	2.08	No
KE34	-5.06	2.18	No
KE38	-6.28	2.07	No
KE44	-0.15	2.02	Yes

Results presented in Table 9 show that only 5 out of the 16 trains analyzed were statistically the same between calibrated radar and Autoscope. However, by observing the collected data, results from the Autoscope speed detector appear to be similar to the calibrated radar data. To further analyze the speeds collected by Autoscope, a second set of analyses was performed. Table 10 shows comparisons between the mean speeds from the calibrated radar and Autoscope speed detector. For supplemental information, comparisons between the coefficients of variance are also provided in Table 10. Equations 11 through 13 show how items in Table 10 are calculated.

TABLE 10 Comparisons between Radar and Autoscope Mean Speeds; and Comparisons between Radar and Autoscope Coefficients of Variance

Train	Absolute Difference Between Mean Speeds	% Difference Between Mean Speeds	Absolute Difference Between Coefficients of Variance	% Difference Between Coefficients of Variance
KE5	1.85	4.3%	-0.01	-52.6%
KE8	-0.18	-0.6%	-0.03	-131.3%
KE9	-0.34	-0.8%	-0.04	-226.0%
KE11	1.88	4.3%	-0.01	-51.0%
KE12	-0.13	-0.3%	-0.04	-600.6%
KE14	-0.03	-0.1%	-0.03	-239.7%
KE15	-1.64	-4.3%	-0.02	-74.0%
KE19	-8.86	-69.7%	-0.24	-123.3%
KE24	-1.47	-3.0%	-0.03	-464.0%
KE27	1.16	2.4%	0.00	1.9%
KE31	-2.25	-6.4%	-0.02	-577.9%
KE32	-1.70	-3.9%	-0.05	-428.8%
KE33	-1.57	-3.4%	-0.02	-225.8%
KE34	-1.92	-3.2%	-0.01	-225.8%
KE38	-2.77	-6.2%	-0.04	-151.3%
KE44	-0.03	-0.2%	-0.03	-6.0%

$$Absolute\quad Difference\quad Between\quad Mean\quad Speeds = Radar\quad Mean\quad Speed - Autoscope\quad Mean\quad Speed \tag{11}$$

$$\%\quad Difference\quad Between\quad Mean\quad Speeds = \frac{Absolute\quad Difference\quad Between\quad Mean\quad Speeds}{Radar\quad Mean\quad Speed} \tag{12}$$

$$Coefficient\quad of\quad Variance = \frac{Standard\quad Deviation\quad of\quad Speed}{Mean\quad Speed} \tag{13}$$

Calculations for “Absolute Difference Between Coefficients of Variance” and “% Difference Between Coefficients of Variance” are similar to those used for “Absolute Difference Between Mean Speeds” and “% Difference Between Mean Speeds”.

Radar speeds and Autoscope speeds for train KE19 varied by a large amount, 69.7% on average. Aside from this train event, other speed data collected with Autoscope mean speeds only varied from the calibrated radar mean speeds by approximately 6.4% at the most.

Several explanations can be made as to the reason for the discrepancy of collected speeds between Autoscope and the calibrated radar. The location of the cameras was approximately 43 feet above ground on a locking mast, as described in section 3.3.1. Due to the placement of these cameras on a high mast the video was subject to constant motion from wind. For many of the trains, Autoscope was able to gather train speed data while the video image appeared to oscillate up/down and left/right. However, this likely prevented Autoscope from collecting data as accurate as possible, as would be the case during calm wind conditions. Additionally, there may have been a small margin of error introduced by calculating train speeds manually for a select number of trains to calibrate the radar data. Although steps were taken to minimize the amount of error during manual lab data collection, error with manual data collection is always a possibility.

Those explanations aside, only three of the 16 trains that had data collected by Autoscope were off by more than 5% of the calibrated radar speeds. Five percent has generally been accepted as the threshold for error by agencies when collecting transportation data. Also, of those three trains where the Autoscope data was off by more than 5% of the calibrated radar speeds, two of them were only off by approximately 6%. The train with the largest discrepancies between speed data collected by Autoscope and the calibrated radar speeds, KE19, had stopped upstream of the crossing, was in the process of accelerating from low speeds while data was being collected and consisted of multiple different railcar types. By examining a plot of the train speeds collected for train KE19 it can be seen that the speeds recorded by Autoscope increase relatively uniform, similar to the uniform increase recorded by the radar. It is likely that the slow speed of the train while accelerating and the variety of railcar types impacted Autoscope's ability to collect accurate speeds for this train event.

The following example shows how using the maximum over-estimate of speed from Autoscope data collected (4.3%), the maximum under-estimate of speed from Autoscope data collected, excluding train KE19, (-6.4%), and the under-estimate of speed from Autoscope data collected for train KE19 (-69.7%) would affect the predicted travel times for a train.

Example

A train travels at a constant 45 mph, and would take 1 minute 20 seconds to traverse one mile. Using the maximum over-estimate of speed from Autoscope data collected (4.3%) would yield a calculated speed of approximately 46.9 mph. At this speed, the train would be expected to traverse one mile in approximately 1 minute 17 seconds; a difference of only 3 seconds from the actual traversed time. Using the maximum under-estimate of speed from Autoscope data collected, excluding train KE19, (-6.4%) would yield a calculated speed of approximately 42.1 mph. At this speed, the train would be expected to traverse one mile in approximately 1 minute 25 seconds; a difference of only 5 seconds from the actual traversed time. Finally, using the under-estimate of speed from Autoscope data collected for train KE19 (-69.7%) would yield a calculated speed of approximately 13.6 mph. At this speed, the train would be expected to traverse one mile in approximately 4 minutes 24 seconds.

The previous example shows that, with the exception of data from train KE19, the Autoscope data can be used to provide train arrival data to traffic signal controllers. From the example, the least conservative results show that the train would arrive approximately 3 seconds before it is expected, and, during most train events, the most conservative results show that the train would arrive approximately 5 seconds after it is expected.

5.2 LENGTH DATA ANALYSES

An additional set of analyses was performed for train length. Analyses for train length calculated from collected Autoscope data were performed by comparing the calculated Autoscope train lengths to train lengths calculated from calibrated radar data. These analyses were performed for the same trains that were analyzed for train speed. Train lengths were determined from the calculated area under the speed profiles. The train length analyses were based on the five second aggregated intervals used in the train speed analyses. Table 11 shows the results from the train length data analyses.

TABLE 11 Comparisons between Radar and Autoscope Train Length

Train	Calculated Estimate of Train Length (ft) Based on Calibrated Radar	Calculated Estimate of Train Length (ft) Based on Autoscope	Absolute Difference[1]	% Difference[2]
KE5	5651.54	5406.87	244.67	4.3%
KE8	7156.46	7197.54	-41.08	-0.6%
KE9	7787.39	7851.56	-64.17	-0.8%
KE11	7423.79	7107.47	316.32	4.3%
KE12*	2943.78	2951.46	-7.68	-0.3%
KE14	6651.16	6655.61	-4.45	-0.1%
KE15	8946.62	9330.44	-383.82	-4.3%
KE19	2051.44	3480.28	-1428.83	-69.7%
KE24*	5076.99	5227.71	-150.71	-3.0%
KE27	7949.00	7761.90	187.11	2.4%
KE31	2309.81	2458.62	-148.81	-6.4%
KE32	5714.28	5938.78	-224.50	-3.9%
KE33	7394.70	7648.06	-253.36	-3.4%
KE34	5742.11	5925.58	-183.47	-3.2%
KE38	7519.30	7986.00	-466.70	-6.2%
KE44*	6743.54	6754.12	-10.59	-0.2%

Note: Train Lengths are based on aggregated 5 second interval values of speed
* - Based only on portion of train that radar data had been collected
1 = "Radar Length" - "Autoscope Length"
2 = "Absolute Difference" / "Radar Length"

As seen in the train speed analyses, aside from train KE19, the estimate of train length from the Autoscope data was within 6.4% of the train length calculated from the calibrated radar data. These results show that Autoscope would be able to reasonably calculate train length and, along with speed, approximate the time for a train to pass a given HRGC.

5.3 DATA ANALYSES CONCLUSIONS

This chapter has presented data analyses performed for manual, radar, and Autoscope data. Although speed measurements recorded by the Autoscope Speed Detector were not statistically the same as the speeds from the calibrated radar for a majority of the analyzed trains, it appears that the results were not as far off as the statistical tests made them appear to be. Other factors that may have affected the results must also be taken into consideration, they include:

- ✓ The assumption that any given location on the train had the same speed at the perpendicular camera view and at the location that radar data was being collected may have yielded slightly erroneous calibration of the radar or an inaccurate comparison between radar and Autoscope speeds.
- ✓ The possibility of erroneous railcar lengths used in the manual measurements, described with the sensitivity analyses, may have also affected the calibration of the radar data.
- ✓ The calibration angle for the radar may have been different if more trains had been used to determine the calibration angle; however, this would have led to fewer trains available for Autoscope analyses due to bias.
- ✓ The adjustment factor input into the Autoscope speed detector may have varied if more trains had been used to determine the adjustment value; however, like previously stated, this would have led to fewer trains available for Autoscope analyses due to bias.
- ✓ Before transferring the videos to DVDs, they were viewed several times. This may have caused stretching of the video tapes prior to the transfer to DVDs, which could have affected recorded manual and Autoscope speeds.

Taking all these factors into consideration, along with the results obtained from Autoscope, Autoscope appears to work sufficiently in detecting train speeds and lengths for relaying the information to traffic signal controllers.

CHAPTER 6. RECOMMENDATIONS AND CONCLUSIONS

This chapter provides recommendations for the set-up of radar and Autoscope equipment for train detection based on the results obtained during data collection and analyses. As part of the evaluation of video detection for trains, data collected with Doppler radar were used. This raises the issue of using two types of detection simultaneously to improve overall train detection. A necessary step to performing this is data fusion. A discussion of possible fusion of data sources is presented as part of the recommendations in this chapter. Also included are suggestions for Autoscope set-up used in future research. The chapter finishes with conclusions on the research presented in this thesis.

6.1 RECOMMENDATIONS

Based on the data collection and analyses, three recommendations are provided for continuing research. The first is the deployment of advanced train detection equipment and verification of this system through field testing. The second recommendation is testing the fusion of data sources to create a more robust system for train detection to further increase safety at HRGCs. The third describes adjustments to Autoscope video detection equipment and detector file set-up for future research.

6.1.1 DEPLOYMENT OF ADVANCED TRAIN DETECTION EQUIPMENT

This thesis has provided verification and testing of advanced train detection equipment with a portable data collection system. The next step for this equipment is to deploy the train detection system in the field and verify that it would work at a permanent site. The following sections provide information for the location of advanced train detection equipment, radar setup, and Autoscope setup.

6.1.1.1 Location of Advanced Train Detection Equipment

The location of advanced train detection equipment relative to HRGCs is critical in determining accurate arrival time predictions of trains at HRGCs. The location of this equipment, when used to activate equipment at the HRI, needs to be such that a minimum warning time of 20 seconds can be provided at the crossing. Also, the location of equipment needs to be close enough to a HRGC so that acceleration or deceleration of a train can be taken into account for arrival time prediction at the crossing. The further away the equipment is located from a HRGC the more variable the prediction arrival times at a HRGC are likely to be. An estimate of the arrival time can be calculated from the first small portion of a train event. This arrival time prediction can then be updated throughout the train event from the continuous data being collected from the advanced train detection equipment.

6.1.1.2 Radar Setup

A radar unit could be deployed at any location near the railroad tracks. For example, in a previously mentioned study be Estes and Rilett (Estes 2000), radar units were mounted on traffic signal poles near grade crossings, and a camera verified that a complete set of observed radar detection was never anything other than a train. It can be noted, however, that by placing the radar unit closer to, or on, the railroad right-of-way can reduce interference from objects other than trains. If the radar is Doppler, placing the radar at a shallow angle to the tracks will yield a smaller calibration angle. Therefore, it is best to place the radar unit such that the angle between the radar line-of-sight and the tracks is minimized. Also, optimum placement would include minimizing the height of the radar above the elevation of trains on a track. Finally, consideration must also be taken as to not aim the radar such that the point of intersection between the radar line-of-sight and tracks is not beyond the range of the radar unit, as radar detectors have limited ranges.

6.1.1.3 Autoscope Setup

To achieve accurate train detection with video detection, several measures must be addressed in the deployment of video detection units. These measures can be broken down into the camera setup and the video detection setup.

Camera Setup

The camera setup includes the physical location of the camera relative to the railroad tracks and the field of view for the camera to provide accurate train detection

Location of Camera Relative to the Railroad Tracks

From the data collection and analyses, suggestions are made for the location of cameras relative to railroad tracks. The camera should be placed as close to the railroad tracks as possible and mounted as high above the tracks as possible. General guidelines for Autoscope video detection suggest a minimum camera height of 30 ft (Econolite 2005-(2)). It may be desirable from a practical perspective to place the camera off of the railroad right-of-way. This reduces the number of stakeholders involved and generally leads to quicker equipment installation and simpler operational agreements.

Field of View

By placing the camera at the described location above yields two fields of view for a train relative to the motion of the train: skewed and perpendicular. Either can be used for train detection; however, a perpendicular view of a train's direction of travel yields a more reliable video detection system as the video detection software detects the gap between the railcars easier than it detects the railcars themselves. The zoom of the camera should be adjusted such that two or three railcars are shown in the image so that an Autoscope speed detector could accurately detect the gap between railcars. The reader should note that the zoom settings used during data collection were not "optimum", but "sufficient".

Video Detection Setup

Accurately setting up the video detection system is vital to the success of train detection with video. Someone with knowledge of the video detection system should be used to set up the video detector files. This includes the calibration and detector placement of the camera. For this thesis, Autoscope was the video detection system used. A description of setup procedures and general guidelines for Autoscope are provided in the following sections.

Calibration

To obtain accurate data, the cameras are calibrated such that their position in space relative to the area in their field of view is known. The calibration is done by incorporating real world distances into images obtained from the Autoscope cameras, as shown in Figure 14 and discussed in Section 4.3.1.1. The determination of the adjustment factor input in the speed detector can also be classified as part of the calibration process.

Types of Detectors

The primary detector used for detecting and predicting arrival times for trains is the speed detector. Speed detectors can measure speed, lengths, counts, occupancy, and time headway of trains directly and acceleration rates indirectly. Detector stations are another type of detector that can collect train data. Detector stations collect a variety of data by linking them to other detectors in the detector file. They collect a summary of data over a specified time interval with 1 second being the smallest retrieval interval.

Detector Placement

Speed detectors should be placed as described and shown in Section 4.3.1.3. Detectors need to be placed such that any train event will activate the detectors at the specific location of equipment deployment. It is important to make sure the detectors are placed such that nearly any type of railcar can be detected.

Issues with Multiple Tracks

Under conditions where multiple tracks exist, ideal placement of detectors is more difficult to obtain. Speed detectors need to be placed so that if a train was on each track at that location at the same time, Autoscope would be able to obtain data on each train regardless of their directions of travel. An attempt was made to set up speed detectors for detection of multiple trains at the same location and time. However, it was determined that the camera position for this attempt was not close enough to the tracks to provide a good camera angle to detect multiple trains on multiple tracks. Based on this attempt, research showed that either multiple cameras should be used or a different mounting position should be used for detection of multiple trains on multiple tracks at the same time. For a set-up using multiple cameras, a camera would ideally be dedicated to a single track. Therefore, to accomplish train detection of multiple trains at the same location and time on multiple tracks, multiple cameras on either side of the tracks should be placed at the desired train detection location.

6.1.2 DATA FUSION

Both radar and video detection have shown to exhibit limitations of their technology. One limitation of radar is that it cannot obtain information on multiple trains at the same location and at the same time. When the radar unit is placed to minimize the height above a train, the radar unit will generally record whichever train is closer. Conversely, when the radar unit is placed at a higher elevation, the radar unit is more likely to record the train that returns the strongest pulse to the radar unit. Therefore, train events could go undetected. Radar detection also has difficulty when it is raining. Rain interrupts the radar signal as the radar unit attempts to recover the returning pulse. Video detection can have difficulty when a low contrast exists in the image, such as at night as discussed in Section 4.3.1.7, or during a time where the image is extremely bright and the camera has not had enough time to adjust its focus, such as low sun angles at dawn and dusk as well as sun glaring off of fresh snow. Due to limitations of each technology, it may be advantageous to use them in combination with one another along with other first generation technologies as a fail-safe mechanism. This would need to be an avenue for future research.

6.1.3 RECOMMENDATIONS FOR FUTURE RESEARCH WITH VIDEO DETECTION

Throughout the process of field and in-lab data collection, recommendations for future research with video detection was apparent. These recommendations include field equipment set-up and train detection as well as recommendations for future in-lab video data collection. The following sections present suggestions for future research with video detection.

6.1.3.1 Field Equipment Recommendations

The most apparent suggestion for field equipment set-up involves camera placement. During Autoscope data collection of trains, and during the attempt to collect data for multiple trains at the same location existing on multiple tracks at the same time, research made evident that a position looking down onto the tracks from an overhead position might be beneficial. This recommendation would involve mounting a camera from an overhead structure such as a bridge. Another field equipment recommendation would be to use first generation technologies to also collect data. This data could be used in combination with video detection to determine if video detecting a train on a specific track and traveling in a specific direction is accurate.

6.1.3.2 Autoscope Detector File Recommendations

Data was able to be collected by using the Autoscope detector file set-up described in this thesis. However, this thesis did not look at setting up a detector file to collect data for trains traveling both directions on a given track, as this does frequently occur. Follow-up research could look into this type of train detection. Also, it could be advantageous to investigate the use of multiple Speed Detectors for trains on a single track, and then use data fusion to fuse data from these Speed Detectors.

6.2 CONCLUSIONS

In conclusion, Autoscope video detection has been shown to be a practical form of train detection by comparing collected Autoscope data to calibrated data from radar. Radar data obtained in the field were calibrated by using manually calculated train speeds. Autoscope has been shown to work well for detecting trains and recovering reasonable data on their speeds. This data would be of potential use to traffic signal controllers near HRGCs in alerting motorists of upcoming train event arrivals and departures from a HRGC. These conclusions have been shown through data analyses conducted on trains near HRGCs in this thesis. From the data collection and analyses presented in this thesis, the research also concluded that much care must be used in setting up the video detection, and it is important to understand how the video detection equipment and software work prior to use with them.

With these conclusions, future avenues of research with video detection may be investigated. As described earlier in this chapter, the next step for future work includes:

the deployment of an advanced train detection system into the field and verification that it would work for a permanent site, different set-ups for equipment and detector files, and work on data fusion techniques to ensure optimum data collection.

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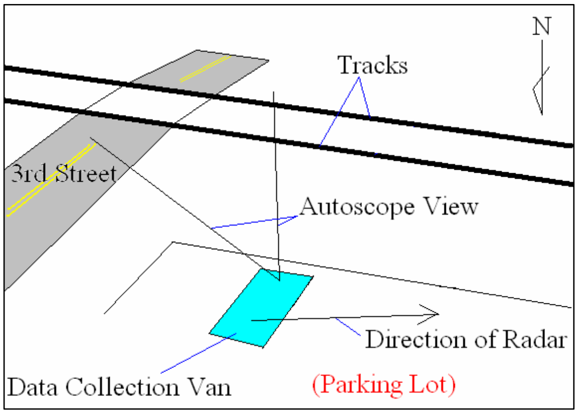
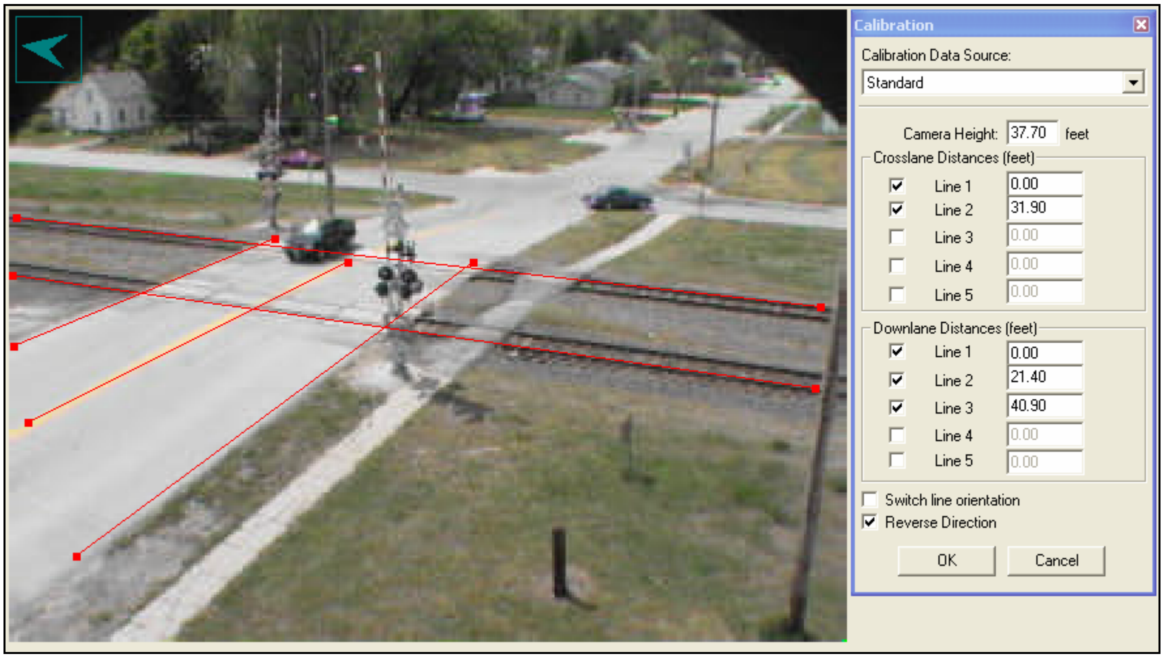
APPENDIX A

Train Index and Manual Measurements

Site: Waterloo, NE
Date: 5/9/2005
Start Time: 1:00 PM
Stop Time: 2:30 PM
Weather: Warm, Partly Cloudy, Windy
Approx. # of Trains Daily: 90
Number of Trains Observed: 3



Location Sketch (Not to scale)



Calibration Data Source: Standard

Camera Height: 37.70 feet

Crosslane Distances (feet)
☑ Line 1 0.00
☑ Line 2 31.90
☐ Line 3 0.00
☐ Line 4 0.00
☐ Line 5 0.00

Downlane Distances (feet)
☑ Line 1 0.00
☑ Line 2 21.40
☑ Line 3 40.90
☐ Line 4 0.00
☐ Line 5 0.00

☐ Switch line orientation
☑ Reverse Direction

Rear Camera Calibration

Rear Camera Detector Location

Waterloo Train Index

						Start Time of Train		End Time of Train	
Train #	Direction	Train Type*	Track	Manual Measurements	Radar Data	Rear Camera	Radar	Rear Camera	Radar Data End Time
WA1	NW	Coal	Close (North)	Yes	1 Train	13:20:43	13:20:45	13:22:25	13:22:35
WA2	SE	Coal	Far (South)	No	1 Train	13:31:11	13:31:08	13:33:05	13:33:28
WA3	SE	Misc.	Close (North)	No	1 Train	14:03:33	14:03:30	14:05:09	14:05:39

* - Misc. is defined as a train that contains various types and/or lengths of railcars

Waterloo Radar Time Determination

Radar File #	Train #	Estimated Radar Time that Train Data Begins (sec)	Average Speed of Train During First Second of Detection (mph)	Time Lag * (sec)	Estimated Time Radar Detects Train	Total Record Time [1] (sec)
1	WA1	0.22	46.9	2.3	13:20:45	110
2	WA2	8.48	41.9	2.6	13:31:08	140
3	WA3	29.62	37.9	2.9	14:03:30	129

* - Time differential between beginning of train detection with radar and beginning of train at center of perpendicular camera view

[1] - Maximum ‘Total Record Time’ for Radar was 300 seconds, train data after this time was not able to be recorded

Train WA1: Manually Calculated Speeds

Segment	Time from Beginning of Train to Beginning Car in Segment Measurement (sec)	Measured from Beginning of Car	Measured to Beginning of Car	Measured Travel Times (sec)				Time from Beginning of Train to Average Time that Calculated Speed Occurred (sec)	Length of Railcar Segment (ft)	Calculated Estimate of Speed* (mph)
				Trial 1	Trial 2	Trial 3	Average			
1	2.1	3	8	3.9	3.8	3.9	3.9	4.0	265.4	46.8
2	6.0	8	13	3.9	3.8	3.9	3.9	7.9	265.4	46.8
3	9.8	13	18	3.9	3.9	3.9	3.9	11.8	265.4	46.4
4	13.7	18	23	3.9	3.9	3.9	3.9	15.7	265.4	46.4
5	17.6	23	28	3.9	3.9	3.9	3.9	19.6	265.4	46.4
6	21.5	28	33	3.9	3.9	3.9	3.9	23.5	265.4	46.4
7	25.4	33	38	3.9	4.0	3.9	3.9	27.4	265.4	46.0
8	29.4	38	43	4.0	3.9	4.0	4.0	31.4	265.4	45.6
9	33.3	43	48	3.9	4.0	4.0	4.0	35.3	265.4	45.6
10	37.3	48	53	4.0	4.0	3.9	4.0	39.3	265.4	45.6
11	41.3	53	58	3.9	4.0	4.0	4.0	43.3	265.4	45.6
12	45.2	58	63	3.9	4.0	4.0	4.0	47.2	265.4	45.6
13	49.2	63	68	4.0	3.9	4.0	4.0	51.2	265.4	45.6
14	53.2	68	73	4.0	4.0	4.0	4.0	55.2	265.4	45.3
15	57.2	73	78	4.0	4.0	4.0	4.0	59.2	265.4	45.3
16	61.2	78	83	4.0	4.0	4.0	4.0	63.2	265.4	45.3
17	65.2	83	88	4.0	4.0	4.0	4.0	67.2	265.4	45.3
18	69.2	88	93	4.0	4.1	4.0	4.0	71.2	265.4	44.9
19	73.2	93	98	4.1	4.0	4.1	4.1	75.2	265.4	44.5
20	77.3	98	103	4.0	4.1	4.0	4.0	79.3	265.4	44.9
21	81.3	103	108	4.1	4.1	4.0	4.1	83.3	265.4	44.5
22	85.4	108	113	4.1	4.1	4.1	4.1	87.4	265.4	44.2
23	89.5	113	118	4.1	4.1	4.1	4.1	91.5	265.4	44.2
24	93.6	118	123	4.1	4.1	4.1	4.1	95.6	265.4	44.2
25	97.7	123	128	4.1	4.1	4.1	4.1	99.7	265.4	44.2

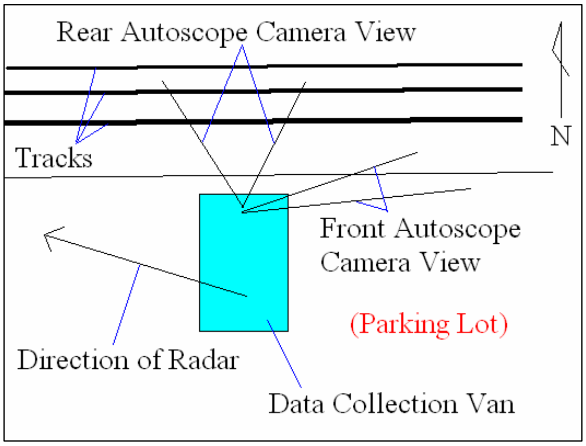
* - Speed was calculated based on the Average Measured Travel Times and the lengths of the railcar segments (5 car segments). All railcars for this train were coal cars with a standard length from coupler to coupler of “Most Likely” 53’ 1” (Simmons-Boardman 1997)

Train WA1: Sensitivity Analysis of Manually Calculated Speeds

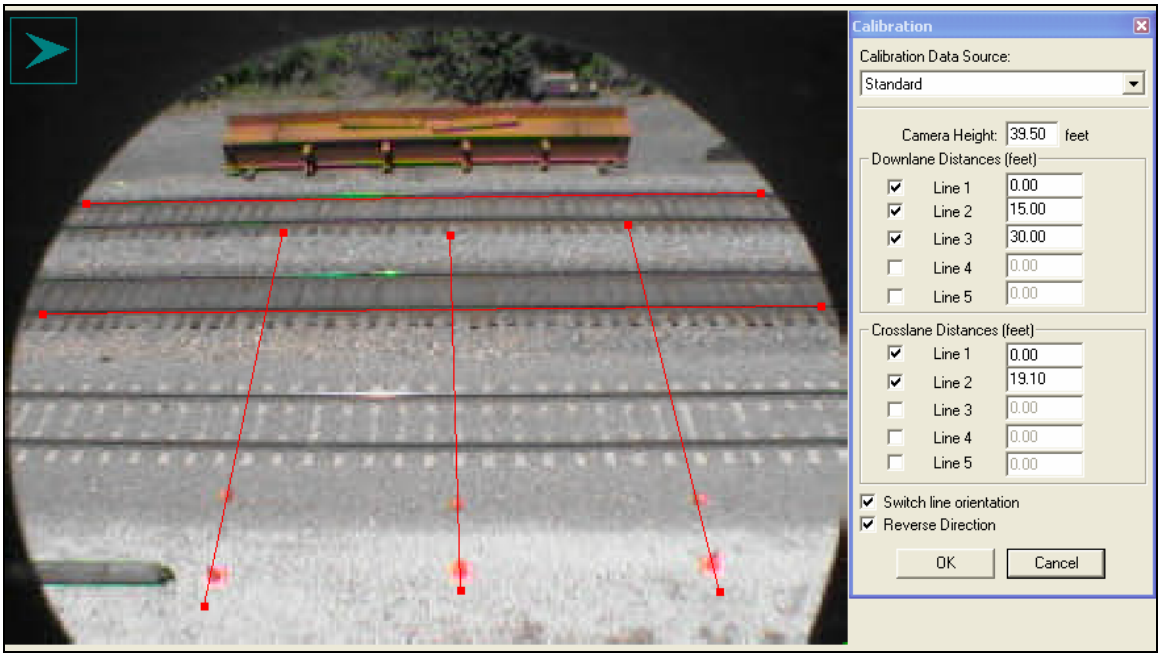
Segment	Average Measured Travel Time (sec)	Lengths of Railcar Segments (ft)			Calculated Estimate of Speed (mph)		
		Shortest	Most Likely	Longest	Shortest	Most Likely	Longest
1	3.9	243.5	265.4	285.2	42.9	46.8	50.3
2	3.9	243.5	265.4	285.2	42.9	46.8	50.3
3	3.9	243.5	265.4	285.2	42.6	46.4	49.9
4	3.9	243.5	265.4	285.2	42.6	46.4	49.9
5	3.9	243.5	265.4	285.2	42.6	46.4	49.9
6	3.9	243.5	265.4	285.2	42.6	46.4	49.9
7	3.9	243.5	265.4	285.2	42.2	46.0	49.4
8	4.0	243.5	265.4	285.2	41.9	45.6	49.0
9	4.0	243.5	265.4	285.2	41.9	45.6	49.0
10	4.0	243.5	265.4	285.2	41.9	45.6	49.0
11	4.0	243.5	265.4	285.2	41.9	45.6	49.0
12	4.0	243.5	265.4	285.2	41.9	45.6	49.0
13	4.0	243.5	265.4	285.2	41.9	45.6	49.0
14	4.0	243.5	265.4	285.2	41.5	45.2	48.6
15	4.0	243.5	265.4	285.2	41.5	45.2	48.6
16	4.0	243.5	265.4	285.2	41.5	45.2	48.6
17	4.0	243.5	265.4	285.2	41.5	45.2	48.6
18	4.0	243.5	265.4	285.2	41.2	44.9	48.2
19	4.1	243.5	265.4	285.2	40.8	44.5	47.8
20	4.0	243.5	265.4	285.2	41.2	44.9	48.2
21	4.1	243.5	265.4	285.2	40.8	44.5	47.8
22	4.1	243.5	265.4	285.2	40.5	44.1	47.4
23	4.1	243.5	265.4	285.2	40.5	44.1	47.4
24	4.1	243.5	265.4	285.2	40.5	44.1	47.4
25	4.1	243.5	265.4	285.2	40.5	44.1	47.4
Average =					41.7	45.4	48.8
Absolute Difference =					-3.7	0.0	3.4
Percent Difference =					**-8.2%**	0.0%	**7.5%**

Note: Shortest = 48’ –8 ½” / Car;
Most Likely = 53’ – 1” / Car;
Longest = 57’ – ½” / Car

Site: Lincoln, NE
Date: 5/14/2005
Start Time: 1:45 PM
Stop Time: 4:15 PM
Weather: Warm, Sunny, Windy
Approx. # of Trains Daily: 70
Number of Trains Observed: 4



Location Sketch (Not to scale)



Calibration Data Source: Standard

Camera Height: 39.50 feet

Downlane Distances (feet)
- ☑ Line 1 0.00
- ☑ Line 2 15.00
- ☑ Line 3 30.00
- ☐ Line 4 0.00
- ☐ Line 5 0.00

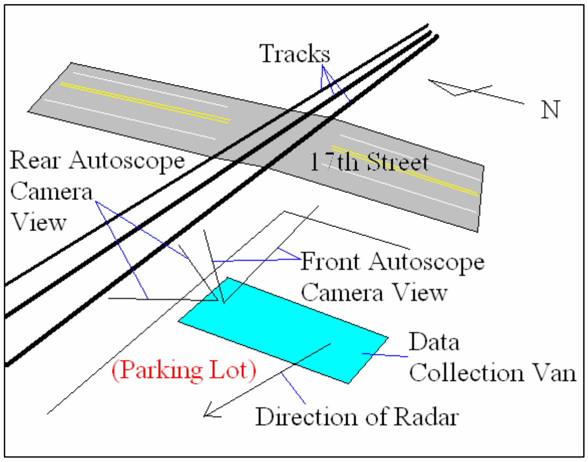
Crosslane Distances (feet)
- ☑ Line 1 0.00
- ☑ Line 2 19.10
- ☐ Line 3 0.00
- ☐ Line 4 0.00
- ☐ Line 5 0.00

☑ Switch line orientation
☑ Reverse Direction

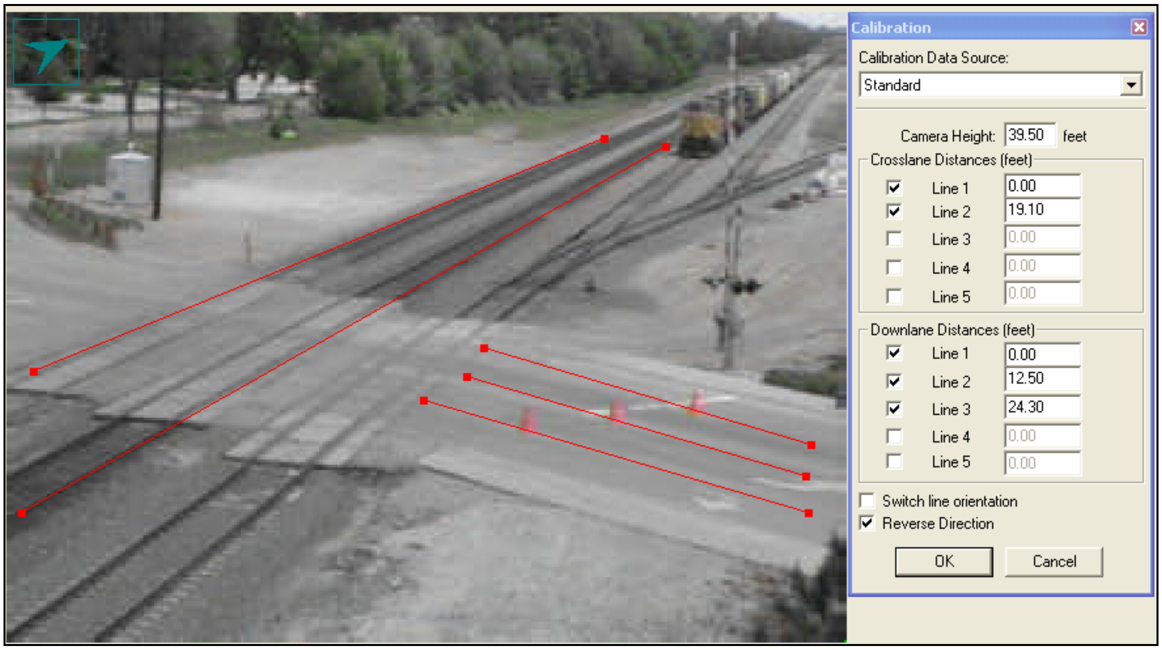
Rear Camera Calibration

Rear Camera Detector Location

Site: Lincoln, NE
Date: 5/14/2005
Start Time: 1:45 PM
Stop Time: 4:15 PM
Weather: Warm, Sunny, Windy
Approx. # of Trains Daily: 70
Number of Trains Observed: 4



Location Sketch (Not to scale)



Calibration Data Source: Standard

Camera Height: 39.50 feet

Crosslane Distances (feet)

☑	Line 1	0.00
☑	Line 2	19.10
☐	Line 3	0.00
☐	Line 4	0.00
☐	Line 5	0.00

Downlane Distances (feet)

☑	Line 1	0.00
☑	Line 2	12.50
☑	Line 3	24.30
☐	Line 4	0.00
☐	Line 5	0.00

☐ Switch line orientation
☑ Reverse Direction

Front Camera Calibration

Front Camera Detector Location

Lincoln Train Index

Train #	Direction	Track	Train Type*	Manual Measurements	Radar Data	Start Time of Train			End Time of Train		Radar Data End Time
						Rear Camera	Front Camera	Radar	Rear Camera	Front Camera	
LD1	SW	Far (North)	Coal	Yes	1 Train	14:16:05	14:15:51	14:16:09	14:21:03	14:20:41	14:20:45
LD2	SW	Far (North)	Misc.	No	1 Train	14:42:18	14:41:51	14:42:23	14:47:56	14:47:26	14:47:21
LD3	NE	Close (South)	Coal	Yes	1 Train	15:02:50	15:03:05	15:02:45	15:06:55	15:07:05	15:07:15
LD4	SW	Far (North)	Coal	No	1 Train	15:52:39	15:52:25	15:52:44	15:58:11	15:57:47	15:57:36

* Misc. is defined as a train that contains various types and/or lengths of railcars

Lincoln Radar Time Determination

Radar File #	Train #	Estimated Radar Time that Train Data Begins (sec)	Average Speed of Train During First Second of Detection (mph)	Time Lag* (sec)	Estimated Time Radar Detects Train	Total Record Time[1] (sec)
1	LD1	23.71	20.9	3.5	14:16:09	300
2	LD2	1.50	14.9	4.9	14:42:23	300
3	LD3	11.62	14.8	5.0	15:02:45	282
4	LD4	8.00	15.0	4.9	15:52:44	300

* Time differential between beginning of train detection with radar and beginning of train at center of perpendicular camera view

[1] Maximum ‘Total Record Time’ for Radar was 300 seconds, train data after this time was not able to be recorded

Train LD1: Manually Calculated Speeds

Segment	Time from Beginning of Train to Beginning Car in Segment Measurement (sec)	Measured from Beginning of Car	Measured to Beginning of Car	Measured Travel Times (sec)				Time from Beginning of Train to Average Time that Calculated Speed Occurred (sec)	Length of Railcar Segment (ft)	Calculated Estimate of Speed* (mph)
				Trial 1	Trial 2	Trial 3	Average			
1	4.6	3	8	8.4	8.4	8.4	8.4	4.2	265.4	21.5
2	13.0	8	13	8.6	8.5	8.5	8.5	12.7	265.4	21.2
3	21.5	13	18	8.8	8.8	8.7	8.8	21.3	265.4	20.6
4	30.3	18	23	9.0	9.0	8.9	9.0	30.2	265.4	20.2
5	39.3	23	28	9.1	9.1	9.1	9.1	39.2	265.4	19.9
6	48.4	28	33	9.4	9.3	9.3	9.3	48.4	265.4	19.4
7	57.7	33	38	9.6	9.5	9.5	9.5	57.9	265.4	19.0
8	67.2	38	43	9.7	9.7	9.7	9.7	67.5	265.4	18.7
9	76.9	43	48	9.8	9.7	9.8	9.8	77.2	265.4	18.5
10	86.7	48	53	9.9	9.8	9.9	9.9	87.0	265.4	18.3
11	96.6	53	58	10.0	9.9	10.0	10.0	97.0	265.4	18.2
12	106.5	58	63	10.3	10.3	10.3	10.3	107.1	265.4	17.6
13	116.8	63	68	10.6	10.7	10.7	10.7	117.6	265.4	17.0
14	127.5	68	73	11.0	11.0	10.9	11.0	128.4	265.4	16.5
15	138.5	73	78	11.7	11.8	11.8	11.8	139.8	265.4	15.4
16	150.2	78	83	12.2	12.3	12.3	12.3	151.8	265.4	14.8
17	162.5	83	88	12.8	12.8	12.8	12.8	164.3	265.4	14.1
18	175.3	88	93	13.5	13.6	13.6	13.6	177.5	265.4	13.3
19	188.9	93	98	13.5	13.4	13.4	13.4	191.0	265.4	13.5
20	202.3	98	103	13.2	13.2	13.1	13.2	204.3	265.4	13.7
21	215.5	103	108	12.9	12.9	12.9	12.9	217.3	265.4	14.0
22	228.4	108	113	12.4	12.5	12.5	12.5	230.0	265.4	14.5
23	240.8	113	118	12.4	12.4	12.4	12.4	242.4	265.4	14.6
24	253.2	118	123	12.7	12.7	12.7	12.7	255.0	265.4	14.2
25	265.9	123	128	12.9	13.0	13.0	13.0	267.8	265.4	14.0
26	278.9	128	133	13.3	13.2	13.3	13.3	280.9	265.4	13.6

* - Speed was calculated based on the Average Measured Travel Times and the lengths of the railcar segments (5 car segments). All railcars for this train were coal cars with standard length from coupler to coupler of “Most Likely” 53’ 1” (Simmons-Boardman 1997)

Train LD1: Sensitivity Analysis of Manually Calculated Speeds

Segment	Average Measured Travel Time (sec)	Lengths of Railcar Segments (ft)			Calculated Estimate of Speed (mph)		
		Shortest	Most Likely	Longest	Shortest	Most Likely	Longest
1	8.4	243.5	265.4	285.2	19.8	21.5	23.2
2	8.5	243.5	265.4	285.2	19.5	21.2	22.8
3	8.8	243.5	265.4	285.2	18.9	20.6	22.2
4	9.0	243.5	265.4	285.2	18.5	20.2	21.7
5	9.1	243.5	265.4	285.2	18.2	19.9	21.4
6	9.3	243.5	265.4	285.2	17.8	19.4	20.8
7	9.5	243.5	265.4	285.2	17.4	19.0	20.4
8	9.7	243.5	265.4	285.2	17.1	18.7	20.0
9	9.8	243.5	265.4	285.2	17.0	18.5	19.9
10	9.9	243.5	265.4	285.2	16.8	18.3	19.7
11	10.0	243.5	265.4	285.2	16.7	18.2	19.5
12	10.3	243.5	265.4	285.2	16.1	17.6	18.9
13	10.7	243.5	265.4	285.2	15.6	17.0	18.2
14	11.0	243.5	265.4	285.2	15.1	16.5	17.7
15	11.8	243.5	265.4	285.2	14.1	15.4	16.5
16	12.3	243.5	265.4	285.2	13.5	14.8	15.9
17	12.8	243.5	265.4	285.2	13.0	14.1	15.2
18	13.6	243.5	265.4	285.2	12.2	13.3	14.3
19	13.4	243.5	265.4	285.2	12.4	13.5	14.5
20	13.2	243.5	265.4	285.2	12.6	13.7	14.8
21	12.9	243.5	265.4	285.2	12.9	14.0	15.1
22	12.5	243.5	265.4	285.2	13.3	14.5	15.6
23	12.4	243.5	265.4	285.2	13.4	14.6	15.7
24	12.7	243.5	265.4	285.2	13.1	14.2	15.3
25	13.0	243.5	265.4	285.2	12.8	14.0	15.0
26	12.7	243.5	265.4	285.2	13.1	14.2	15.3
Average =					15.4	16.8	18.1
Absolute Difference =					-1.4	0.0	1.3
Percent Difference =					**-8.2%**	0.0%	**7.5%**

Note: Shortest = 48’ –8 ½” / Car;
Most Likely = 53’ – 1” / Car;
Longest = 57’ – ½” / Car

Train LD3: Manually Calculated Speeds

Segment	Time from Beginning of Train to Beginning Car in Segment Measurement (sec)	Measured from Beginning of Car	Measured to Beginning of Car	Measured Travel Times (sec) Trial 1	Trial 2	Trial 3	Average	Time from Beginning of Train to Average Time that Calculated Speed Occurred (sec)	Length of Railcar Segment (ft)	Calculated Estimate of Speed* (mph)
1	6.9	3	8	12.4	12.4	12.4	12.4	13.1	265.4	14.6
2	19.3	8	13	12.4	12.4	12.4	12.4	25.5	265.4	14.6
3	31.7	13	18	12.2	12.2	12.2	12.2	37.8	265.4	14.8
4	43.9	18	23	12.3	12.1	12.2	12.2	50.0	265.4	14.8
5	56.1	23	28	12.1	12.1	12.1	12.1	62.2	265.4	15.0
6	68.2	28	33	12.0	12.0	12.0	12.0	74.2	265.4	15.1
7	80.2	33	38	12.0	12.0	12.0	12.0	86.2	265.4	15.1
8	92.2	38	43	11.7	11.7	11.7	11.7	98.1	265.4	15.5
9	103.9	43	48	11.2	11.2	11.2	11.2	109.5	265.4	16.2
10	115.1	48	53	10.5	10.5	10.5	10.5	120.4	265.4	17.2
11	125.6	53	58	9.9	9.9	10.0	9.9	130.6	265.4	18.2
12	135.5	58	63	9.5	9.5	9.4	9.5	140.3	265.4	19.1
13	145.0	63	68	9.0	9.0	9.0	9.0	149.5	265.4	20.1
14	154.0	68	73	8.7	8.6	8.7	8.7	158.3	265.4	20.9
15	162.7	73	78	8.4	8.3	8.3	8.3	166.8	265.4	21.7
16	171.0	78	83	8.1	8.1	8.1	8.1	175.1	265.4	22.3
17	179.1	83	88	7.9	7.8	7.8	7.8	183.0	265.4	23.1
18	186.9	88	93	7.7	7.7	7.6	7.7	190.8	265.4	23.6
19	194.6	93	98	7.6	7.6	7.6	7.6	198.4	265.4	23.8
20	202.2	98	103	7.4	7.4	7.4	7.4	205.9	265.4	24.5
21	209.6	103	108	7.4	7.4	7.4	7.4	213.3	265.4	24.5
22	217.0	108	113	7.3	7.4	7.4	7.4	220.7	265.4	24.6
23	224.4	113	118	7.3	7.3	7.3	7.3	228.0	265.4	24.8
24	231.7	118	123	7.3	7.3	7.2	7.3	235.3	265.4	24.9

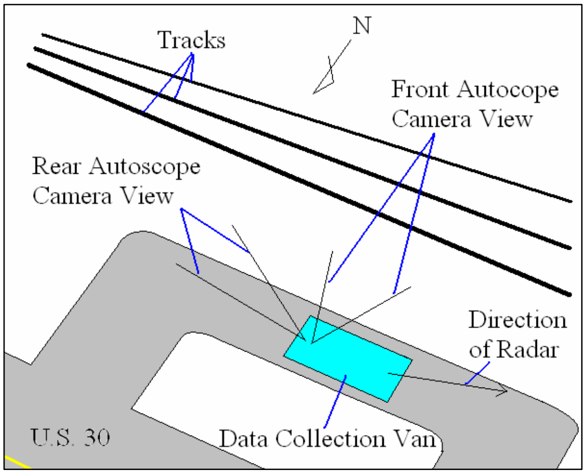
* - Speed was calculated based on the Average Measured Travel Times and the lengths of the railcar segments (5 car segments). All railcars for this train were coal cars with standard length from coupler to coupler of “Most Likely” 53’ 1” (Simmons-Boardman 1997)

Train LD3: Sensitivity Analysis of Manually Calculated Speeds

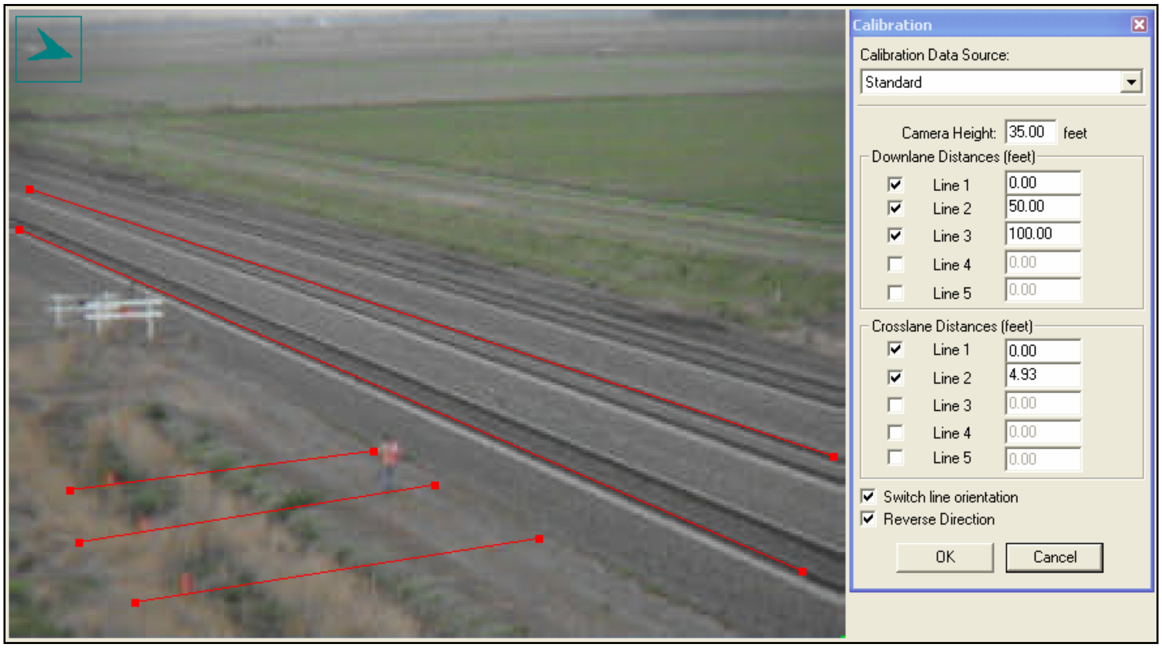
Segment	Average Measured Travel Time (sec)	Lengths of Railcar Segments (ft)			Calculated Estimate of Speed (mph)		
		Shortest	Most Likely	Longest	Shortest	Most Likely	Longest
1	12.4	243.5	265.4	285.2	13.4	14.6	15.7
2	12.4	243.5	265.4	285.2	13.4	14.6	15.7
3	12.2	243.5	265.4	285.2	13.6	14.8	15.9
4	12.2	243.5	265.4	285.2	13.6	14.8	15.9
5	12.1	243.5	265.4	285.2	13.7	15.0	16.1
6	12.0	243.5	265.4	285.2	13.8	15.1	16.2
7	12.0	243.5	265.4	285.2	13.8	15.1	16.2
8	11.7	243.5	265.4	285.2	14.2	15.5	16.6
9	11.2	243.5	265.4	285.2	14.8	16.2	17.4
10	10.5	243.5	265.4	285.2	15.8	17.2	18.5
11	9.9	243.5	265.4	285.2	16.7	18.2	19.6
12	9.5	243.5	265.4	285.2	17.5	19.1	20.5
13	9.0	243.5	265.4	285.2	18.5	20.1	21.6
14	8.7	243.5	265.4	285.2	19.2	20.9	22.4
15	8.3	243.5	265.4	285.2	19.9	21.7	23.3
16	8.1	243.5	265.4	285.2	20.5	22.3	24.0
17	7.8	243.5	265.4	285.2	21.2	23.1	24.8
18	7.7	243.5	265.4	285.2	21.7	23.6	25.4
19	7.6	243.5	265.4	285.2	21.8	23.8	25.6
20	7.4	243.5	265.4	285.2	22.4	24.5	26.3
21	7.4	243.5	265.4	285.2	22.4	24.5	26.3
22	7.4	243.5	265.4	285.2	22.5	24.6	26.4
23	7.3	243.5	265.4	285.2	22.7	24.8	26.6
24	7.3	243.5	265.4	285.2	22.9	24.9	26.8
Average =					17.9	19.5	21.0
Absolute Difference =					-1.6	0.0	1.5
Percent Difference =					-8.2%	0.0%	7.5%

Note: Shortest = 48’ –8 ½” / Car;
Most Likely = 53’ – 1” / Car;
Longest = 57’ – ½” / Car

Site: Overton, NE
Date: 5/24/2005
Start Time: 5:30 PM
Stop Time: 8:15 PM
Weather: Warm, Cloudy, Rain
Approx. # of Trains Daily: 135
Number of Trains Observed: 12



Location Sketch (Not to scale)



Calibration Data Source: Standard

Camera Height: 35.00 feet

Downlane Distances (feet)

☑ Line 1 0.00
☑ Line 2 50.00
☑ Line 3 100.00
☐ Line 4 0.00
☐ Line 5 0.00

Crosslane Distances (feet)

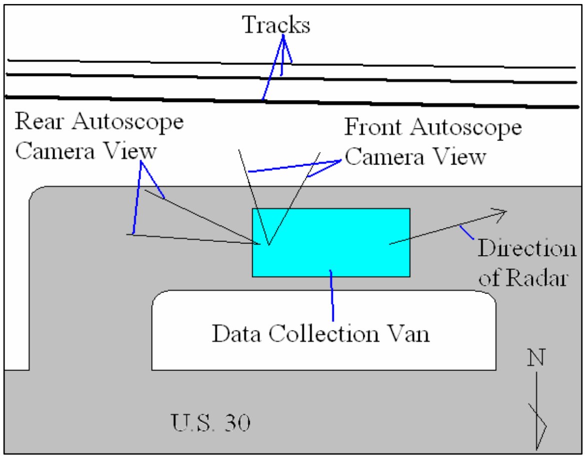
☑ Line 1 0.00
☑ Line 2 4.93
☐ Line 3 0.00
☐ Line 4 0.00
☐ Line 5 0.00

☑ Switch line orientation
☑ Reverse Direction

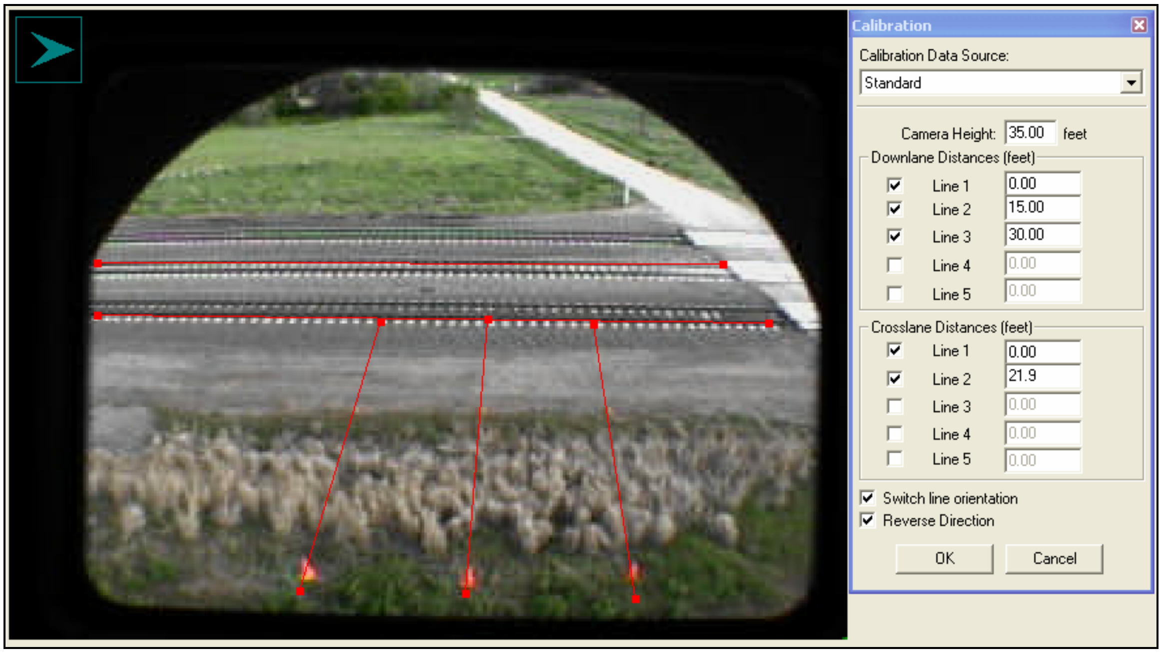
Rear Camera Calibration

Rear Camera Detector Location

Site: Overton, NE
Date: 5/24/2005
Start Time: 5:30 PM
Stop Time: 8:15 PM
Weather: Warm, Cloudy, Rain
Approx. # of Trains Daily: 135
Number of Trains Observed: 12



Location Sketch (Not to scale)



Calibration Data Source: Standard

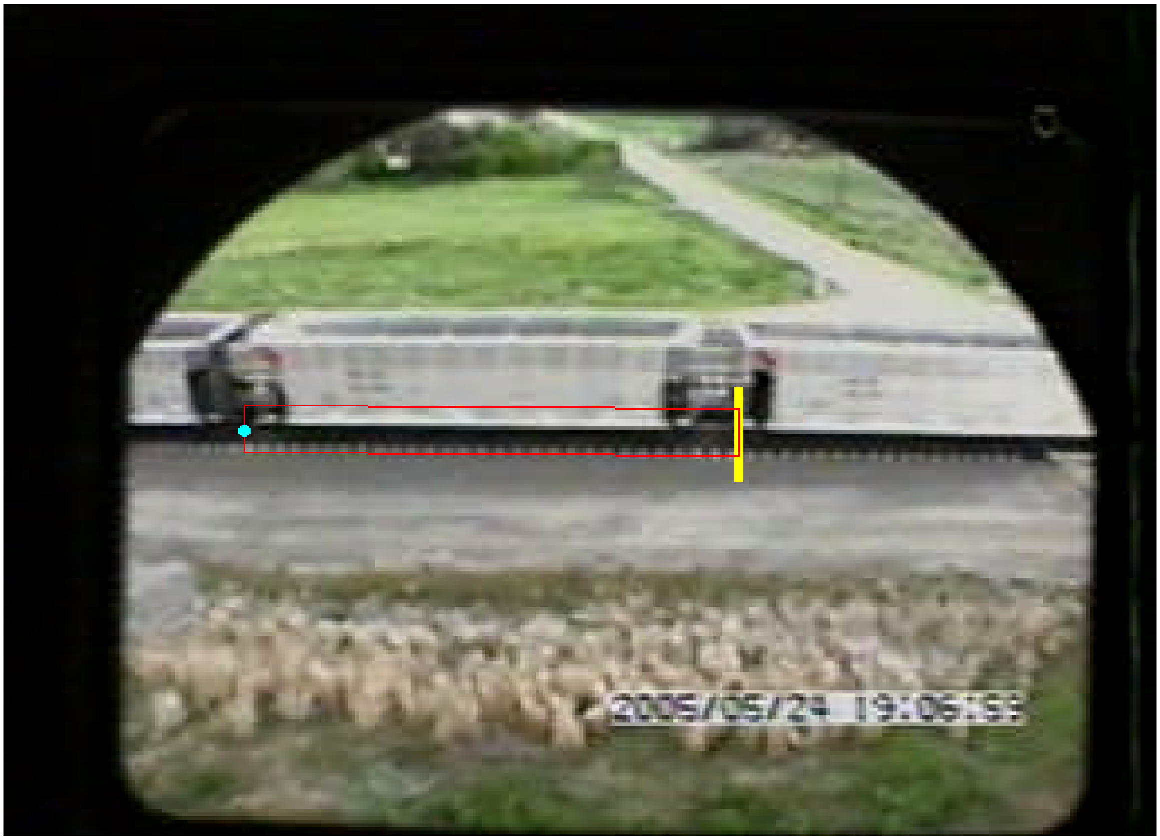
Camera Height: 35.00 feet

Downlane Distances (feet)
☑ Line 1 0.00
☑ Line 2 15.00
☑ Line 3 30.00
☐ Line 4 0.00
☐ Line 5 0.00

Crosslane Distances (feet)
☑ Line 1 0.00
☑ Line 2 21.9
☐ Line 3 0.00
☐ Line 4 0.00
☐ Line 5 0.00

☑ Switch line orientation
☑ Reverse Direction

Front Camera Calibration



Front Camera Detector Location

Overton Train Index

						Start Time of Train			End Time of Train		
Train #	Direction	Track	Train Type*	Manual Measurements	Radar Data	Rear Camera	Front Camera	Radar	Rear Camera	Front Camera	Radar Data End Time
OV1	West	Close (North)	Coal	No	None	17:49:09	N/A	N/A	17:50:37	N/A	N/A
OV2	West	Middle	Misc.	No	None	17:50:21	N/A	N/A	17:51:47	N/A	N/A
OV3	East	Far (South)	Misc.	No	None	17:50:34	N/A	N/A	17:53:40	N/A	N/A
OV4	West	Close (North)	Coal	No	2 Trains	19:06:37	19:06:44	19:06:47	19:08:11	19:08:19	19:09:04
OV5	West	Middle	Coal	No		19:07:31	19:07:39		19:08:51	19:08:59	
OV6	East	Far (South)	Coal	No	1 Train	19:14:04	19:13:50	19:13:47	19:15:43	19:15:29	19:15:27
OV7	East	Far (South)	Coal	No	1 Train	19:24:34	19:24:20	19:24:17	19:26:06	19:25:50	19:26:00
OV8	West	Close (North)	Coal	No	2 Trains	19:37:44	19:37:49	19:37:52	19:38:54	19:38:58	19:40:23
OV9	West	Middle	Coal	No		19:38:19	19:38:28		19:40:02	19:40:10	
OV10	West	Middle	Coal	Yes	1 Train	19:49:04	19:49:11	19:49:14	19:50:09	19:50:16	19:50:27
OV11	East	Far (South)	Coal	No	1 Train	19:51:33	19:51:20	19:51:17	19:53:17	19:53:02	19:53:05
OV12	West	Close (North)	Coal	Yes	1 Train	19:58:23	19:58:28	19:58:31	19:59:44	19:59:49	19:59:55

* - Misc. is defined as a train that contains various types and/or lengths of railcars
N/A – Not Available

Overton Radar Time Determination

Radar File #	Train #	Estimated Radar Time that Train Data Begins (sec)	Average Speed of Train During First Second of Detection (mph)	Time Lag * (sec)	Estimated Time Radar Detects Train	Total Record Time ¹ (sec)
1	OV4, OV5	0.06	52.4	3.1	19:06:47	137
2	OV 6	0.13	48.3	3.3	19:13:47	100
3	OV 7	0.64	50.0	3.2	19:24:17	104
4	OV 8, OV 9	17.15	60.2	2.7	19:37:52	168
5	OV 10	9.70	60.5	2.6	19:49:14	83
6	OV 11	7.55	51.6	3.1	19:51:17	116
7	OV 12	19.52	57.1	2.8	19:58:31	104

* - Time differential between beginning of train detection with radar and beginning of train at center of perpendicular camera view

¹ - Maximum 'Total Record Time' for Radar was 300 seconds, train data after this time was not able to be recorded

Train OV10: Manually Calculated Speeds

Segment	Time from Beginning of Train to Beginning Car in Segment Measurement (sec)	Measured from Beginning of Car	Measured to Beginning of Car	Measured Travel Times (sec)				Time from Beginning of Train to Average Time that Calculated Speed Occurred (sec)	Length of Railcar Segment (ft)	Calculated Estimate of Speed* (mph)
				Trial 1	Trial 2	Trial 3	Average			
1	1.6	3	8	3.0	3.0	3.0	3.0	3.1	53.1	60.3
2	4.6	8	13	3.0	3.0	3.0	3.0	6.1	53.1	60.3
3	7.6	13	18	3.0	3.0	3.0	3.0	9.1	53.1	60.3
4	10.6	18	23	3.0	3.0	3.0	3.0	12.1	53.1	60.3
5	13.6	23	28	3.0	3.0	3.0	3.0	15.1	53.1	60.3
6	16.6	28	33	3.0	3.0	3.0	3.0	18.1	53.1	60.3
7	19.6	33	38	3.0	3.0	3.0	3.0	21.1	53.1	60.3
8	22.6	38	43	3.0	3.0	3.0	3.0	24.1	53.1	60.3
9	25.6	43	48	3.0	3.0	3.0	3.0	27.1	53.1	60.3
10	28.6	48	53	3.0	3.0	3.0	3.0	30.1	53.1	60.3
11	31.6	53	58	3.0	3.0	3.0	3.0	33.1	53.1	60.3
12	34.6	58	63	3.0	3.0	3.0	3.0	36.1	53.1	60.3
13	37.6	63	68	3.0	3.0	3.0	3.0	39.1	53.1	60.3
14	40.6	68	73	3.0	3.1	3.0	3.0	42.1	53.1	59.7
15	43.6	73	78	3.0	3.1	3.1	3.1	45.2	53.1	59.0
16	46.7	78	83	3.1	3.0	3.1	3.1	48.2	53.1	59.0
17	49.8	83	88	3.0	3.1	3.1	3.1	51.3	53.1	59.0
18	52.8	88	93	3.0	3.1	3.1	3.1	54.4	53.1	59.0
19	55.9	93	98	3.1	3.1	3.0	3.1	57.4	53.1	59.0
20	59.0	98	103	3.1	3.0	3.1	3.1	60.5	53.1	59.0
21	62.0	103	108	3.0	3.1	3.0	3.0	63.6	53.1	59.7

* - Speed was calculated based on the Average Measured Travel Times and the lengths of the railcar segments (5 car segments). All railcars for this train were coal cars with standard length from coupler to coupler of "Most Likely" 53' 1" (Simmons-Boardman 1997)

Train OV10: Sensitivity Analysis of Manually Calculated Speeds

Segment	Average Measured Travel Time (sec)	Lengths of Railcar Segments (ft)			Calculated Estimate of Speed (mph)		
		Shortest	Most Likely	Longest	Shortest	Most Likely	Longest
1	3.0	243.5	265.4	285.2	55.4	60.3	64.8
2	3.0	243.5	265.4	285.2	55.4	60.3	64.8
3	3.0	243.5	265.4	285.2	55.4	60.3	64.8
4	3.0	243.5	265.4	285.2	55.4	60.3	64.8
5	3.0	243.5	265.4	285.2	55.4	60.3	64.8
6	3.0	243.5	265.4	285.2	55.4	60.3	64.8
7	3.0	243.5	265.4	285.2	55.4	60.3	64.8
8	3.0	243.5	265.4	285.2	55.4	60.3	64.8
9	3.0	243.5	265.4	285.2	55.4	60.3	64.8
10	3.0	243.5	265.4	285.2	55.4	60.3	64.8
11	3.0	243.5	265.4	285.2	55.4	60.3	64.8
12	3.0	243.5	265.4	285.2	55.4	60.3	64.8
13	3.0	243.5	265.4	285.2	55.4	60.3	64.8
14	3.0	243.5	265.4	285.2	54.7	59.7	64.1
15	3.1	243.5	265.4	285.2	54.1	59.0	63.4
16	3.1	243.5	265.4	285.2	54.1	59.0	63.4
17	3.1	243.5	265.4	285.2	54.1	59.0	63.4
18	3.1	243.5	265.4	285.2	54.1	59.0	63.4
19	3.1	243.5	265.4	285.2	54.1	59.0	63.4
20	3.1	243.5	265.4	285.2	54.1	59.0	63.4
21	3.0	243.5	265.4	285.2	54.7	59.7	64.1
Average =					54.9	59.9	64.3
Absolute Difference =					-4.9	0.0	4.5
Percent Difference =					-8.2%	0.0%	7.5%

Note: Shortest = 48’ –8 ½” / Car;
Most Likely = 53’ – 1” / Car;
Longest = 57’ – ½” / Car

Train OV12: Manually Calculated Speeds

Segment	Time from Beginning of Train to Beginning Car in Segment Measurement (sec)	Measured from Beginning of Car	Measured to Beginning of Car	Measured Travel Times (sec)				Time from Beginning of Train to Average Time that Calculated Speed Occurred (sec)	Length of Railcar Segment (ft)	Calculated Estimate of Speed* (mph)
				Trial 1	Trial 2	Trial 3	Average			
1	0.8	2	7	3.2	3.2	3.2	3.2	2.4	53.1	56.6
2	4.0	7	12	3.2	3.2	3.2	3.2	5.6	53.1	56.6
3	7.2	12	17	3.2	3.2	3.2	3.2	8.8	53.1	56.6
4	10.4	17	22	3.2	3.2	3.2	3.2	12.0	53.1	56.6
5	13.6	22	27	3.2	3.2	3.2	3.2	15.2	53.1	56.6
6	16.8	27	32	3.2	3.2	3.2	3.2	18.4	53.1	56.6
7	20.0	32	37	3.2	3.2	3.2	3.2	21.6	53.1	56.6
8	23.2	37	42	3.2	3.2	3.2	3.2	24.8	53.1	56.6
9	26.4	42	47	3.2	3.2	3.2	3.2	28.0	53.1	56.6
10	29.6	47	52	3.2	3.2	3.2	3.2	31.2	53.1	56.6
11	32.8	52	57	3.2	3.2	3.2	3.2	34.4	53.1	56.6
12	36.0	57	62	3.2	3.2	3.2	3.2	37.6	53.1	56.6
13	39.2	62	67	3.2	3.2	3.2	3.2	40.8	53.1	56.6
14	42.4	67	72	3.2	3.2	3.2	3.2	44.0	53.1	56.6
15	45.6	72	77	3.2	3.2	3.2	3.2	47.2	53.1	56.6
16	48.8	77	82	3.2	3.2	3.2	3.2	50.4	53.1	56.6
17	52.0	82	87	3.2	3.2	3.2	3.2	53.6	53.1	56.6
18	55.2	87	92	3.2	3.2	3.2	3.2	56.8	53.1	56.6
19	58.4	92	97	3.2	3.2	3.2	3.2	60.0	53.1	56.6
20	61.6	97	102	3.2	3.2	3.2	3.2	63.2	53.1	56.6
21	64.8	102	107	3.2	3.2	3.2	3.2	66.4	53.1	56.6
22	68.0	107	112	3.2	3.2	3.2	3.2	69.6	53.1	56.6
23	71.2	112	117	3.2	3.2	3.2	3.2	72.8	53.1	56.6
24	74.4	117	122	3.2	3.2	3.2	3.2	76.0	53.1	56.6

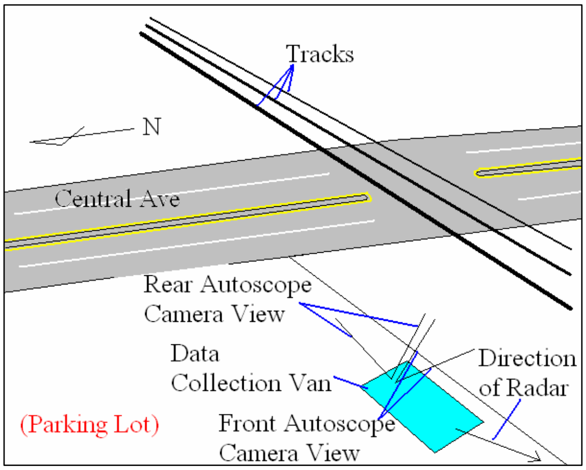
* - Speed was calculated based on the Average Measured Travel Times and the lengths of the railcar segments (5 car segments). All railcars for this train were coal cars with standard length from coupler to coupler of “Most Likely” 53’ 1” (Simmons-Boardman 1997)

Train OV12: Sensitivity Analysis of Manually Calculated Speeds

Segment	Average Measured Travel Time (sec)	Lengths of Railcar Segments (ft)			Calculated Estimate of Speed (mph)		
		Shortest	Most Likely	Longest	Shortest	Most Likely	Longest
1	3.2	243.5	265.4	285.2	51.9	56.6	60.8
2	3.2	243.5	265.4	285.2	51.9	56.6	60.8
3	3.2	243.5	265.4	285.2	51.9	56.6	60.8
4	3.2	243.5	265.4	285.2	51.9	56.6	60.8
5	3.2	243.5	265.4	285.2	51.9	56.6	60.8
6	3.2	243.5	265.4	285.2	51.9	56.6	60.8
7	3.2	243.5	265.4	285.2	51.9	56.6	60.8
8	3.2	243.5	265.4	285.2	51.9	56.6	60.8
9	3.2	243.5	265.4	285.2	51.9	56.6	60.8
10	3.2	243.5	265.4	285.2	51.9	56.6	60.8
11	3.2	243.5	265.4	285.2	51.9	56.6	60.8
12	3.2	243.5	265.4	285.2	51.9	56.6	60.8
13	3.2	243.5	265.4	285.2	51.9	56.6	60.8
14	3.2	243.5	265.4	285.2	51.9	56.6	60.8
15	3.2	243.5	265.4	285.2	51.9	56.6	60.8
16	3.2	243.5	265.4	285.2	51.9	56.6	60.8
17	3.2	243.5	265.4	285.2	51.9	56.6	60.8
18	3.2	243.5	265.4	285.2	51.9	56.6	60.8
19	3.2	243.5	265.4	285.2	51.9	56.6	60.8
20	3.2	243.5	265.4	285.2	51.9	56.6	60.8
21	3.2	243.5	265.4	285.2	51.9	56.6	60.8
22	3.2	243.5	265.4	285.2	51.9	56.6	60.8
23	3.2	243.5	265.4	285.2	51.9	56.6	60.8
24	3.2	243.5	265.4	285.2	51.9	56.6	60.8
Average =					51.9	56.6	60.8
Absolute Difference =					-4.7	0.0	4.2
Percent Difference =					-8.2%	0.0%	7.5%

Note: Shortest = 48’ –8 ½” / Car;
Most Likely = 53’ – 1” / Car;
Longest = 57’ – ½” / Car

Site: Kearney, NE
Date: 5/25/2005
Start Time: 11:45 AM
Stop Time: 10:30 PM
Weather: Warm to Cool, Sunny, Windy
Approx. # of Trains Daily: 135
Number of Trains Observed: 59



Location Sketch (Not to scale)

Calibration Data Source: Standard

Camera Height: 42.00 feet

Downlane Distances (feet)

☑ Line 1	0.00
☑ Line 2	29.30
☑ Line 3	44.00
☐ Line 4	0.00
☐ Line 5	0.00

Crosslane Distances (feet)

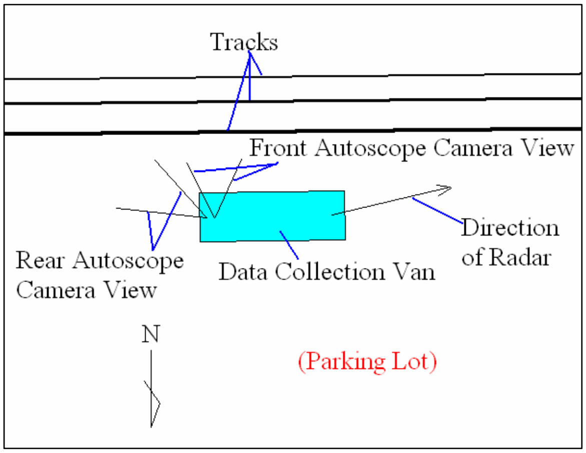
☑ Line 1	0.00
☑ Line 2	21.90
☐ Line 3	0.00
☐ Line 4	0.00
☐ Line 5	0.00

☑ Switch line orientation
☑ Reverse Direction

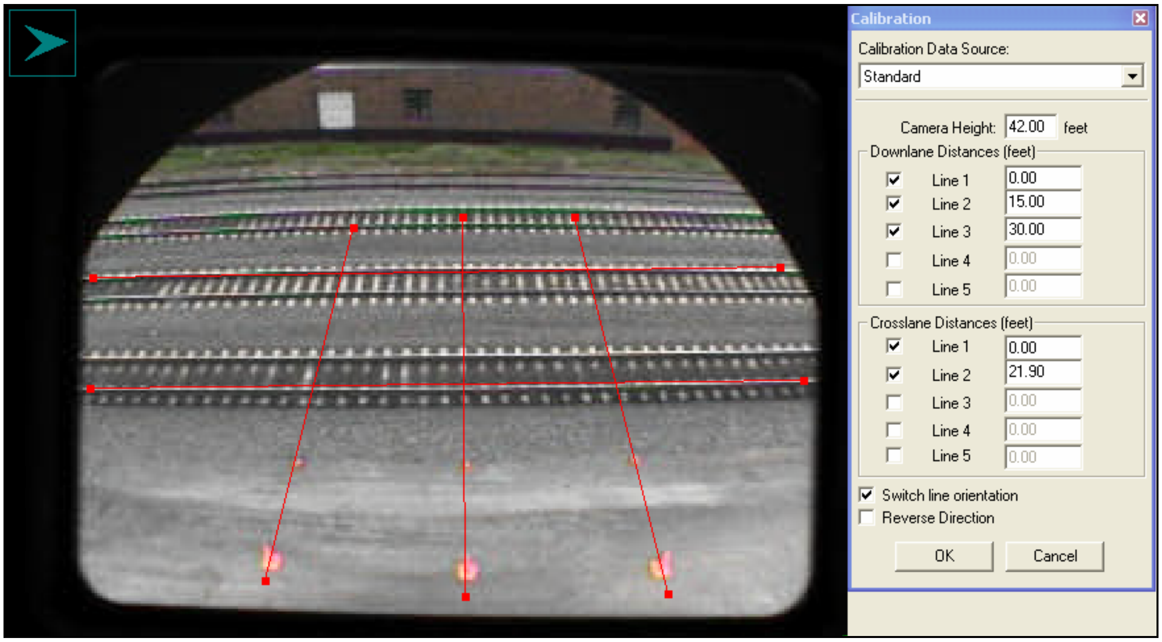
Rear Camera Calibration

Rear Camera Detector Location

Site: Kearney, NE
Date: 5/25/2005
Start Time: 11:45 AM
Stop Time: 10:30 PM
Weather: Warm to Cool, Sunny, Windy
Approx. # of Trains Daily: 135
Number of Trains Observed: 59



Location Sketch (Not to scale)



Calibration

Calibration Data Source: Standard

Camera Height: 42.00 feet

Downlane Distances (feet)
☑ Line 1 0.00
☑ Line 2 15.00
☑ Line 3 30.00
☐ Line 4 0.00
☐ Line 5 0.00

Crosslane Distances (feet)
☑ Line 1 0.00
☑ Line 2 21.90
☐ Line 3 0.00
☐ Line 4 0.00
☐ Line 5 0.00

☑ Switch line orientation
☐ Reverse Direction

Front Camera Calibration

Front Camera Detector Location

Kearney Train Index (Table 1 of 4)

						Start Time of Train			End Time of Train		
Train #	Direction	Track	Train Type*	Manual Measurements	Radar Data	Rear Camera	Front Camera	Radar†	Rear Camera	Front Camera	Radar Data End Time†
KE1	East	Close (North)	Coal	No	2 Trains	11:50:47	11:50:44	11:50:42	11:55:40	11:55:31	11:55:37
KE2	East	Middle	Misc.	No		11:51:50	11:51:47		11:52:44	11:52:40	
KE3	East	Close (North)	RR Equip	No	None	12:22:48	12:22:40	N/A	12:23:00	12:22:53	N/A
KE4	East	Middle	Misc.	No	1 Train	12:35:32	12:35:29	12:35:27	12:36:54	12:36:50	12:36:44
KE5	West	Close (North)	Coal	No	1 Train	13:13:36	13:13:37	13:13:39	13:15:02	13:15:03	13:15:11
KE6	West	Close (North)	Car Transporter	No	1 Train	13:30:28	13:30:34	Unknown	13:40:03	13:40:04	Unknown
KE7	West	Close (North)	Coal	Yes	1 Train	13:50:13	13:50:14	13:50:16	13:52:13	13:52:14	13:53:10
KE8	West	Close (North)	Coal	No	1 Train	14:02:26	14:02:29	14:02:31	14:05:03	14:05:05	14:05:18
KE9	West	Close (North)	Misc.	No	1 Train	14:14:29	14:14:31	14:14:33	14:16:36	14:16:37	14:16:48
KE10	East	Far (South)	Coal	No	1 Train	14:19:28	14:19:25	14:19:24	14:21:26	14:21:22	14:21:30
KE11	West	Close (North)	Coal	No	1 Train	14:27:28	14:27:29	14:27:31	14:29:20	14:29:21	14:29:28
KE12	West	Close (North)	Coal	No	2 Trains	14:39:25	14:39:28	14:39:29	14:41:07	14:41:09	14:44:25
KE13	East	Middle	Misc.	No		14:40:26	14:40:23		14:45:47	14:45:36	
KE14	West	Close (North)	Misc.	No	1 Train	14:53:24	14:53:27	14:53:29	14:55:03	14:55:06	14:55:16
KE15	West	Close (North)	Misc.	No	1 Train	15:09:22	15:09:25	15:09:27	15:11:59	15:12:02	15:12:20

* - Misc. is defined as a train that contains various types and/or lengths of railcars
N/A – Not Available
† - "Unknown" was unable to be determined with the available data from radar file

Kearney Train Index (Table 2 of 4)

						Start Time of Train			End Time of Train		
Train #	Direction	Track	Train Type*	Manual Measurements	Radar Data	Rear Camera	Front Camera	Radar†	Rear Camera	Front Camera	Radar Data End Time†
KE16	East	Far (South)	Misc.	No	1 Train	15:26:32	15:26:29	15:26:27	15:28:31	15:28:28	15:28:36
KE17	East	Middle	Coal	No	1 Train	15:40:04	15:39:53	15:39:46	15:46:46	15:46:37	15:44:37
KE18[1]	West	Close (North)	Car Transporter	No	1 Train	16:20:33	16:38:56	Unknown	16:46:59	16:47:03	Unknown
KE19	West	Close (North)	Misc.	No	2 Trains	16:57:04	16:57:48	16:57:50	16:59:34	16:59:37	17:02:43
KE20	East	Far (South)	Coal	No		17:00:11	16:59:59		17:04:04	17:03:59	
KE21	West	Close (North)	Coal	No	1 Train	17:09:22	Error	17:09:27	17:11:02	17:11:05	17:11:08
KE22	East	Far (South)	Coal	No	1 Train	17:13:25	17:13:21	17:13:19	17:15:55	17:15:51	17:15:33
KE23	East	Middle	Car Transporter	Yes	1 Train	17:18:49	17:18:36	17:18:33	17:20:52	17:20:48	17:20:55
KE24	West	Close (North)	Coal	No	1 Train	17:21:03	17:21:05	17:21:06	17:22:29	17:22:31	17:22:13
KE25	East	Far (South)	Misc.	No	1 Train	17:26:06	17:26:03	17:26:01	17:28:59	17:28:59	17:28:56
KE26	East	Middle	Car Transporter	No	2 Trains	17:31:11	17:31:05	17:31:01	17:34:16	17:34:11	17:35:01
KE27	West	Close (North)	Misc.	No		17:33:06	17:33:09		17:34:53	17:34:55	
KE28	East	Middle	Coal	No	1 Train	17:48:09	17:48:07	17:48:05	17:50:17	17:50:13	17:50:19
KE29	East	Middle	Coal	No	1 Train	18:05:09	18:05:04	18:05:00	18:09:40	18:09:31	18:09:51
KE30	West	Close (North)	Misc.	Yes	1 Train	18:20:56	18:20:59	18:21:02	18:23:16	18:23:18	18:23:29

* - Misc. is defined as a train that contains various types and/or lengths of railcars

[1] - Train 18 enters view of rear camera at 16:20:33, stops short of center of screen at 16:21:05, began moving backwards at 16:23:33, entered screen again and was at the center of the view of the rear camera at 16:38:33. Train stopped at 16:42:32, started moving forward at 16:43:22, and was at the center of the view of the rear and front camera at the times listed

† - "Unknown" was unable to be determined with available data from radar file

Error – Video unavailable during beginning of train

Kearney Train Index (Table 3 of 4)

Train #	Direction	Track	Train Type*	Manual Measurements	Radar Data	Start Time of Train			End Time of Train		Radar Data End Time
						Rear Camera	Front Camera	Radar	Rear Camera	Front Camera	
KE31	West	Close (North)	Misc.	No	1 Train	18:31:06	18:31:09	18:31:11	18:31:50	18:31:53	18:32:03
KE32	West	Close (North)	Misc.	No	1 Train	18:41:47	18:41:50	18:41:52	18:43:14	18:43:16	18:43:26
KE33	West	Close (North)	Coal	No	1 Train	18:57:49	18:57:51	18:57:53	18:59:34	18:59:36	18:59:58
KE34	West	Close (North)	Misc.	No	1 Train	19:08:49	19:08:51	19:08:52	19:09:50	19:09:51	19:10:02
KE35	East	Far (South)	Coal	No	1 Train	19:14:05	19:13:59	19:13:56	19:16:47	19:16:43	19:16:35
KE36	West	Close (North)	Coal	Yes	1 Train	19:18:53	19:18:55	19:18:56	19:20:17	19:20:19	19:20:28
KE37	East	Far (South)	Coal	No	1 Train	19:24:32	19:24:29	19:24:27	19:26:24	19:26:21	19:26:33
KE38	West	Close (North)	Coal	No	2 Trains	19:39:39	19:39:42	19:39:44	19:41:32	19:41:34	19:41:58
KE39	East	Far (South)	Car Transporter	No		19:39:45	19:39:42		19:40:36	19:40:32	
KE40	East	Far (South)	Misc.	No	1 Train	19:50:09	19:50:05	19:50:02	19:52:28	19:52:24	19:52:23
KE41	East	Far (South)	Coal	No	1 Train	20:05:24	20:05:19	20:05:17	20:07:39	20:07:35	20:07:36
KE42[1]	West	Close (North)	Misc.	No	1 Train	20:08:49	20:08:56	Data Start Time = 20:10:35	20:14:42	20:14:44	20:14:43
KE43	East	Far (South)	Misc.	No	1 Train	20:15:36	20:15:31	Data Start Time = 20:15:59	20:17:32	20:17:28	20:17:26

* - Misc. is defined as a train that contains various types and/or lengths of railcars

[1] - Train 42 stops at 20:09:36, started moving forward again at 20:11:13, and was at the center of the view of the rear and front camera at the times listed

[2] - Train 44 stops at 20:24:45, started moving forward again at 20:26:10, and was at the center of the view of the rear and front camera at the times listed

Kearney Train Index (Table 4 of 4)

						Start Time of Train			End Time of Train		
Train #	Direction	Track	Train Type*	Manual Measurements	Radar Data	Rear Camera	Front Camera	Radar	Rear Camera	Front Camera	Radar Data End Time
KE44[2]	West	Close (North)	Coal	No	2 Trains	20:23:44	20:23:55	Data Start Time = 20:24:50	20:30:05	20:30:07	20:30:50
KE45	East	Middle	Misc.	No		20:25:13	20:25:10		20:26:30	20:26:26	
KE46	West	Middle	Misc.	No	1 Train	20:32:35	20:32:38	20:32:40	20:34:19	20:34:21	20:34:32
KE47	East	Far (South)	Coal	No	1 Train	20:41:08	20:41:04	20:41:02	20:42:43	20:42:40	20:42:36
KE48	East	Far (South)	Coal	No	1 Train	20:52:07	20:52:03	20:52:01	20:54:38	20:54:34	20:54:32
KE49	East	Far (South)	Coal	No	1 Train	21:05:10	21:05:05	21:05:02	21:09:37	21:09:25	21:09:31
KE50	West	Middle	Coal	No	1 Train	21:13:35	21:13:37	21:13:38	21:14:50	21:14:53	21:15:02
KE51	West	Middle	Car Transporter	No	2 Trains	21:24:24	21:24:26	21:24:28	21:26:16	21:26:18	21:28:17
KE52	East	Far (South)	Car Transporter	No		21:26:13	21:26:09		21:28:24	21:28:20	
KE53	East	Far (South)	Misc.	No	1 Train	21:43:59	21:43:58	21:43:56	21:44:58	21:44:56	21:44:58
KE54	West	Middle	Coal	No	1 Train	21:48:43	21:48:46	21:48:48	21:50:24	21:50:27	21:50:35
KE55	West	Middle	Coal	No	1 Train	22:00:12	22:00:15	22:00:17	22:02:19	22:02:21	22:02:26
KE56	East	Far (South)	Misc.	No	1 Train	22:07:24	22:07:21	22:07:19	22:08:34	22:08:31	22:08:31
KE57	West	Middle	Coal	No	1 Train	22:13:20	22:13:23	22:13:25	22:14:55	22:14:58	22:15:04
KE58	East	Far (South)	Misc.	No	1 Train	22:18:50	22:18:47	22:18:45	22:20:07	22:20:04	22:19:57
KE59	West	Middle	Coal	No	1 Train	22:23:48	22:23:51	22:23:53	22:25:53	22:25:55	22:26:17

* - Misc. is defined as a train that contains various types and/or lengths of railcars

Kearney Radar Time Determination (Table 1 of 3)

Radar File #	Train #	Estimated Radar Time that Train Data Begins (sec)	Average Speed of Train During First Second of Detection (mph)	Time Lag * (sec)	Estimated Time Radar Detects Train	Total Record Time [1] (sec)
1	KE1, KE2	0.19	31.9	2.1	11:50:42	295
2	KE4	0.03	43.2	1.5	12:35:27	77
3	KE5	8.83	42.0	1.6	13:13:39	101
4	KE6	Unknown [†]	Unknown [†]	Unknown [†]	Unknown [†]	261
5	KE7	9.79	40.7	1.6	13:50:16	184
6	KE8	6.69	29.8	2.2	14:02:31	174
7	KE9	8.86	40.3	1.7	14:14:33	144
8	KE10	0.19	48.8	1.4	14:19:24	126
9	KE11	0.70	43.1	1.6	14:27:31	118
10	KE12, KE13	0.19	50.2	1.3	14:39:29	296
11	KE14	5.15	44.6	1.5	14:53:29	112
12	KE15	0.67	37.0	1.8	15:09:27	174
13	KE16	0.19	37.5	1.8	15:26:27	129
14	KE17	4.06	9.7	6.9	15:39:46	295
15	KE18	Unknown [†]	Unknown [†]	Unknown [†]	Unknown [†]	300
16	KE19, KE20	0.03	28.7	2.3	16:57:50	293
17	KE21	0.03	43.5	1.5	17:09:27	101
18	KE22	0.19	32.1	2.1	17:13:19	134
19	KE23	0.06	25.3	2.6	17:18:33	142
20	KE24	0.03	49.4	1.4	17:21:06	67

* - Time differential between beginning of train detection with radar and beginning of train at center of perpendicular camera view

[1] - Maximum ‘Total Record Time’ for Radar was 300 seconds, train data after this time was not able to be recorded

[†] - Unable to be determined or calculated with available data from radar file

Kearney Radar Time Determination (Table 2 of 3)

Radar File #	Train #	Estimated Radar Time that Train Data Begins (sec)	Average Speed of Train During First Second of Detection (mph)	Time Lag * (sec)	Estimated Time Radar Detects Train	Total Record Time [1] (sec)
21	KE25	27.17	30.9	2.2	17:26:01	202
22	KE26, KE27	0.03	17.4	3.8	17:31:01	240
23	KE28	0.03	34.2	2.0	17:48:05	134
24	KE29	0.03	15.2	4.4	18:05:00	291
25	KE30	0.00	22.1	3.0	18:21:02	147
26	KE31	1.22	35.3	1.9	18:31:11	53
27	KE32	1.28	42.2	1.6	18:41:52	95
28	KE33	11.01	44.9	1.5	18:57:53	136
29	KE34	0.70	61.4	1.1	19:08:52	70
30	KE35	0.03	25.4	2.6	19:13:56	159
31	KE36	0.00	49.1	1.4	19:18:56	92
32	KE37	8.99	33.9	2.0	19:24:27	135
33	KE38, KE39	1.31	39.7	1.7	19:39:44	135
34	KE40	Unknown [†]	Unknown [†]	Unknown [†]	19:50:02	158
35	KE41	10.59	27.5	2.4	20:05:17	150
36	KE42	Unknown [†]	Unknown [†]	Unknown [†]	Data Start Time = 20:10:35	248
37	KE43	Unknown [†]	Unknown [†]	Unknown [†]	Data Start Time = 20:15:59	87

* - Time differential between beginning of train detection with radar and beginning of train at center of perpendicular camera view

[1] - Maximum 'Total Record Time' for Radar was 300 seconds, train data after this time was not able to be recorded

† - Unable to be determined or calculated with available data from radar file

Kearney Radar Time Determination (Table 3 of 3)

Radar File #	Train #	Estimated Radar Time that Train Data Begins (sec)	Average Speed of Train During First Second of Detection (mph)	Time Lag * (sec)	Estimated Time Radar Detects Train	Total Record Time[1] (sec)
38	KE44, KE45	Unknown[†]	Unknown[†]	Unknown[†]	Data Start Time = 20:24:50	300
39	KE46	6.78	43.2	1.5	20:32:40	119
40	KE47	0.03	37.6	1.8	20:41:02	94
41	KE48	0.03	31.2	2.1	20:52:01	151
42	KE49	0.06	25.2	2.7	21:05:02	269
43	KE50	0.54	46.7	1.4	21:13:38	85
44	KE51, KE52	0.80	44.2	1.5	21:24:28	230
45	KE53	13.12	44.8	1.5	21:43:56	75
46	KE54	6.05	44.7	1.5	21:48:48	113
47	KE55	15.07	34.6	1.9	22:00:17	144
48	KE56	11.71	38.0	1.8	22:07:19	84
49	KE57	0.10	43.8	1.5	22:13:25	99
50	KE58	19.84	41.8	1.6	22:18:45	92
51	KE59	8.96	40.0	1.7	22:23:53	153

* - Time differential between beginning of train detection with radar and beginning of train at center of perpendicular camera view

[1] - Maximum ‘Total Record Time’ for Radar was 300 seconds, train data after this time was not able to be recorded

† - Unable to be determined or calculated with available data from radar file

Train KE7: Manually Calculated Speeds

Segment	Time from Beginning of Train to Beginning Car in Segment Measurement (sec)	Measured from Beginning of Car	Measured to Beginning of Car	Measured Travel Times (sec)				Time from Beginning of Train to Average Time that Calculated Speed Occurred (sec)	Length of Railcar Segment (ft)	Calculated Estimate of Speed* (mph)
				Trial 1	Trial 2	Trial 3	Average			
1	2.6	3	8	4.4	4.5	4.5	4.5	4.8	265.4	40.5
2	7.1	8	13	4.5	4.5	4.5	4.5	9.3	265.4	40.2
3	11.6	13	18	4.4	4.5	4.4	4.4	13.8	265.4	40.8
4	16.0	18	23	4.5	4.5	4.4	4.5	18.2	265.4	40.5
5	20.5	23	28	4.4	4.3	4.4	4.4	22.7	265.4	41.4
6	24.8	28	33	4.4	4.4	4.4	4.4	27.0	265.4	41.1
7	29.2	33	38	4.4	4.4	4.3	4.4	31.4	265.4	41.4
8	33.6	38	43	4.4	4.4	4.4	4.4	35.8	265.4	41.1
9	38.0	43	48	4.4	4.4	4.4	4.4	40.2	265.4	41.1
10	42.4	48	53	4.4	4.4	4.4	4.4	44.6	265.4	41.1
11	46.8	53	58	4.4	4.4	4.4	4.4	49.0	265.4	41.1
12	51.2	58	63	4.4	4.3	4.4	4.4	53.4	265.4	41.4
13	55.6	63	68	4.3	4.3	4.3	4.3	57.7	265.4	42.1
14	59.9	68	73	4.3	4.2	4.3	4.3	62.0	265.4	42.4
15	64.1	73	78	4.3	4.4	4.3	4.3	66.3	265.4	41.8
16	68.5	78	83	4.3	4.3	4.3	4.3	70.6	265.4	42.1
17	72.8	83	88	4.2	4.3	4.3	4.3	74.9	265.4	42.4
18	77.0	88	93	4.3	4.3	4.3	4.3	79.2	265.4	42.1
19	81.3	93	98	4.3	4.3	4.3	4.3	83.5	265.4	42.1
20	85.6	98	103	4.2	4.3	4.3	4.3	87.8	265.4	42.4
21	89.9	103	108	4.2	4.2	4.2	4.2	92.0	265.4	43.1
22	94.1	108	113	4.2	4.2	4.3	4.2	96.2	265.4	42.7
23	98.3	113	118	4.2	4.2	4.2	4.2	100.4	265.4	43.1
24	102.5	118	123	4.2	4.2	4.2	4.2	104.6	265.4	43.1
25	106.7	123	128	4.1	4.2	4.2	4.2	108.8	265.4	43.4
26	110.9	128	133	4.2	4.2	4.2	4.2	113.0	265.4	43.1

* - Speed was calculated based on the Average Measured Travel Times and the lengths of the railcar segments (5 car segments). All railcars for this train were coal cars with standard length from coupler to coupler of "Most Likely" 53' 1" (Simmons-Boardman 1997)

Train KE7: Sensitivity Analysis of Manually Calculated Speeds

Segment	Average Measured Travel Time (sec)	Lengths of Railcar Segments (ft)			Calculated Estimate of Speed (mph)		
		Shortest	Most Likely	Longest	Shortest	Most Likely	Longest
1	4.5	243.5	265.4	285.2	37.2	40.5	43.5
2	4.5	243.5	265.4	285.2	36.9	40.2	43.2
3	4.4	243.5	265.4	285.2	37.5	40.8	43.9
4	4.5	243.5	265.4	285.2	37.2	40.5	43.5
5	4.4	243.5	265.4	285.2	38.0	41.4	44.5
6	4.4	243.5	265.4	285.2	37.7	41.1	44.2
7	4.4	243.5	265.4	285.2	38.0	41.4	44.5
8	4.4	243.5	265.4	285.2	37.7	41.1	44.2
9	4.4	243.5	265.4	285.2	37.7	41.1	44.2
10	4.4	243.5	265.4	285.2	37.7	41.1	44.2
11	4.4	243.5	265.4	285.2	37.7	41.1	44.2
12	4.4	243.5	265.4	285.2	38.0	41.4	44.5
13	4.3	243.5	265.4	285.2	38.6	42.1	45.2
14	4.3	243.5	265.4	285.2	38.9	42.4	45.6
15	4.3	243.5	265.4	285.2	38.3	41.8	44.9
16	4.3	243.5	265.4	285.2	38.6	42.1	45.2
17	4.3	243.5	265.4	285.2	38.9	42.4	45.6
18	4.3	243.5	265.4	285.2	38.6	42.1	45.2
19	4.3	243.5	265.4	285.2	38.6	42.1	45.2
20	4.3	243.5	265.4	285.2	38.9	42.4	45.6
21	4.2	243.5	265.4	285.2	39.5	43.1	46.3
22	4.2	243.5	265.4	285.2	39.2	42.7	45.9
23	4.2	243.5	265.4	285.2	39.5	43.1	46.3
24	4.2	243.5	265.4	285.2	39.5	43.1	46.3
25	4.2	243.5	265.4	285.2	39.9	43.4	46.7
26	4.2	243.5	265.4	285.2	39.2	42.7	45.9
Average =					38.4	41.8	44.9
Absolute Difference =					-3.4	0.0	3.1
Percent Difference =					-8.2%	0.0%	7.5%

Note: Shortest = 48’ –8 ½” / Car;
Most Likely = 53’ – 1” / Car;
Longest = 57’ – ½” / Car

Train KE23: Manually Calculated Speeds

Segment	Time from Beginning of Train to Beginning Car in Segment Measurement (sec)	Measured from Beginning of Car	Measured to Beginning of Car	Measured Travel Times (sec)				Time from Beginning of Train to Average Time that Calculated Speed Occurred (sec)	Length of Railcar Segment (ft)	Calculated Estimate of Speed* (mph)
				Trial 1	Trial 2	Trial 3	Average			
1	3.7	3	8	11.7	11.7	11.7	11.7	9.6	463.1	26.9
2	15.4	8	13	11.7	11.7	11.7	11.7	21.3	463.1	27.1
3	27.1	13	18	11.6	11.6	11.6	11.6	32.9	463.1	27.3
4	38.7	18	23	11.8	11.7	11.8	11.7	44.6	463.1	26.9
5	50.4	23	28	11.8	11.7	11.8	11.8	56.3	463.1	26.8
6	62.2	28	33	11.8	11.8	11.8	11.8	68.1	463.1	26.7
7	74.0	33	38	12.1	12.1	12.1	12.1	80.1	463.1	26.2
8	86.1	38	43	12.2	12.3	12.3	12.2	92.2	463.1	25.8
9	98.3	43	48	12.7	12.7	12.7	12.7	104.7	463.1	24.8
10	111.1	48	53	13.0	13.0	13.0	13.0	117.5	463.1	24.3

* - Speed was calculated based on the Average Measured Travel Times and the lengths of the railcar segments (5 car segments). All railcars for this train were automotive vehicle transporter railcars with standard length from coupler to coupler of "Most Likely" 92' 7.5" (Simmons-Boardman 1997)

Train KE23: Sensitivity Analysis of Manually Calculated Speeds

Segment	Average Measured Travel Time (sec)	Lengths of Railcar Segments (ft)			Calculated Estimate of Speed (mph)		
		Shortest	Most Likely	Longest	Shortest	Most Likely	Longest
1	11.7	463.1	463.1	473.3	26.9	26.9	27.5
2	11.7	463.1	463.1	473.3	27.1	27.1	27.7
3	11.6	463.1	463.1	473.3	27.3	27.3	27.9
4	11.7	463.1	463.1	473.3	26.9	26.9	27.5
5	11.8	463.1	463.1	473.3	26.8	26.8	27.4
6	11.8	463.1	463.1	473.3	26.7	26.7	27.3
7	12.1	463.1	463.1	473.3	26.2	26.2	26.7
8	12.2	463.1	463.1	473.3	25.8	25.8	26.4
9	12.7	463.1	463.1	473.3	24.8	24.8	25.4
10	13.0	463.1	463.1	473.3	24.3	24.3	24.9
Average =					26.3	26.3	26.9
Absolute Difference =					0.0	0.0	0.6
Percent Difference =					0.0%	0.0%	2.2%

Note: Shortest = 92’ – 7 ½” / Car;
Most Likely = 92’ – 7 ½” / Car;
Longest = 94’ – 8” / Car

Train KE30: Manually Calculated Speeds

Segment	Time from Beginning of Train to Beginning Car in Segment Measurement (sec)	Measured from Beginning of Car	Measured to Beginning of Car	Measured Travel Times (sec)				Time from Beginning of Train to Average Time that Calculated Speed Occurred (sec)	Length of Railcar Segment (ft)	Calculated Estimate of Speed* (mph)
				Trial 1	Trial 2	Trial 3	Average			
1	4.4	3	8	7.6	7.7	7.6	7.6	8.2	276.0	24.7
2	12.0	8	13	7.2	7.2	7.2	7.2	15.6	276.0	26.1
3	19.2	13	16	5.1	5.1	5.2	5.1	21.8	206.0	27.4
4	24.4	16	21	6.5	6.6	6.5	6.5	27.6	276.0	28.8
5	30.9	21	26	7.0	7.0	7.0	7.0	34.4	307.2	29.9
6	37.9	26	31	6.6	6.7	6.7	6.7	41.2	307.2	31.4
7	44.6	31	36	5.7	5.7	5.7	5.7	47.4	276.0	33.0
8	50.3	36	39	4.2	4.2	4.2	4.2	52.4	206.0	33.4
9	54.5	39	44	5.2	5.3	5.3	5.3	57.1	265.1	34.3
10	59.7	44	49	5.9	5.8	5.9	5.9	62.7	307.2	35.7
11	65.6	49	54	5.8	5.8	5.7	5.8	68.5	307.2	36.3
12	71.4	54	57	4.3	4.2	4.2	4.2	73.5	214.0	34.5
13	75.6	57	62	4.8	4.8	4.8	4.8	78.0	265.1	37.7
14	80.4	62	66	5.0	5.0	5.0	5.0	82.9	277.3	37.8
15	85.4	66	71	5.3	5.3	5.3	5.3	88.1	307.2	39.5
16	90.7	71	76	5.0	5.0	5.0	5.0	93.2	307.2	41.9
17	95.7	76	81	4.5	4.5	4.6	4.5	98.0	276.0	41.5
18	100.2	81	86	5.9	5.9	5.9	5.9	103.2	348.7	40.3
19	106.1	86	90	4.7	4.6	4.7	4.7	108.5	285.3	41.7
20	110.8	90	95	4.9	4.9	4.9	4.9	113.3	307.2	42.7
21	115.7	95	100	4.9	4.8	4.9	4.9	118.1	307.2	43.0
22	120.6	100	103	3.2	3.2	3.2	3.2	122.2	206.0	43.9
23	123.8	103	108	4.7	4.7	4.8	4.7	126.1	307.2	44.2
24	128.5	108	113	5.4	5.5	5.5	5.5	131.2	348.7	43.5
25	134.0	113	116	3.5	3.6	3.5	3.5	135.7	214.0	41.3

* - Speed was calculated based on the Average Measured Travel Times and the lengths of the railcar segments (number of cars in segments varied). Railcars for this train were comprised of articulated and unarticulated well cars whose lengths varied (Simmons-Boardman 1997).

Train KE30: Car Types and Lengths for Sensitivity Analysis (Table 1 of 3)

Segment	Car Type and Length		
	Shortest	Most Likely	Longest
1	*“5 – Unit Articulated Well Cars”* (Scaled Length = 238.4’)	*“5 – Unit Articulated Well Cars”* (Scaled Length = 276’)	Thrall Five-Unit 125-Ton Articulated Well Car Length = 307’ – 3 ½”
2	*“5 – Unit Articulated Well Cars”* (Scaled Length = 238.4’)	*“5 – Unit Articulated Well Cars”* (Scaled Length = 276’)	Thrall Five-Unit 125-Ton Articulated Well Car Length = 307’ – 3 ½”
3	Gunderson Maxi-Stack Length = 189’ – 4 1/8”	*“3 – Unit Articulated Well Cars”* (Scaled Length = 206’)	Thrall Three-Unit Well Car Length = 216’ – 4 3/8”
4	*“5 – Unit Articulated Well Cars”* (Scaled Length = 238.4’)	*“5 – Unit Articulated Well Cars”* (Scaled Length = 276’)	Thrall Five-Unit 125-Ton Articulated Well Car Length = 307’ – 3 ½”
5	Gunderson DTTX Maxi-Stack Length = 265’ – 3 ½”	Trinity DTTX Five-Unit Articulated Well Cars Length = 307’ – 2 1/8”	*“5 – Unit Articulated Well Cars”* (Scaled Length = 342’)
6	Gunderson DTTX Maxi-Stack Length = 265’ – 3 ½”	Trinity DTTX Five-Unit Articulated Well Cars Length = 307’ – 2 1/8”	*“5 – Unit Articulated Well Cars”* (Scaled Length = 342’)
7	*“5 – Unit Articulated Well Cars”* (Scaled Length = 238.4’)	*“5 – Unit Articulated Well Cars”* (Scaled Length = 276’)	Thrall Five-Unit 125-Ton Articulated Well Car Length = 307’ – 3 ½”
8	Gunderson Maxi-Stack Length = 189’ – 4 1/8”	*“3 – Unit Articulated Well Cars”* (Scaled Length = 206’)	Thrall Three-Unit Well Car Length = 216’ – 4 3/8”
9	Gunderson DTTX Twin-Stack Length = 265’ – 1 ½”	Gunderson DTTX Twin-Stack Length = 265’ – 1 ½”	Gunderson DTTX Twin-Stack Length = 265’ – 1 ½”

Note: Cars chosen for “Shortest”, “Most Likely”, and “Longest” were chosen under the researcher’s best assumptions from the 1997 Edition of the Car and Locomotive Cyclopedia (Simmons-Boardman 1997). Unknown articulated well cars were scaled off of other assumed to be known articulated well cars.

Train KE30: Car Types and Lengths for Sensitivity Analysis (Table 2 of 3)

Segment	Car Type and Length		
	Shortest	Most Likely	Longest
10	Gunderson DTTX Maxi-Stack Length = 265’ – 3 ½”	Trinity DTTX Five-Unit Articulated Well Cars Length = 307’ – 2 1/8”	*“5 – Unit Articulated Well Cars”* (Scaled Length = 342’)
11	Gunderson DTTX Maxi-Stack Length = 265’ – 3 ½”	Trinity DTTX Five-Unit Articulated Well Cars Length = 307’ – 2 1/8”	*“5 – Unit Articulated Well Cars”* (Scaled Length = 342’)
12	(3) COFC double-stack well car Length = 212’ – 3”	(3) 110-Ton COFC Double-Stack Well Cars Length = 214’	(3) Gunderson Husky-Stack Well Cars Length = 214’ – 9 ¾”
13	Gunderson DTTX Twin-Stack Length = 265’ – 1 ½”	Gunderson DTTX Twin-Stack Length = 265’ – 1 ½”	Gunderson DTTX Twin-Stack Length = 265’ – 1 ½”
14	(1) COFC double-stack well car Length = 70’ – 9”	(1) Gunderson Husky-Stack Well Car Length = 71’ – 4”	(1) Gunderson Husky-Stack 2 + 2 Well Car Length = 79’ – 10 ¾”
	Gunderson Maxi-Stack Length = 189’ – 4 1/8”	*“3 – Unit Articulated Well Cars”* (Scaled Length = 206’)	Thrall Three-Unit Well Car Length = 216’ – 4 3/8”
15	Gunderson DTTX Maxi-Stack Length = 265’ – 3 ½”	Trinity DTTX Five-Unit Articulated Well Cars Length = 307’ – 2 1/8”	*“5 – Unit Articulated Well Cars”* (Scaled Length = 342’)
16	Gunderson DTTX Maxi-Stack Length = 265’ – 3 ½”	Trinity DTTX Five-Unit Articulated Well Cars Length = 307’ – 2 1/8”	*“5 – Unit Articulated Well Cars”* (Scaled Length = 342’)
17	*“5 – Unit Articulated Well Cars”* (Scaled Length = 238.4’)	*“5 – Unit Articulated Well Cars”* (Scaled Length = 276’)	Thrall Five-Unit 125-Ton Articulated Well Car Length = 307’ – 3 ½”

Note: Cars chosen for “Shortest”, “Most Likely”, and “Longest” were chosen under the researcher’s best assumptions from the 1997 Edition of the Car and Locomotive Cyclopedia (Simmons-Boardman 1997). Unknown articulated well cars were scaled off of other assumed to be known articulated well cars.

Train KE30: Car Types and Lengths for Sensitivity Analysis (Table 3 of 3)

Segment	Car Type and Length		
	Shortest	Most Likely	Longest
18	(2) COFC double-stack well car Length = 141' - 6"	(2) 110-Ton COFC Double-Stack Well Cars Length = 142' – 8"	(2) Gunderson Husky-Stack Well Cars Length = 143' – 2 ½"
	Gunderson Maxi-Stack Length = 189' – 4 1/8"	*"3 – Unit Articulated Well Cars"* (Scaled Length = 206')	Thrall Three-Unit Well Car Length = 216' – 4 3/8"
19	(4) COFC double-stack well car Length = 283'	(4) Gunderson Husky-Stack Well Cars Length = 285' – 4"	(4) Gunderson Husky-Stack 2 + 2 Well Cars Length = 319' – 7"
20	Gunderson DTTX Maxi-Stack Length = 265' – 3 ½"	Trinity DTTX Five-Unit Articulated Well Cars Length = 307' – 2 1/8"	*"5 – Unit Articulated Well Cars"* (Scaled Length = 342')
21	Gunderson DTTX Maxi-Stack Length = 265' – 3 ½"	Trinity DTTX Five-Unit Articulated Well Cars Length = 307' – 2 1/8"	*"5 – Unit Articulated Well Cars"* (Scaled Length = 342')
22	Gunderson Maxi-Stack Length = 189' – 4 1/8"	*"3 – Unit Articulated Well Cars"* (Scaled Length = 206')	Thrall Three-Unit Well Car Length = 216' – 4 3/8"
23	Gunderson DTTX Maxi-Stack Length = 265' – 3 ½"	Trinity DTTX Five-Unit Articulated Well Cars Length = 307' – 2 1/8"	*"5 – Unit Articulated Well Cars"* (Scaled Length = 342')
24	(1) COFC double-stack well car Length = 70' – 9"	(1) 110-Ton COFC Double-Stack Well Car Length = 71' – 4"	(1) Gunderson Husky-Stack Well Cars Length = 71' – 7 ¼"
	(1) COFC double-stack well car Length = 70' – 9"	(1) Gunderson Husky-Stack Well Car Length = 71' – 4"	(1) Gunderson Husky-Stack 2 + 2 Well Car Length = 79' – 10 ¾"
	Gunderson Maxi-Stack Length = 189' – 4 1/8"	*"3 – Unit Articulated Well Cars"* (Scaled Length = 206')	Thrall Three-Unit Well Car Length = 216' – 4 3/8"
25	(3) COFC double-stack well car Length = 212' – 3"	(3) 110-Ton COFC Double-Stack Well Cars Length = 214'	(3) Gunderson Husky-Stack Well Cars Length = 214' – 9 ¾"

Note: Cars chosen for "Shortest", "Most Likely", and "Longest" were chosen under the researcher's best assumptions from the 1997 Edition of the Car and Locomotive Cyclopedia (Simmons-Boardman 1997). Unknown articulated well cars were scaled off of other assumed to be known articulated well cars.

Train KE30: Sensitivity Analysis of Manually Calculated Speeds

Segment	Average Measured Travel Time (sec)	Lengths of Railcar Segments (ft)			Calculated Estimate of Speed (mph)		
		Shortest	Most Likely	Longest	Shortest	Most Likely	Longest
1	7.6	238.4	276.0	307.3	21.3	21.3	21.3
2	7.2	238.4	276.0	307.3	22.6	22.6	22.6
3	5.1	189.3	206.0	216.4	25.1	25.1	25.1
4	6.5	238.4	276.0	307.3	24.9	24.9	24.9
5	7.0	265.3	307.2	342.0	25.8	25.8	25.8
6	6.7	265.3	307.2	342.0	27.1	27.1	27.1
7	5.7	238.4	276.0	307.3	28.5	28.5	28.5
8	4.2	189.3	206.0	216.4	30.7	30.7	30.7
9	5.3	265.1	265.1	265.1	34.3	34.3	34.3
10	5.9	265.3	307.2	342.0	30.8	30.8	30.8
11	5.8	265.3	307.2	342.0	31.4	31.4	31.4
12	4.2	212.3	214.0	214.8	34.2	34.2	34.2
13	4.8	265.1	265.1	265.1	37.7	37.7	37.7
14	5.0	260.1	277.3	296.3	35.5	35.5	35.5
15	5.3	265.3	307.2	342.0	34.1	34.1	34.1
16	5.0	265.3	307.2	342.0	36.2	36.2	36.2
17	4.5	238.4	276.0	307.3	35.9	35.9	35.9
18	5.9	330.8	348.7	359.6	38.2	38.2	38.2
19	4.7	283.0	285.3	319.6	41.3	41.3	41.3
20	4.9	265.3	307.2	342.0	36.9	36.9	36.9
21	4.9	265.3	307.2	342.0	37.2	37.2	37.2
22	3.2	189.3	206.0	216.4	40.3	40.3	40.3
23	4.7	265.3	307.2	342.0	38.2	38.2	38.2
24	5.5	330.8	348.7	367.9	41.3	41.3	41.3
25	3.5	189.3	206.0	216.4	40.3	40.3	40.3
Average:					33.2	36.7	39.7
Absolute Difference:					-3.5	0.0	3.0
Percent Difference:					-9.5%	0.0%	8.2%

Note: *See also* “Train KE30: Car Types and Lengths for Sensitivity Analysis”

Train KE36: Manually Calculated Speeds

Segment	Time from Beginning of Train to Beginning Car in Segment Measurement (sec)	Measured from Beginning of Car	Measured to Beginning of Car	Measured Travel Times (sec)				Time from Beginning of Train to Average Time that Calculated Speed Occurred (sec)	Length of Railcar Segment (ft)	Calculated Estimate of Speed* (mph)
				Trial 1	Trial 2	Trial 3	Average			
1	2.0	3	8	3.7	3.7	3.7	3.7	3.9	265.4	48.4
2	5.7	8	13	3.7	3.7	3.7	3.7	7.6	265.4	49.3
3	9.4	13	18	3.7	3.7	3.7	3.7	11.2	265.4	49.4
4	13.1	18	23	3.6	3.6	3.6	3.6	14.9	265.4	49.8
5	16.7	23	28	3.7	3.7	3.7	3.7	18.5	265.4	49.3
6	20.4	28	33	3.6	3.6	3.6	3.6	22.2	265.4	49.9
7	24.0	33	38	3.6	3.6	3.6	3.6	25.8	265.4	50.0
8	27.6	38	43	3.6	3.6	3.6	3.6	29.4	265.4	50.3
9	31.2	43	48	3.6	3.6	3.6	3.6	33.0	265.4	49.7
10	34.9	48	53	3.6	3.6	3.6	3.6	36.7	265.4	50.2
11	38.5	53	58	3.6	3.6	3.6	3.6	40.2	265.4	50.7
12	42.0	58	63	3.6	3.6	3.6	3.6	43.8	265.4	50.7
13	45.6	63	68	3.6	3.6	3.6	3.6	47.4	265.4	50.3
14	49.2	68	73	3.5	3.5	3.5	3.5	51.0	265.4	51.1
15	52.7	73	78	3.5	3.5	3.5	3.5	54.5	265.4	51.0
16	56.3	78	83	3.6	3.6	3.6	3.6	58.1	265.4	50.9
17	59.8	83	88	3.6	3.6	3.6	3.6	61.6	265.4	50.7
18	63.4	88	93	3.5	3.5	3.5	3.5	65.2	265.4	51.1
19	66.9	93	98	3.5	3.5	3.5	3.5	68.7	265.4	51.2
20	70.5	98	103	3.5	3.5	3.5	3.5	72.2	265.4	51.7
21	74.0	103	108	3.5	3.5	3.5	3.5	75.7	265.4	51.5
22	77.5	108	113	3.6	3.6	3.6	3.6	79.3	265.4	50.9

* - Speed was calculated based on the Average Measured Travel Times and the lengths of the railcar segments (5 car segments). All railcars for this train were coal cars with standard length from coupler to coupler of "Most Likely" 53' 1" (Simmons-Boardman 1997)

Train KE36: Sensitivity Analysis of Manually Calculated Speeds

Segment	Average Measured Travel Time (sec)	Lengths of Railcar Segments (ft)			Calculated Estimate of Speed (mph)		
		Shortest	Most Likely	Longest	Shortest	Most Likely	Longest
1	3.7	243.5	265.4	285.2	44.5	48.4	52.1
2	3.7	243.5	265.4	285.2	45.2	49.3	53.0
3	3.7	243.5	265.4	285.2	45.3	49.4	53.1
4	3.6	243.5	265.4	285.2	45.7	49.8	53.5
5	3.7	243.5	265.4	285.2	45.3	49.3	53.0
6	3.6	243.5	265.4	285.2	45.8	49.9	53.6
7	3.6	243.5	265.4	285.2	45.9	50.0	53.8
8	3.6	243.5	265.4	285.2	46.1	50.3	54.0
9	3.6	243.5	265.4	285.2	45.6	49.7	53.4
10	3.6	243.5	265.4	285.2	46.1	50.2	54.0
11	3.6	243.5	265.4	285.2	46.5	50.7	54.5
12	3.6	243.5	265.4	285.2	46.5	50.7	54.5
13	3.6	243.5	265.4	285.2	46.1	50.3	54.0
14	3.5	243.5	265.4	285.2	46.9	51.1	54.9
15	3.5	243.5	265.4	285.2	46.8	51.0	54.8
16	3.6	243.5	265.4	285.2	46.7	50.9	54.7
17	3.6	243.5	265.4	285.2	46.5	50.7	54.5
18	3.5	243.5	265.4	285.2	46.9	51.1	54.9
19	3.5	243.5	265.4	285.2	47.0	51.2	55.0
20	3.5	243.5	265.4	285.2	47.4	51.7	55.5
21	3.5	243.5	265.4	285.2	47.3	51.5	55.4
22	3.6	243.5	265.4	285.2	46.7	50.9	54.7
Average:					46.2	50.4	54.1
Absolute Difference:					-4.2	0.0	3.8
Percent Difference:					-8.2%	0.0%	7.5%

Note: Shortest = 48’ –8 ½” / Car;
Most Likely = 53’ – 1” / Car;
Longest = 57’ – ½” / Car

APPENDIX B

Data and Results from Autoscope Data Analyses

Adjustment Factor for Autoscope Speed Detector, Train KE7

Time into Train Event (sec)		Average Speed (mph) from Time X1 to X2	
X1	X2	Calibrated Radar	Autoscope
0	5	40.23	40.40
5	10	40.31	39.75
10	15	40.68	38.60
15	20	40.89	39.25
20	25	40.68	39.83
25	30	40.86	39.50
30	35	40.98	39.50
35	40	41.40	39.00
40	45	41.80	39.50
45	50	41.58	39.33
50	55	41.50	40.80
55	60	41.90	39.75
60	65	41.94	40.50
65	70	42.22	40.25
70	75	42.28	40.20
75	80	42.52	41.25
80	85	42.48	41.50
85	90	42.63	41.60
90	95	42.61	41.50
95	100	42.68	41.40
100	105	42.70	40.60
105	110	43.22	42.50
110	115	43.18	41.80
115	120	43.82	42.33
Average Speed =		41.88	40.44
Adjustment Factor =			**1.04**
Adjusted Average Speed =			41.88

Adjustment Factor for Autoscope Speed Detector, Train KE30

Time into Train Event (sec)		Average Speed (mph) from Time X1 to X2	
X1	X2	Calibrated Radar	Autoscope
0	5	22.70	24.00
5	10	23.84	23.33
10	15	25.10	23.33
15	20	26.29	24.67
20	25	27.19	26.00
25	30	28.43	27.00
30	35	29.29	27.00
35	40	30.17	30.50
40	45	31.39	31.75
45	50	32.90	32.60
50	55	33.49	32.80
55	60	34.33	32.00
60	65	34.92	37.00
65	70	35.76	37.25
70	75	36.87	38.50
75	80	37.68	37.00
80	85	38.44	38.50
85	90	39.04	39.67
90	95	39.67	40.00
95	100	40.45	39.25
100	105	41.20	42.40
105	110	41.40	42.75
110	115	41.93	38.00
115	120	43.12	41.50
120	125	43.38	44.20
125	130	43.84	40.00
130	135	44.13	43.75
135	140	45.13	45.80
Average Speed =		35.43	35.02
Adjustment Factor =			**1.01**
Adjusted Average Speed =			35.43

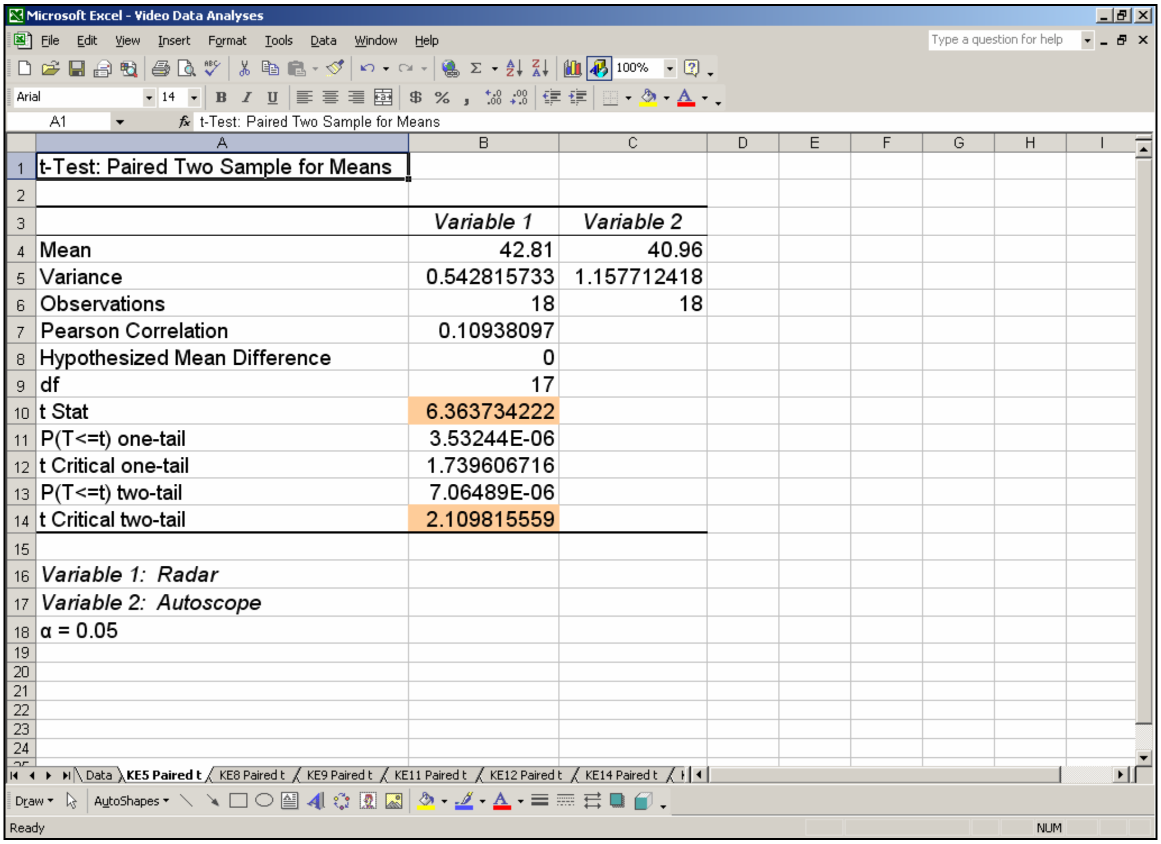
Adjustment Factor for Autoscope Speed Detector, Train KE36

Time into Train Event (sec)		Average Speed (mph) from Time X1 to X2	
X1	X2	Calibrated Radar	Autoscope
0	5	48.32	47.00
5	10	48.52	55.40
10	15	48.64	57.00
15	20	49.20	55.83
20	25	49.45	54.00
25	30	49.42	55.57
30	35	49.65	56.00
35	40	49.81	55.40
40	45	49.94	55.57
45	50	50.11	56.60
50	55	50.24	58.00
55	60	50.29	58.40
60	65	50.37	55.60
65	70	50.43	55.86
70	75	50.56	54.67
75	80	50.58	55.00
80	85	51.36	59.00
Average Speed =		41.82	55.58
Adjustment Factor =			**0.90**
Adjusted Average Speed =			49.82

Autoscope Speed Detector Data paired with Calibrated Radar Data, Train KE5

Time		Average Speed (mph) From Times X1 to X2 Inclusively	
X1	X2	From Calibrated Radar	From Autoscope Speed Detector
1:13:37 PM	1:13:41 PM	41.30	43.00
1:13:42 PM	1:13:46 PM	41.56	41.33
1:13:47 PM	1:13:51 PM	41.95	40.60
1:13:52 PM	1:13:56 PM	42.15	39.50
1:13:57 PM	1:14:01 PM	42.23	39.00
1:14:02 PM	1:14:06 PM	42.40	40.50
1:14:07 PM	1:14:11 PM	42.73	40.80
1:14:12 PM	1:14:16 PM	42.75	40.83
1:14:17 PM	1:14:21 PM	42.80	40.20
1:14:22 PM	1:14:26 PM	43.15	40.40
1:14:27 PM	1:14:31 PM	43.15	40.00
1:14:32 PM	1:14:36 PM	43.41	40.75
1:14:37 PM	1:14:41 PM	43.25	42.20
1:14:42 PM	1:14:46 PM	43.47	41.25
1:14:47 PM	1:14:51 PM	43.41	41.60
1:14:52 PM	1:14:56 PM	43.72	40.33
1:14:57 PM	1:15:01 PM	43.65	42.50
1:15:02 PM	1:15:06 PM	43.58	(42.50)

(###) – Value copied from previous interval to replace void in Autoscope data set

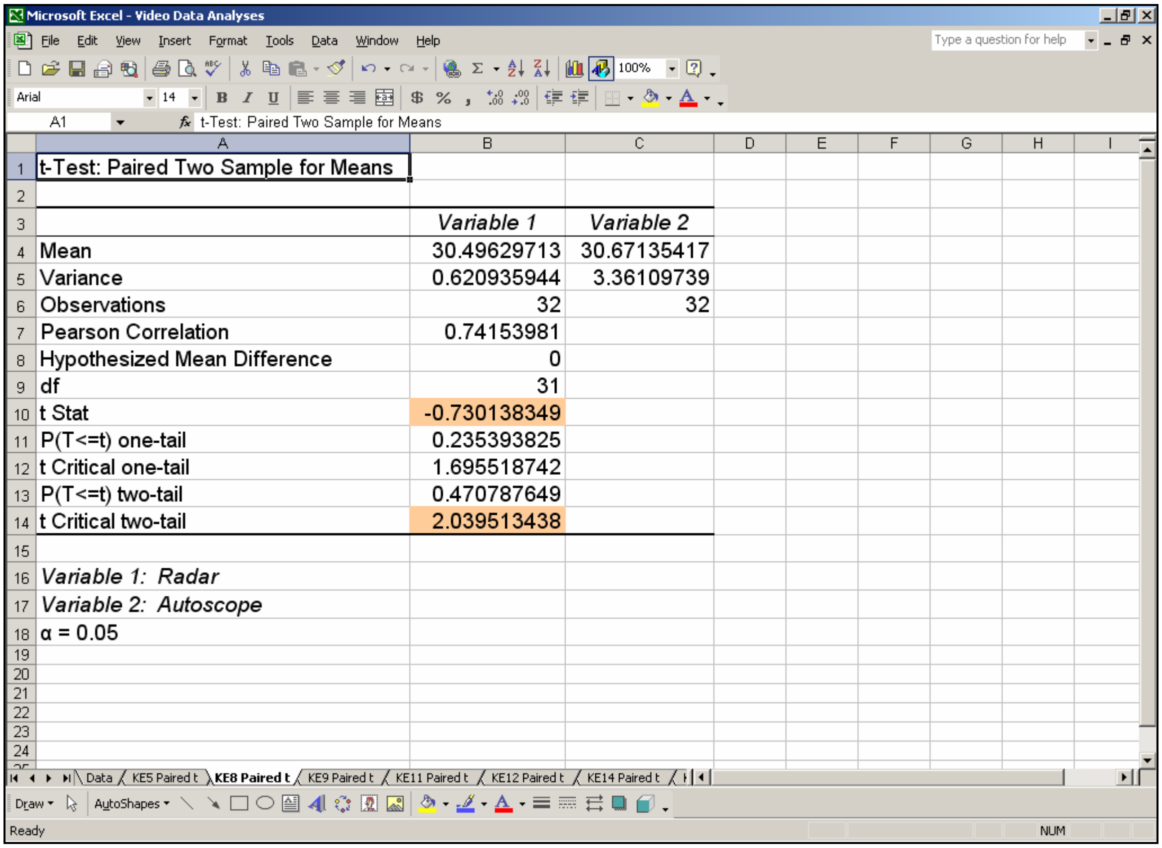


	A	B	C
1	t-Test: Paired Two Sample for Means		
2			
3		*Variable 1*	*Variable 2*
4	Mean	42.81	40.96
5	Variance	0.542815733	1.157712418
6	Observations	18	18
7	Pearson Correlation	0.10938097	
8	Hypothesized Mean Difference	0	
9	df	17	
10	t Stat	6.363734222	
11	P(T<=t) one-tail	3.53244E-06	
12	t Critical one-tail	1.739606716	
13	P(T<=t) two-tail	7.06489E-06	
14	t Critical two-tail	2.109815559	
15			
16	*Variable 1: Radar*		
17	*Variable 2: Autoscope*		
18	α = 0.05		

Paired t-test Output from Excel for Train KE5

Autoscope Speed Detector Data paired with Calibrated Radar Data, Train KE8

Time		Average Speed (mph) From Times X1 to X2 Inclusively	
X1	X2	From Calibrated Radar	From Autoscope Speed Detector
2:02:29 PM	2:02:33 PM	29.34	31.00
2:02:34 PM	2:02:38 PM	29.41	29.50
2:02:39 PM	2:02:43 PM	29.56	29.40
2:02:44 PM	2:02:48 PM	29.69	27.75
2:02:49 PM	2:02:53 PM	29.51	30.25
2:02:54 PM	2:02:58 PM	29.84	29.33
2:02:59 PM	2:03:03 PM	29.57	30.75
2:03:04 PM	2:03:08 PM	29.83	30.00
2:03:09 PM	2:03:13 PM	29.76	30.00
2:03:14 PM	2:03:18 PM	30.04	28.75
2:03:19 PM	2:03:23 PM	30.22	31.67
2:03:24 PM	2:03:28 PM	30.08	30.00
2:03:29 PM	2:03:33 PM	30.39	30.75
2:03:34 PM	2:03:38 PM	30.33	28.00
2:03:39 PM	2:03:43 PM	30.39	30.00
2:03:44 PM	2:03:48 PM	30.46	30.25
2:03:49 PM	2:03:53 PM	30.44	28.67
2:03:54 PM	2:03:58 PM	30.70	30.50
2:03:59 PM	2:04:03 PM	30.51	29.50
2:04:04 PM	2:04:08 PM	30.67	29.00
2:04:09 PM	2:04:13 PM	30.50	30.00
2:04:14 PM	2:04:18 PM	30.74	31.25
2:04:19 PM	2:04:23 PM	30.74	30.67
2:04:24 PM	2:04:28 PM	30.66	31.00
2:04:29 PM	2:04:33 PM	30.70	31.00
2:04:34 PM	2:04:38 PM	31.00	31.00
2:04:39 PM	2:04:43 PM	31.27	32.75
2:04:44 PM	2:04:48 PM	31.66	31.75
2:04:49 PM	2:04:53 PM	31.57	33.00
2:04:54 PM	2:04:58 PM	32.02	34.00
2:04:59 PM	2:05:03 PM	32.08	33.00
2:05:04 PM	2:05:05 PM	32.21	37.00



t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	30.49629713	30.67135417
Variance	0.620935944	3.36109739
Observations	32	32
Pearson Correlation	0.74153981	
Hypothesized Mean Difference	0	
df	31	
t Stat	-0.730138349	
P(T<=t) one-tail	0.235393825	
t Critical one-tail	1.695518742	
P(T<=t) two-tail	0.470787649	
t Critical two-tail	2.039513438	

Variable 1: Radar

Variable 2: Autoscope

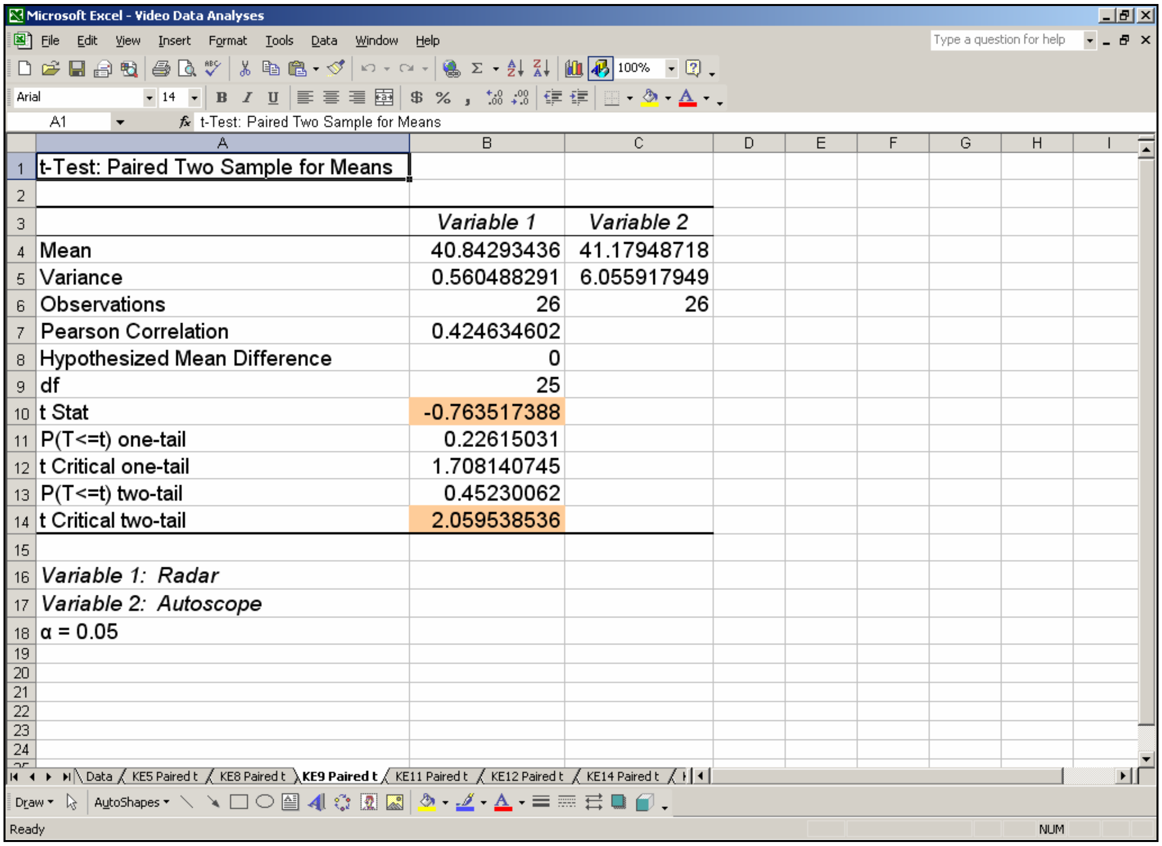
α = 0.05

Paired t-test Output from Excel for Train KE8

Autoscope Speed Detector Data paired with Calibrated Radar Data, Train KE9

Time		Average Speed (mph) From Times X1 to X2 Inclusively	
X1	X2	From Calibrated Radar	From Autoscope Speed Detector
2:14:31 PM	2:14:35 PM	39.63	41.00
2:14:36 PM	2:14:40 PM	39.68	42.00
2:14:41 PM	2:14:45 PM	39.67	40.50
2:14:46 PM	2:14:50 PM	39.67	41.00
2:14:51 PM	2:14:55 PM	40.14	42.33
2:14:56 PM	2:15:00 PM	40.09	42.33
2:15:01 PM	2:15:05 PM	40.22	36.00
2:15:06 PM	2:15:10 PM	40.56	39.80
2:15:11 PM	2:15:15 PM	40.64	38.00
2:15:16 PM	2:15:20 PM	40.54	41.00
2:15:21 PM	2:15:25 PM	40.80	42.00
2:15:26 PM	2:15:30 PM	40.63	40.00
2:15:31 PM	2:15:35 PM	40.81	37.00
2:15:36 PM	2:15:40 PM	40.73	41.00
2:15:41 PM	2:15:45 PM	40.97	38.00
2:15:46 PM	2:15:50 PM	41.24	38.00
2:15:51 PM	2:15:55 PM	41.14	38.50
2:15:56 PM	2:16:00 PM	41.44	45.00
2:16:01 PM	2:16:05 PM	41.11	42.00
2:16:06 PM	2:16:10 PM	41.56	(42.00)
2:16:11 PM	2:16:15 PM	41.38	42.50
2:16:16 PM	2:16:20 PM	41.80	44.20
2:16:21 PM	2:16:25 PM	41.80	44.50
2:16:26 PM	2:16:30 PM	41.74	44.00
2:16:31 PM	2:16:35 PM	41.76	(44.00)
2:16:36 PM	2:16:37 PM	42.17	(44.00)

(###) – Value copied from previous interval to replace void in Autoscope data set



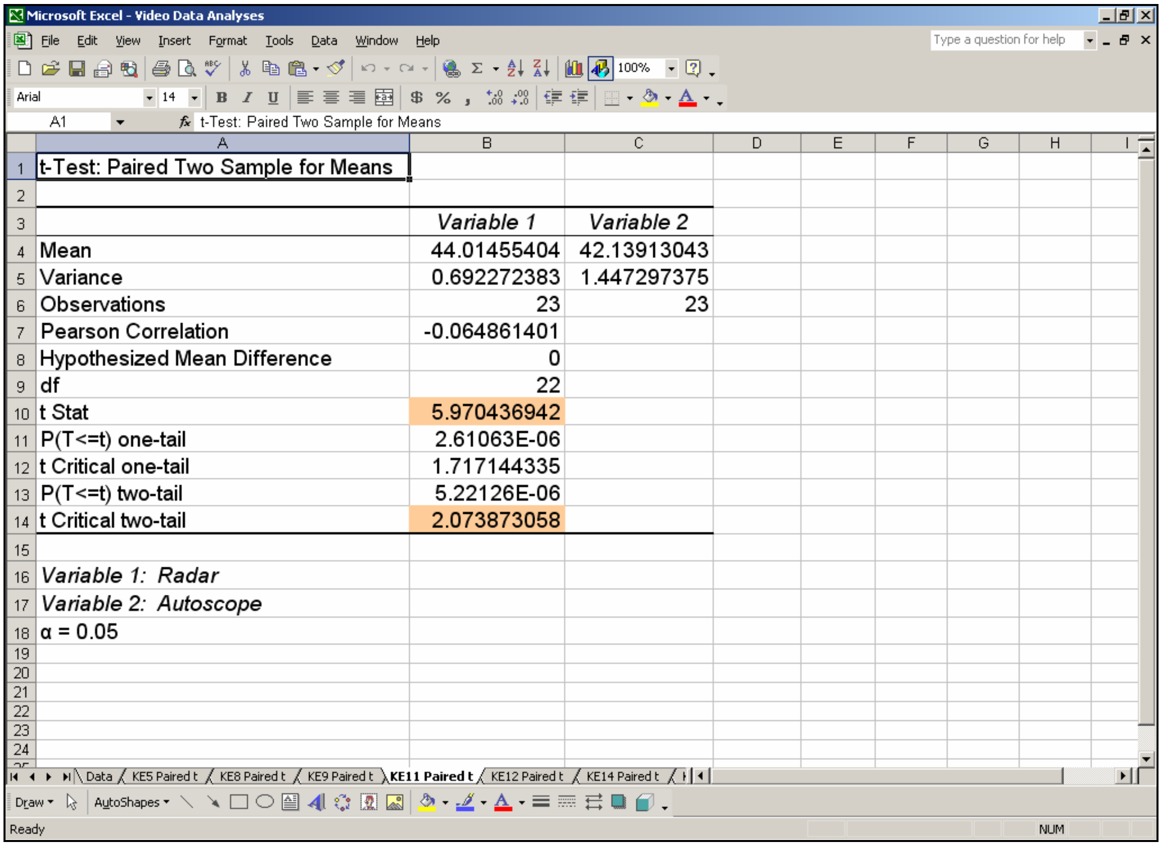
t-Test: Paired Two Sample for Means		
	Variable 1	*Variable 2*
Mean	40.84293436	41.17948718
Variance	0.560488291	6.055917949
Observations	26	26
Pearson Correlation	0.424634602	
Hypothesized Mean Difference	0	
df	25	
t Stat	-0.763517388	
P(T<=t) one-tail	0.22615031	
t Critical one-tail	1.708140745	
P(T<=t) two-tail	0.45230062	
t Critical two-tail	2.059538536	

Variable 1: Radar
Variable 2: Autoscope
α = 0.05

Paired t-test Output from Excel for Train KE9

Autoscope Speed Detector Data paired with Calibrated Radar Data, Train KE11

Time		Average Speed (mph) From Times X1 to X2 Inclusively	
X1	X2	From Calibrated Radar	From Autoscope Speed Detector
2:27:29 PM	2:27:33 PM	42.47	46.00
2:27:34 PM	2:27:38 PM	42.72	42.20
2:27:39 PM	2:27:43 PM	42.87	41.40
2:27:44 PM	2:27:48 PM	43.13	42.00
2:27:49 PM	2:27:53 PM	43.24	42.60
2:27:54 PM	2:27:58 PM	43.46	41.50
2:27:59 PM	2:28:03 PM	43.32	40.17
2:28:04 PM	2:28:08 PM	43.65	42.17
2:28:09 PM	2:28:13 PM	43.84	41.00
2:28:14 PM	2:28:18 PM	43.91	41.80
2:28:19 PM	2:28:23 PM	43.87	41.00
2:28:24 PM	2:28:28 PM	44.10	41.67
2:28:29 PM	2:28:33 PM	44.35	41.17
2:28:34 PM	2:28:38 PM	44.41	42.43
2:28:39 PM	2:28:43 PM	44.54	42.33
2:28:44 PM	2:28:48 PM	44.70	41.00
2:28:49 PM	2:28:53 PM	44.95	41.00
2:28:54 PM	2:28:58 PM	45.00	42.50
2:28:59 PM	2:29:03 PM	45.06	43.60
2:29:04 PM	2:29:08 PM	45.07	43.50
2:29:09 PM	2:29:13 PM	44.92	42.57
2:29:14 PM	2:29:18 PM	45.19	42.60
2:29:19 PM	2:29:21 PM	43.57	43.00



t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	44.01455404	42.13913043
Variance	0.692272383	1.447297375
Observations	23	23
Pearson Correlation	-0.064861401	
Hypothesized Mean Difference	0	
df	22	
t Stat	5.970436942	
P(T<=t) one-tail	2.61063E-06	
t Critical one-tail	1.717144335	
P(T<=t) two-tail	5.22126E-06	
t Critical two-tail	2.073873058	

Variable 1: Radar

Variable 2: Autoscope

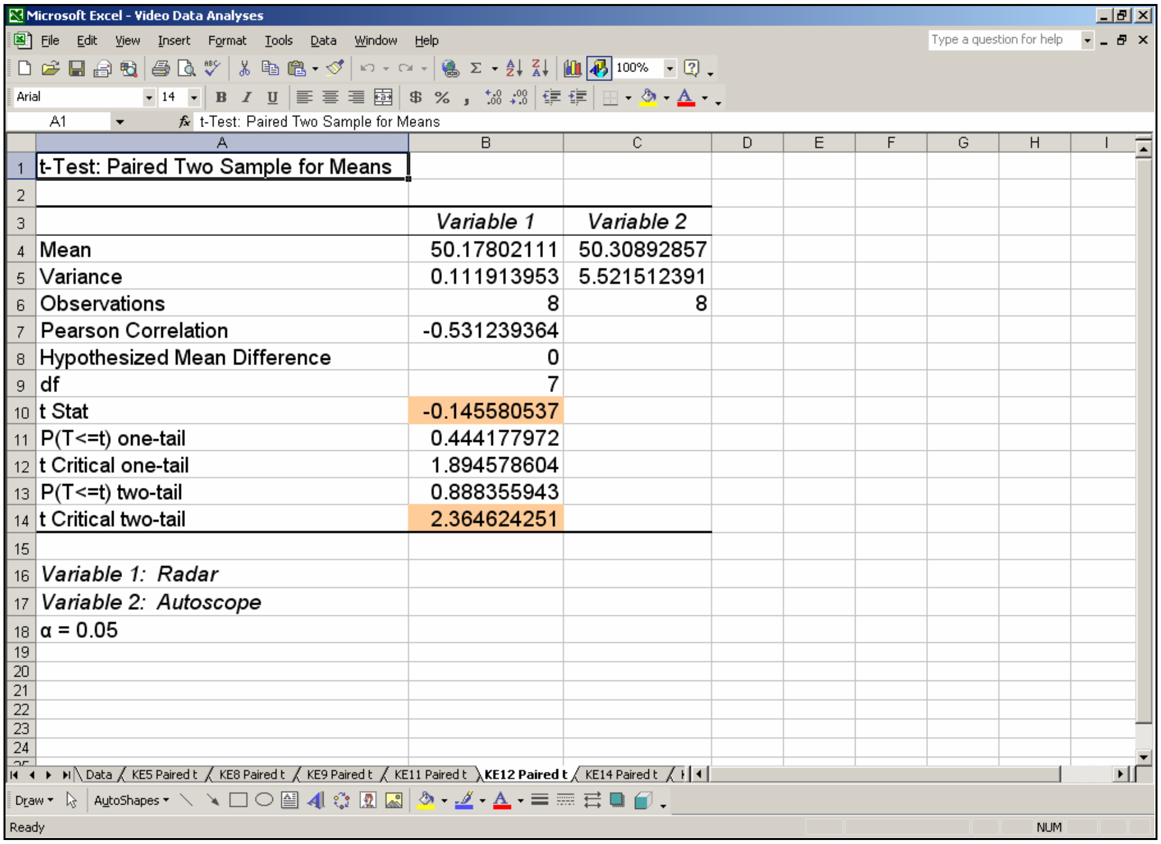
α = 0.05

Paired t-test Output from Excel for Train KE11

Autoscope Speed Detector Data paired with Calibrated Radar Data, Train KE12

Time		Average Speed (mph) From Times X1 to X2 Inclusively	
X1	X2	From Calibrated Radar	From Autoscope Speed Detector
2:39:28 PM	2:39:32 PM	49.88	54.00
2:39:33 PM	2:39:37 PM	50.21	49.14
2:39:38 PM	2:39:42 PM	50.88	48.43
2:39:43 PM	2:39:47 PM	50.29	47.00
2:39:48 PM	2:39:52 PM	50.11	51.40
2:39:53 PM	2:39:57 PM	50.19	49.50
2:39:58 PM	2:40:02 PM	49.75	50.00
2:40:03 PM	2:40:07 PM	50.12	53.00
2:40:08 PM	2:40:12 PM		48.75
2:40:13 PM	2:40:17 PM		50.00
2:40:18 PM	2:40:22 PM		48.20
2:40:23 PM	2:40:27 PM		49.29
2:40:28 PM	2:40:32 PM		48.50
2:40:33 PM	2:40:37 PM		49.14
2:40:38 PM	2:40:42 PM		48.67
2:40:43 PM	2:40:47 PM		48.67
2:40:48 PM	2:40:52 PM		48.75
2:40:53 PM	2:40:57 PM		49.29
2:40:58 PM	2:41:02 PM		48.17
2:41:03 PM	2:41:07 PM		49.20
2:41:08 PM	2:41:09 PM		49.00

* - Radar data for KE12 was over-ridden by data for KE13 after 2:40:07 PM



t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	50.17802111	50.30892857
Variance	0.111913953	5.521512391
Observations	8	8
Pearson Correlation	-0.531239364	
Hypothesized Mean Difference	0	
df	7	
t Stat	-0.145580537	
P(T<=t) one-tail	0.444177972	
t Critical one-tail	1.894578604	
P(T<=t) two-tail	0.888355943	
t Critical two-tail	2.364624251	

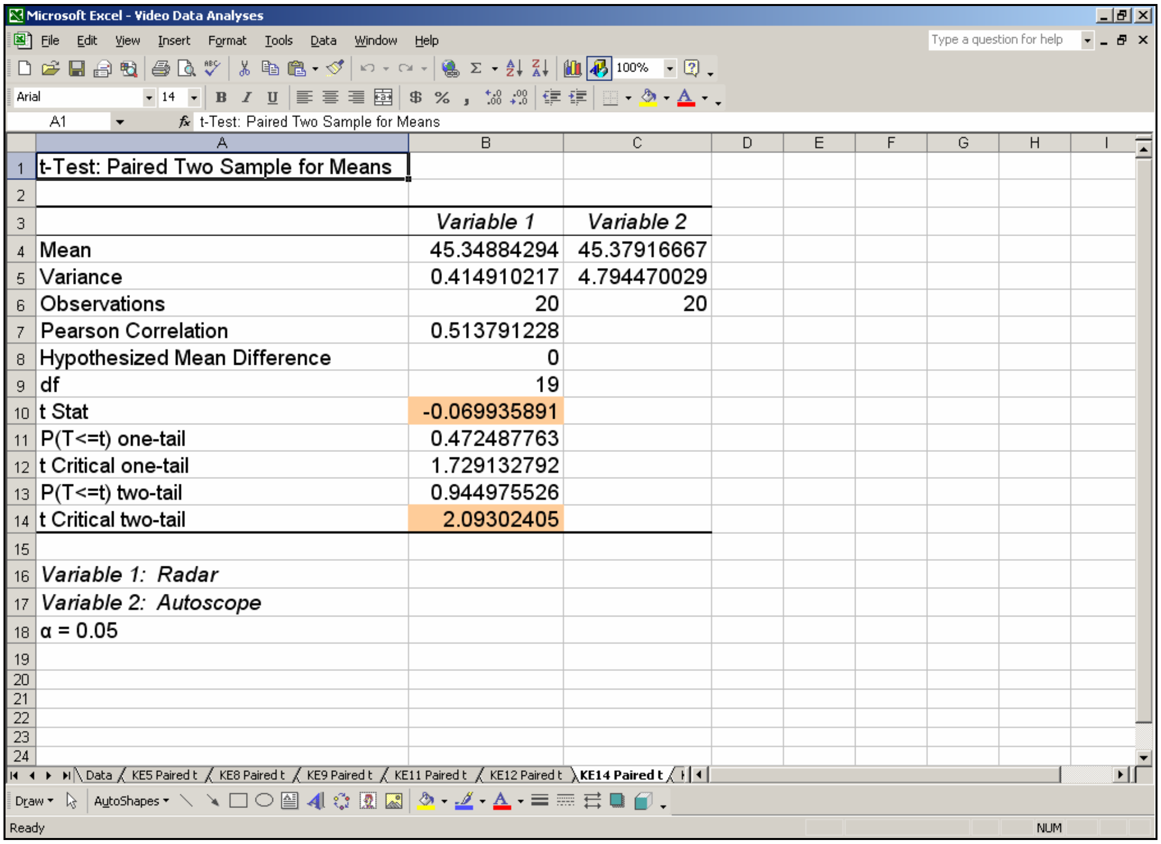
Variable 1: Radar
Variable 2: Autoscope
α = 0.05

Paired t-test Output from Excel for Train KE12

Autoscope Speed Detector Data paired with Calibrated Radar Data, Train KE14

Time		Average Speed (mph) From Times X1 to X2 Inclusively	
X1	X2	From Calibrated Radar	From Autoscope Speed Detector
2:53:27 PM	2:53:31 PM	44.17	40.00
2:53:32 PM	2:53:36 PM	44.34	46.33
2:53:37 PM	2:53:41 PM	44.69	46.00
2:53:42 PM	2:53:46 PM	44.74	42.00
2:53:47 PM	2:53:51 PM	44.68	(42.00)
2:53:52 PM	2:53:56 PM	45.18	44.00
2:53:57 PM	2:54:01 PM	44.94	46.75
2:54:02 PM	2:54:06 PM	45.48	49.00
2:54:07 PM	2:54:11 PM	45.19	43.80
2:54:12 PM	2:54:16 PM	45.28	46.00
2:54:17 PM	2:54:21 PM	45.37	47.00
2:54:22 PM	2:54:26 PM	45.45	44.67
2:54:27 PM	2:54:31 PM	45.57	45.33
2:54:32 PM	2:54:36 PM	45.84	46.33
2:54:37 PM	2:54:41 PM	45.57	44.67
2:54:42 PM	2:54:46 PM	46.05	48.00
2:54:47 PM	2:54:51 PM	45.70	47.67
2:54:52 PM	2:54:56 PM	45.95	46.20

(###) – Value copied from previous interval to replace void in Autoscope data set



t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	45.34884294	45.37916667
Variance	0.414910217	4.794470029
Observations	20	20
Pearson Correlation	0.513791228	
Hypothesized Mean Difference	0	
df	19	
t Stat	-0.069935891	
P(T<=t) one-tail	0.472487763	
t Critical one-tail	1.729132792	
P(T<=t) two-tail	0.944975526	
t Critical two-tail	2.09302405	

Variable 1: Radar

Variable 2: Autoscope

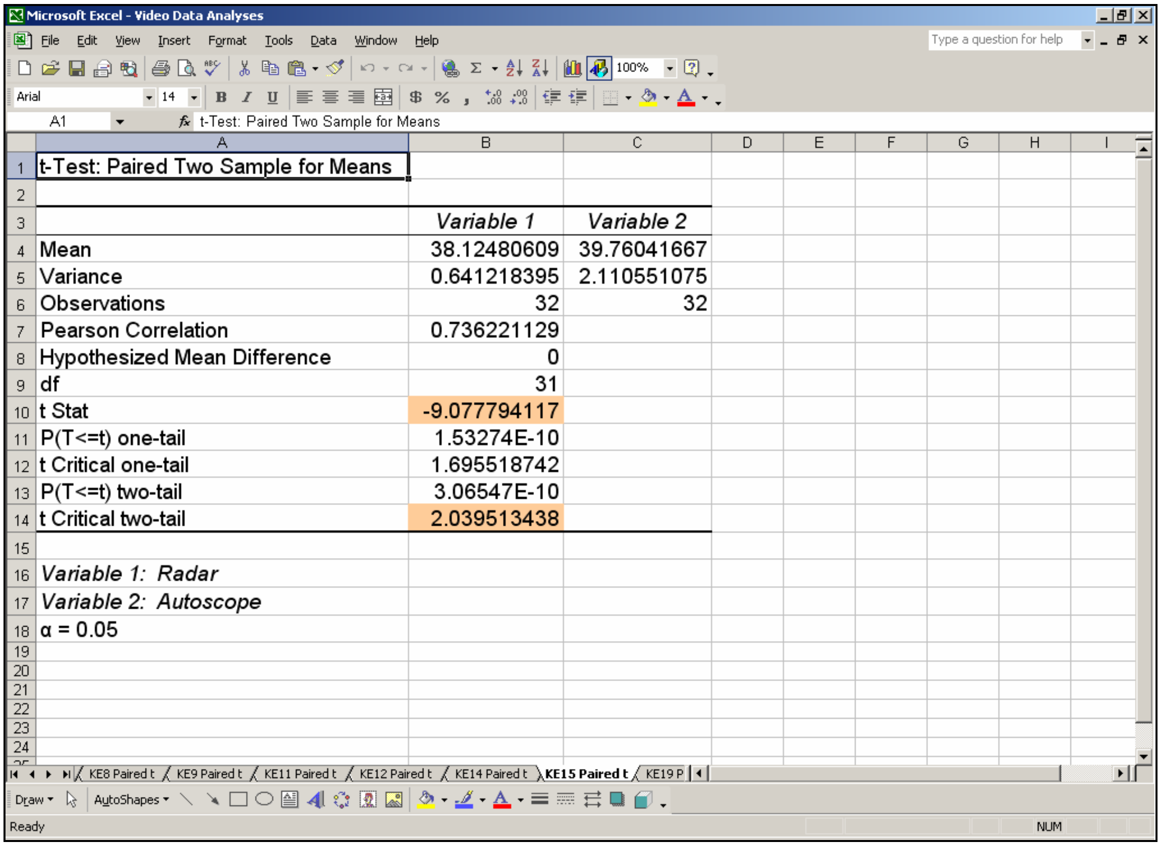
α = 0.05

Paired t-test Output from Excel for Train KE14

Autoscope Speed Detector Data paired with Calibrated Radar Data, Train KE15

Time		Average Speed (mph) From Times X1 to X2 Inclusively	
X1	X2	From Calibrated Radar	From Autoscope Speed Detector
3:09:25 PM	3:09:29 PM	36.60	39.00
3:09:30 PM	3:09:34 PM	36.93	38.00
3:09:35 PM	3:09:39 PM	36.97	38.75
3:09:40 PM	3:09:44 PM	36.83	38.00
3:09:45 PM	3:09:49 PM	37.10	37.00
3:09:50 PM	3:09:54 PM	37.14	38.67
3:09:55 PM	3:09:59 PM	37.56	38.50
3:10:00 PM	3:10:04 PM	37.44	38.00
3:10:05 PM	3:10:09 PM	37.44	39.67
3:10:10 PM	3:10:14 PM	37.50	39.67
3:10:15 PM	3:10:19 PM	37.58	38.00
3:10:20 PM	3:10:24 PM	37.95	39.00
3:10:25 PM	3:10:29 PM	37.77	39.00
3:10:30 PM	3:10:34 PM	38.17	40.00
3:10:35 PM	3:10:39 PM	38.18	39.67
3:10:40 PM	3:10:44 PM	38.73	39.67
3:10:45 PM	3:10:49 PM	38.19	(39.67)
3:10:50 PM	3:10:54 PM	38.38	(39.67)
3:10:55 PM	3:10:59 PM	38.31	41.00
3:11:00 PM	3:11:04 PM	38.50	(41.00)
3:11:05 PM	3:11:09 PM	38.58	41.00
3:11:10 PM	3:11:14 PM	38.84	(41.00)
3:11:15 PM	3:11:19 PM	38.40	(41.00)
3:11:20 PM	3:11:24 PM	38.96	40.00
3:11:25 PM	3:11:29 PM	38.65	37.00
3:11:30 PM	3:11:34 PM	39.14	40.67
3:11:35 PM	3:11:39 PM	38.95	41.00
3:11:40 PM	3:11:44 PM	38.77	41.00
3:11:45 PM	3:11:49 PM	38.97	41.00
3:11:50 PM	3:11:54 PM	39.06	42.75
3:11:55 PM	3:11:59 PM	38.65	42.00
3:12:00 PM	3:12:02 PM	39.73	(42.00)

(###) – Value copied from previous interval to replace void in Autoscope data set



t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	38.12480609	39.76041667
Variance	0.641218395	2.110551075
Observations	32	32
Pearson Correlation	0.736221129	
Hypothesized Mean Difference	0	
df	31	
t Stat	-9.077794117	
P(T<=t) one-tail	1.53274E-10	
t Critical one-tail	1.695518742	
P(T<=t) two-tail	3.06547E-10	
t Critical two-tail	2.039513438	

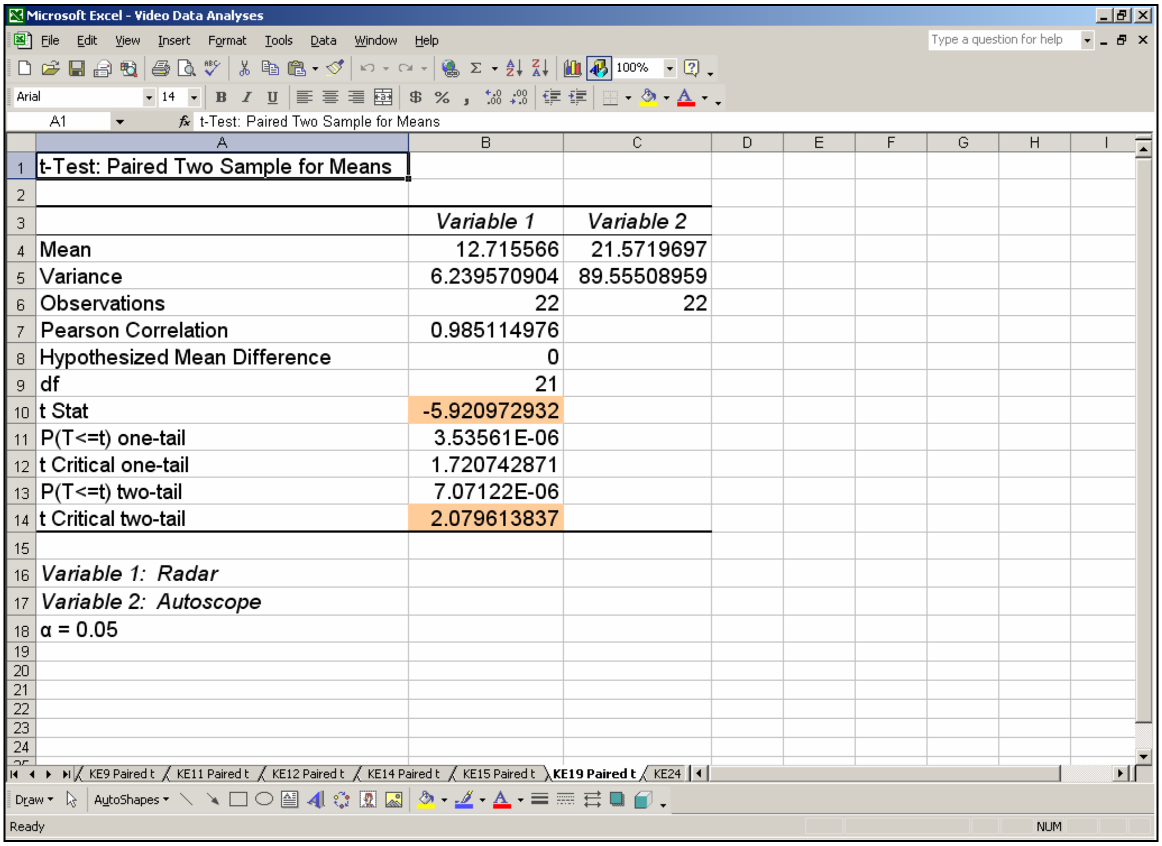
Variable 1: Radar
Variable 2: Autoscope
α = 0.05

Paired t-test Output from Excel for Train KE15

Autoscope Speed Detector Data paired with Calibrated Radar Data, Train KE19

Time		Average Speed (mph) From Times X1 to X2 Inclusively	
X1	X2	From Calibrated Radar	From Autoscope Speed Detector
4:57:48 PM	4:57:52 PM	8.34	6.00
4:57:53 PM	4:57:57 PM	9.32	(6.00)
4:57:58 PM	4:58:02 PM	9.56	9.00
4:58:03 PM	4:58:07 PM	9.76	12.50
4:58:08 PM	4:58:12 PM	10.73	(12.50)
4:58:13 PM	4:58:17 PM	10.56	14.00
4:58:18 PM	4:58:22 PM	11.13	15.00
4:58:23 PM	4:58:27 PM	11.88	16.00
4:58:28 PM	4:58:32 PM	11.66	16.50
4:58:33 PM	4:58:37 PM	11.67	20.50
4:58:38 PM	4:58:42 PM	12.15	21.00
4:58:43 PM	4:58:47 PM	12.77	24.00
4:58:48 PM	4:58:52 PM	13.07	24.75
4:58:53 PM	4:58:57 PM	13.92	(24.75)
4:58:58 PM	4:59:02 PM	13.88	(24.75)
4:59:03 PM	4:59:07 PM	14.28	27.33
4:59:08 PM	4:59:12 PM	15.11	31.00
4:59:13 PM	4:59:17 PM	14.99	32.00
4:59:18 PM	4:59:22 PM	15.66	33.33
4:59:23 PM	4:59:27 PM	16.10	34.00
4:59:28 PM	4:59:32 PM	16.02	33.67
4:59:33 PM	4:59:37 PM	17.18	36.00

(###) – Value copied from previous interval to replace void in Autoscope data set



t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	12.715566	21.5719697
Variance	6.239570904	89.55508959
Observations	22	22
Pearson Correlation	0.985114976	
Hypothesized Mean Difference	0	
df	21	
t Stat	-5.920972932	
P(T<=t) one-tail	3.53561E-06	
t Critical one-tail	1.720742871	
P(T<=t) two-tail	7.07122E-06	
t Critical two-tail	2.079613837	

Variable 1: Radar

Variable 2: Autoscope

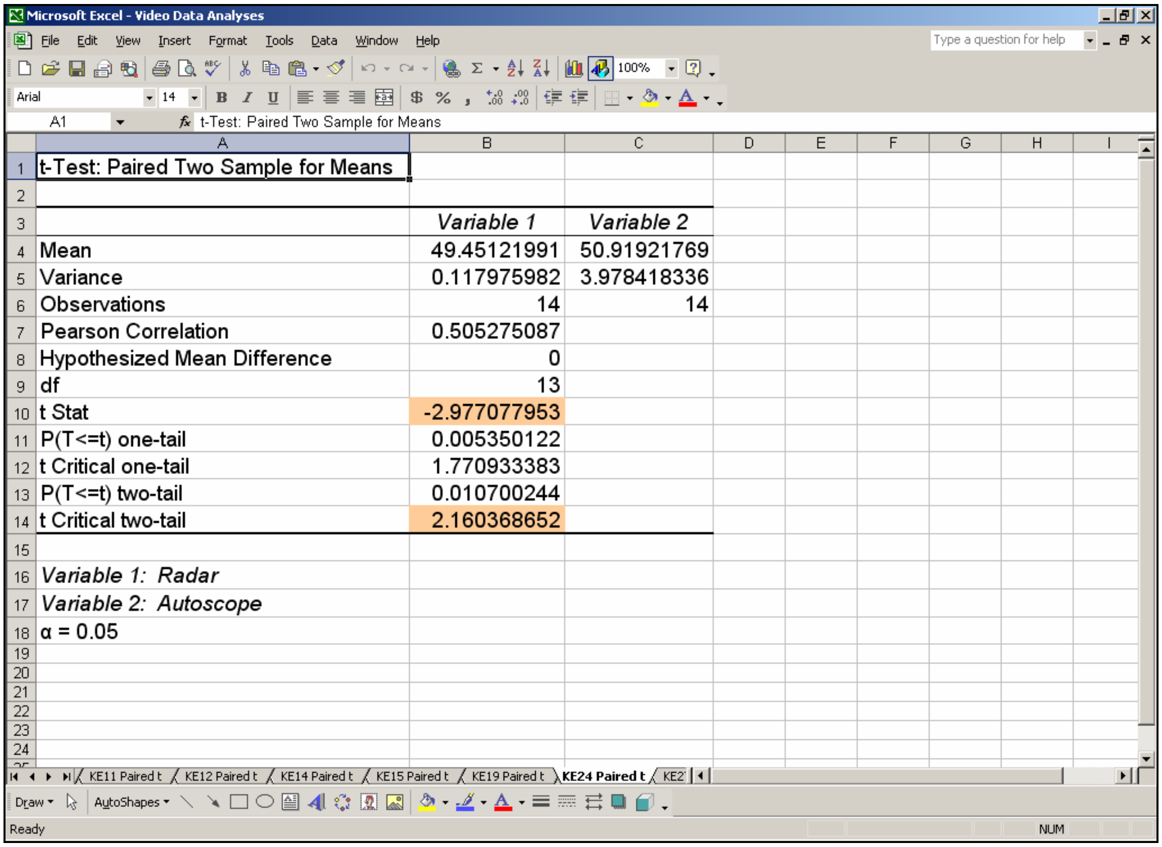
α = 0.05

Paired t-test Output from Excel for Train KE19

Autoscope Speed Detector Data paired with Calibrated Radar Data, Train KE24

Time		Average Speed (mph) From Times X1 to X2 Inclusively	
X1	X2	From Calibrated Radar	From Autoscope Speed Detector
5:21:05 PM	5:21:09 PM	48.71	48.00
5:21:10 PM	5:21:14 PM	49.08	48.00
5:21:15 PM	5:21:19 PM	49.03	51.25
5:21:20 PM	5:21:24 PM	49.18	50.67
5:21:25 PM	5:21:29 PM	49.48	51.50
5:21:30 PM	5:21:34 PM	49.47	47.33
5:21:35 PM	5:21:39 PM	49.68	49.67
5:21:40 PM	5:21:44 PM	49.59	51.29
5:21:45 PM	5:21:49 PM	49.62	52.50
5:21:50 PM	5:21:54 PM	49.86	52.50
5:21:55 PM	5:21:59 PM	49.84	51.00
5:22:00 PM	5:22:04 PM	49.87	52.67
5:22:05 PM	5:22:09 PM	49.48	52.67
5:22:10 PM	5:22:14 PM	49.41	53.83
5:22:15 PM	5:22:19 PM		53.43
5:22:20 PM	5:22:24 PM		53.00
5:22:25 PM	5:22:29 PM		53.25
5:22:30 PM	5:22:31 PM		53.00

* - Radar data unavailable after 5:22:14 PM



t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	49.45121991	50.91921769
Variance	0.117975982	3.978418336
Observations	14	14
Pearson Correlation	0.505275087	
Hypothesized Mean Difference	0	
df	13	
t Stat	-2.977077953	
P(T<=t) one-tail	0.005350122	
t Critical one-tail	1.770933383	
P(T<=t) two-tail	0.010700244	
t Critical two-tail	2.160368652	

Variable 1: Radar

Variable 2: Autoscope

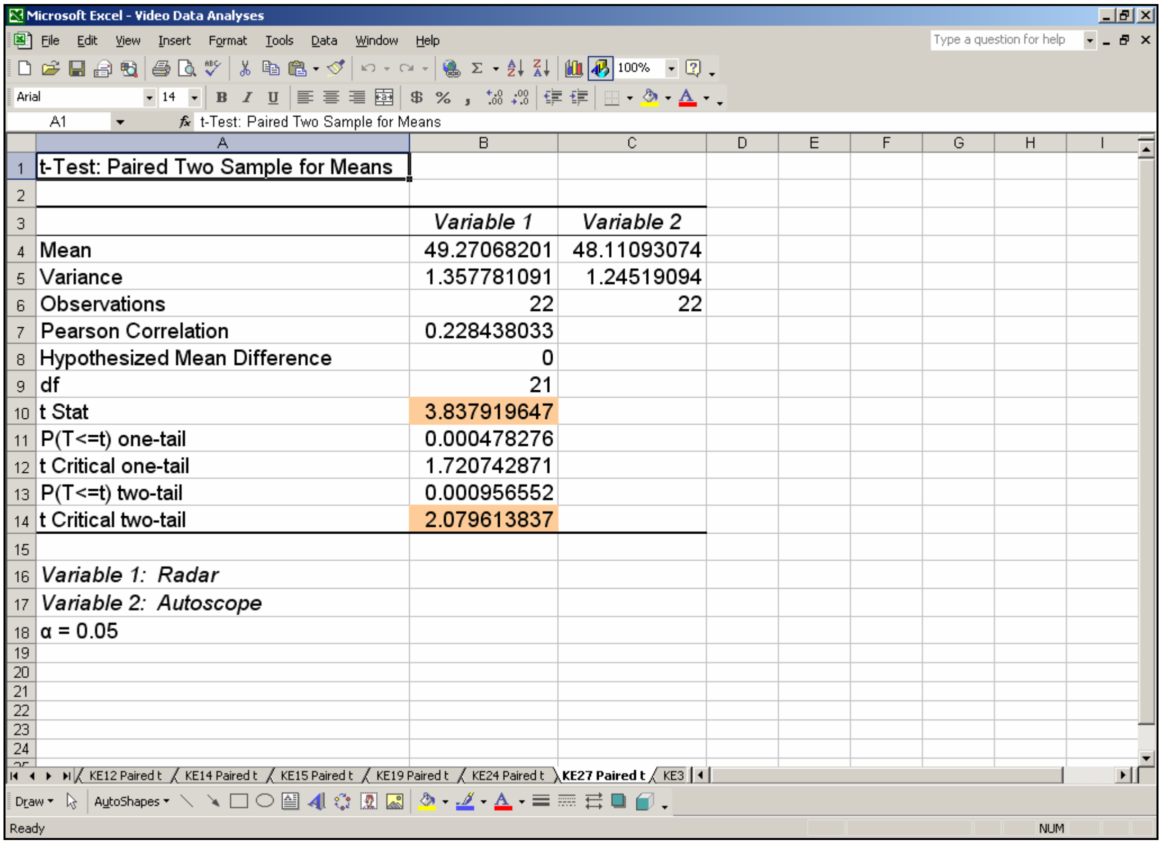
α = 0.05

Paired t-test Output from Excel for Train KE24

Autoscope Speed Detector Data paired with Calibrated Radar Data, Train KE27

Time		Average Speed (mph) From Times X1 to X2 Inclusively	
X1	X2	From Calibrated Radar	From Autoscope Speed Detector
5:33:09 PM	5:33:13 PM	47.18	45.33
5:33:14 PM	5:33:18 PM	47.75	46.67
5:33:19 PM	5:33:23 PM	47.74	48.00
5:33:24 PM	5:33:28 PM	52.23	(48.00)
5:33:29 PM	5:33:33 PM	48.11	47.25
5:33:34 PM	5:33:38 PM	48.53	46.86
5:33:39 PM	5:33:43 PM	48.23	47.67
5:33:44 PM	5:33:48 PM	48.95	49.50
5:33:49 PM	5:33:53 PM	48.36	50.20
5:33:54 PM	5:33:58 PM	49.10	50.00
5:33:59 PM	5:34:03 PM	49.14	48.80
5:34:04 PM	5:34:08 PM	49.27	47.50
5:34:09 PM	5:34:13 PM	49.14	49.20
5:34:14 PM	5:34:18 PM	49.55	48.67
5:34:19 PM	5:34:23 PM	49.51	48.50
5:34:24 PM	5:34:28 PM	49.72	48.50
5:34:29 PM	5:34:33 PM	50.00	47.67
5:34:34 PM	5:34:38 PM	49.78	48.67
5:34:39 PM	5:34:43 PM	50.28	48.00
5:34:44 PM	5:34:48 PM	50.50	47.40
5:34:49 PM	5:34:53 PM	50.01	48.40
5:34:54 PM	5:34:55 PM	50.87	47.67

(###) – Value copied from previous interval to replace void in Autoscope data set



t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	49.27068201	48.11093074
Variance	1.357781091	1.24519094
Observations	22	22
Pearson Correlation	0.228438033	
Hypothesized Mean Difference	0	
df	21	
t Stat	3.837919647	
P(T<=t) one-tail	0.000478276	
t Critical one-tail	1.720742871	
P(T<=t) two-tail	0.000956552	
t Critical two-tail	2.079613837	

Variable 1: Radar

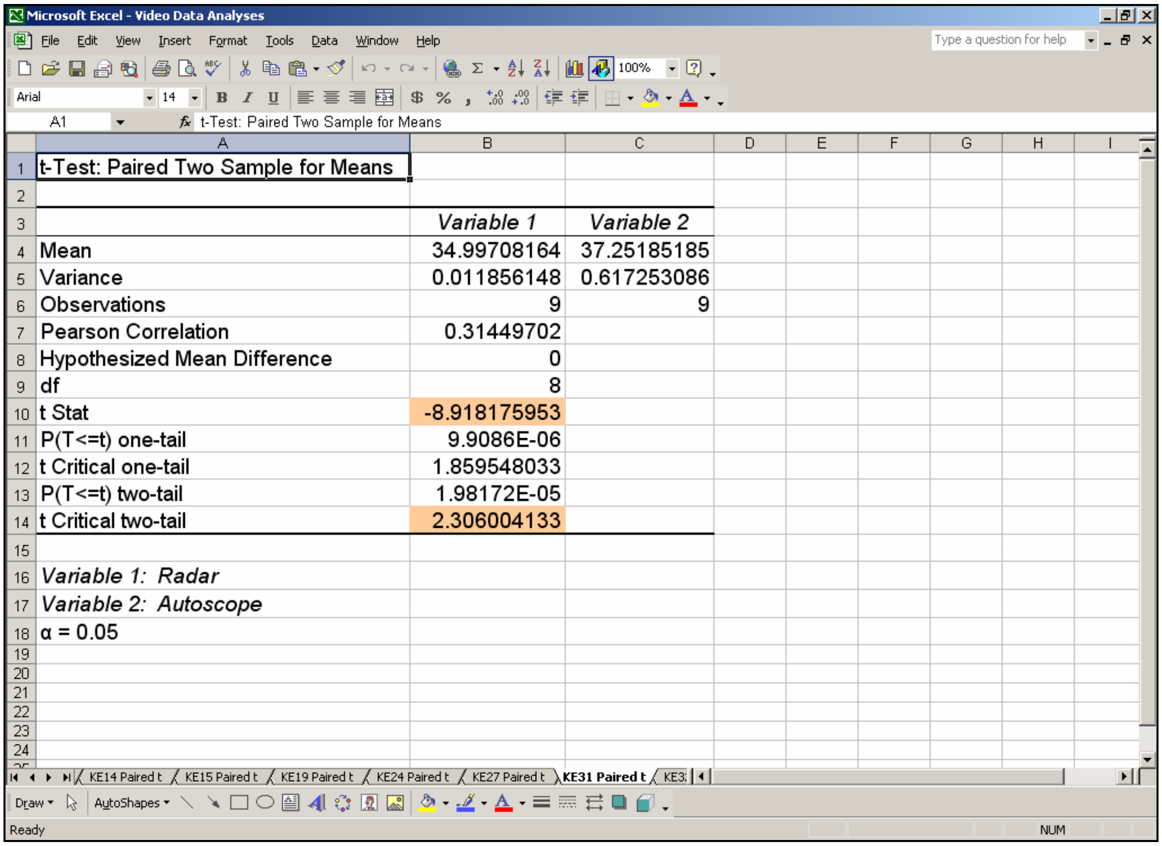
Variable 2: Autoscope

α = 0.05

Paired t-test Output from Excel for Train KE27

Autoscope Speed Detector Data paired with Calibrated Radar Data, Train KE31

Time		Average Speed (mph) From Times X1 to X2 Inclusively	
X1	X2	From Calibrated Radar	From Autoscope Speed Detector
6:31:09 PM	6:31:13 PM	35.13	38.00
6:31:14 PM	6:31:18 PM	35.03	37.83
6:31:19 PM	6:31:23 PM	35.05	38.00
6:31:24 PM	6:31:28 PM	34.98	36.50
6:31:29 PM	6:31:33 PM	34.93	36.33
6:31:34 PM	6:31:38 PM	35.00	37.40
6:31:39 PM	6:31:43 PM	34.91	38.20
6:31:44 PM	6:31:48 PM	34.80	36.40
6:31:49 PM	6:31:53 PM	35.15	36.60



t-Test: Paired Two Sample for Means

	Variable 1	Variable 2
Mean	34.99708164	37.25185185
Variance	0.011856148	0.617253086
Observations	9	9
Pearson Correlation	0.31449702	
Hypothesized Mean Difference	0	
df	8	
t Stat	-8.918175953	
P(T<=t) one-tail	9.9086E-06	
t Critical one-tail	1.859548033	
P(T<=t) two-tail	1.98172E-05	
t Critical two-tail	2.306004133	

Variable 1: Radar

Variable 2: Autoscope

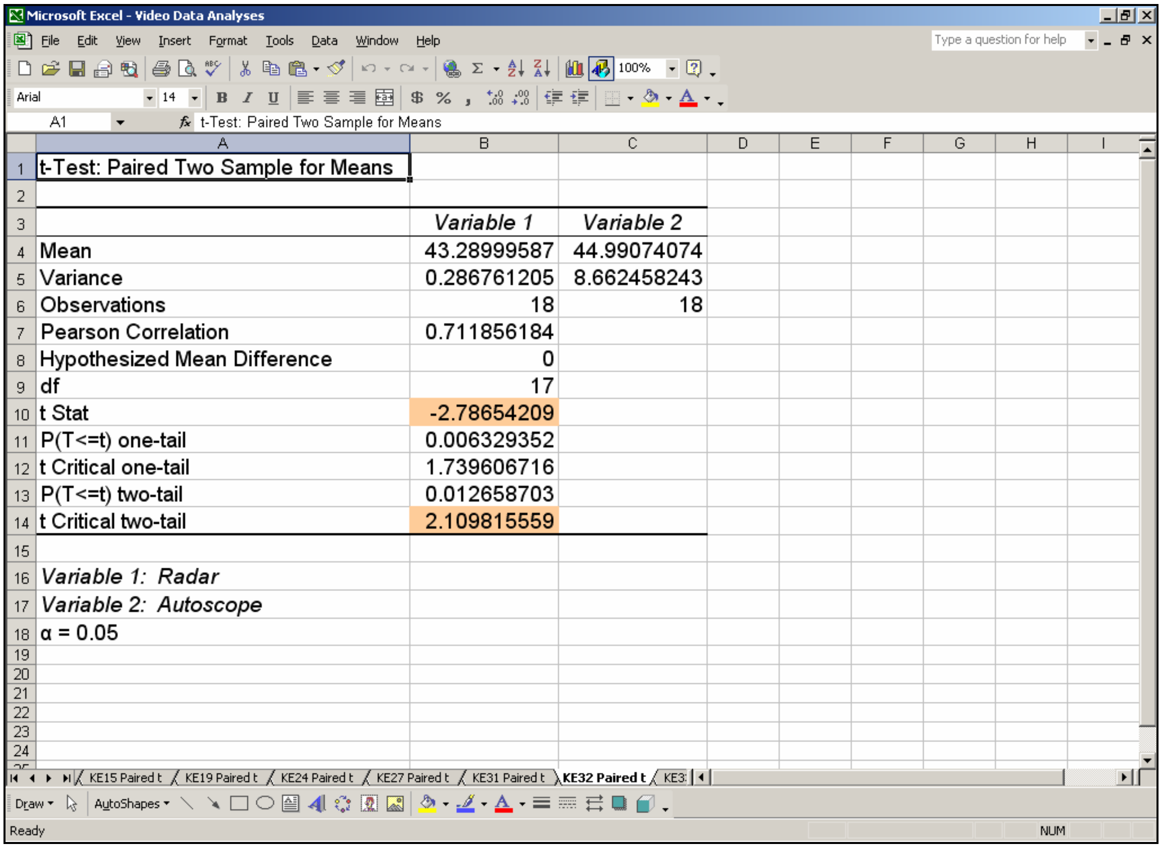
α = 0.05

Paired t-test Output from Excel for Train KE31

Autoscope Speed Detector Data paired with Calibrated Radar Data, Train KE32

Time		Average Speed (mph) From Times X1 to X2 Inclusively	
X1	X2	From Calibrated Radar	From Autoscope Speed Detector
6:41:50 PM	6:41:54 PM	42.17	38.00
6:41:55 PM	6:41:59 PM	42.26	39.00
6:42:00 PM	6:42:04 PM	42.79	39.50
6:42:05 PM	6:42:09 PM	42.61	46.00
6:42:10 PM	6:42:14 PM	43.05	45.80
6:42:15 PM	6:42:19 PM	43.16	47.67
6:42:20 PM	6:42:24 PM	43.10	47.00
6:42:25 PM	6:42:29 PM	43.43	47.00
6:42:30 PM	6:42:34 PM	43.60	46.00
6:42:35 PM	6:42:39 PM	43.44	45.20
6:42:40 PM	6:42:44 PM	43.60	45.00
6:42:45 PM	6:42:49 PM	43.41	47.00
6:42:50 PM	6:42:54 PM	43.71	(47.00)
6:42:55 PM	6:42:59 PM	43.52	46.00
6:43:00 PM	6:43:04 PM	43.80	47.00
6:43:05 PM	6:43:09 PM	43.86	46.00
6:43:10 PM	6:43:14 PM	43.99	45.33
6:43:15 PM	6:43:16 PM	43.71	(45.33)

(###) – Value copied from previous interval to replace void in Autoscope data set



t-Test: Paired Two Sample for Means		
	Variable 1	*Variable 2*
Mean	43.28999587	44.99074074
Variance	0.286761205	8.662458243
Observations	18	18
Pearson Correlation	0.711856184	
Hypothesized Mean Difference	0	
df	17	
t Stat	-2.78654209	
P(T<=t) one-tail	0.006329352	
t Critical one-tail	1.739606716	
P(T<=t) two-tail	0.012658703	
t Critical two-tail	2.109815559	

Variable 1: Radar

Variable 2: Autoscope

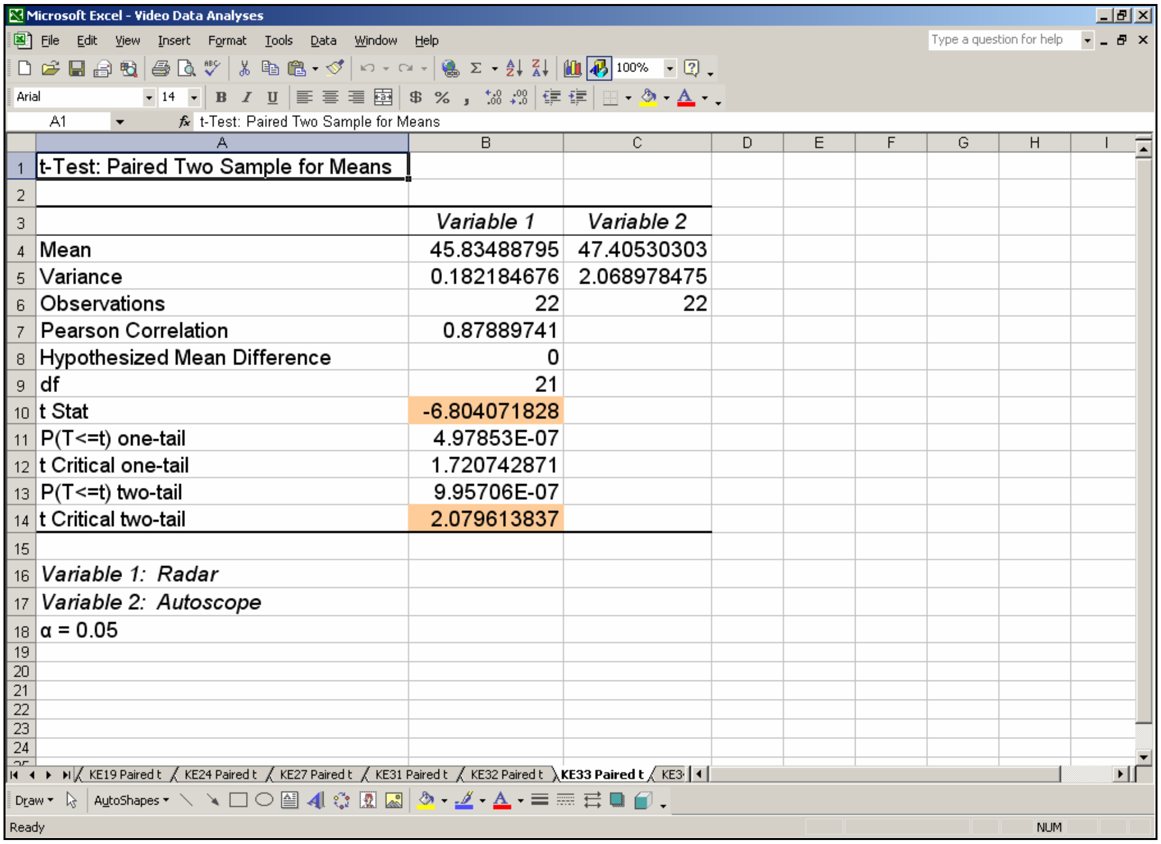
α = 0.05

Paired t-test Output from Excel for Train KE32

Autoscope Speed Detector Data paired with Calibrated Radar Data, Train KE33

Time		Average Speed (mph) From Times X1 to X2 Inclusively	
X1	X2	From Calibrated Radar	From Autoscope Speed Detector
6:57:51 PM	6:57:55 PM	44.92	44.00
6:57:56 PM	6:58:00 PM	45.08	44.00
6:58:01 PM	6:58:05 PM	45.13	46.00
6:58:06 PM	6:58:10 PM	45.35	47.00
6:58:11 PM	6:58:15 PM	45.39	46.25
6:58:16 PM	6:58:20 PM	45.59	46.50
6:58:21 PM	6:58:25 PM	45.65	47.67
6:58:26 PM	6:58:30 PM	45.66	47.00
6:58:31 PM	6:58:35 PM	45.88	48.00
6:58:36 PM	6:58:40 PM	45.91	48.00
6:58:41 PM	6:58:45 PM	45.89	48.25
6:58:46 PM	6:58:50 PM	46.08	47.50
6:58:51 PM	6:58:55 PM	46.24	48.25
6:58:56 PM	6:59:00 PM	46.22	(48.25)
6:59:01 PM	6:59:05 PM	46.20	49.00
6:59:06 PM	6:59:10 PM	46.32	49.00
6:59:11 PM	6:59:15 PM	46.12	48.67
6:59:16 PM	6:59:20 PM	46.16	48.50
6:59:21 PM	6:59:25 PM	46.21	48.75
6:59:26 PM	6:59:30 PM	46.27	48.33
6:59:31 PM	6:59:35 PM	46.11	48.00
6:59:36 PM	6:59:36 PM	46.01	46.00

(###) – Value copied from previous interval to replace void in Autoscope data set



t-Test: Paired Two Sample for Means		
	Variable 1	*Variable 2*
Mean	45.83488795	47.40530303
Variance	0.182184676	2.068978475
Observations	22	22
Pearson Correlation	0.87889741	
Hypothesized Mean Difference	0	
df	21	
t Stat	-6.804071828	
P(T<=t) one-tail	4.97853E-07	
t Critical one-tail	1.720742871	
P(T<=t) two-tail	9.95706E-07	
t Critical two-tail	2.079613837	

Variable 1: Radar

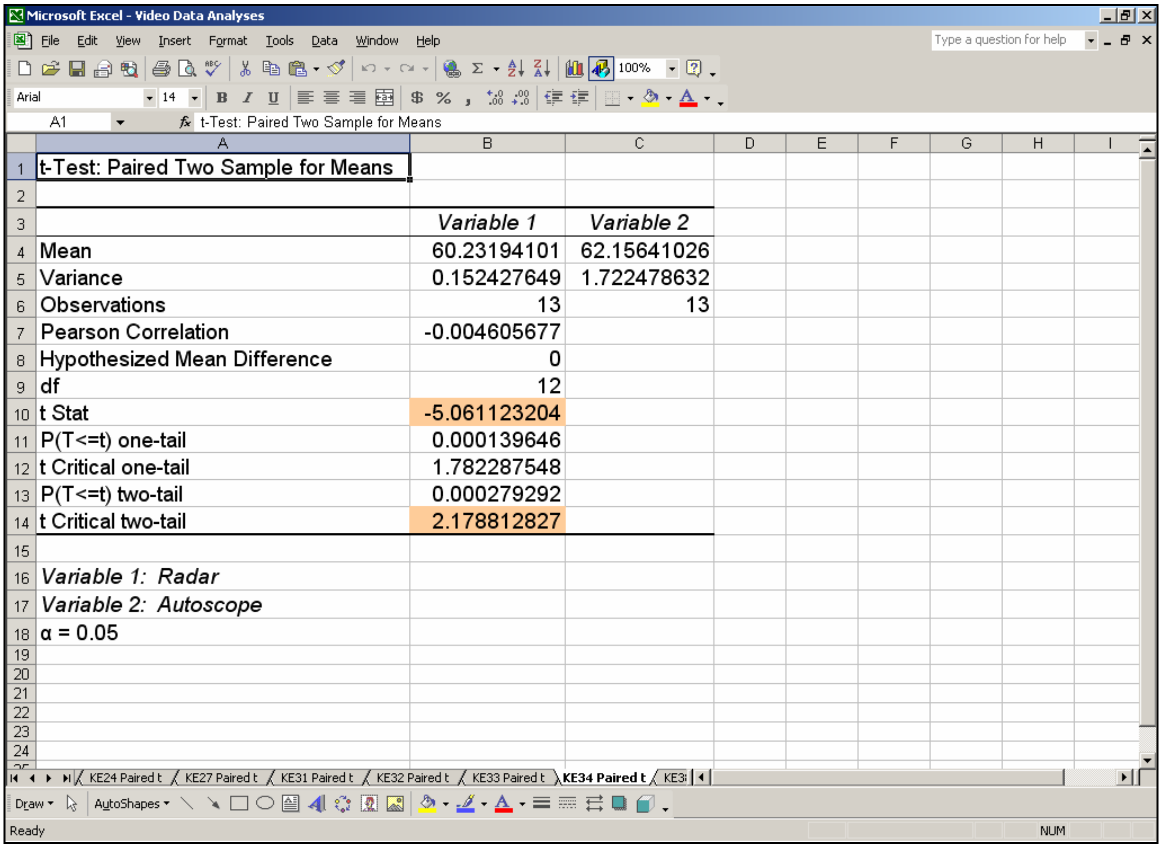
Variable 2: Autoscope

α = 0.05

Paired t-test Output from Excel for Train KE33

Autoscope Speed Detector Data paired with Calibrated Radar Data, Train KE34

Time		Average Speed (mph) From Times X1 to X2 Inclusively	
X1	X2	From Calibrated Radar	From Autoscope Speed Detector
7:08:51 PM	7:08:55 PM	60.31	58.50
7:08:56 PM	7:09:00 PM	60.08	62.00
7:09:01 PM	7:09:05 PM	59.90	63.00
7:09:06 PM	7:09:10 PM	60.13	63.00
7:09:11 PM	7:09:15 PM	60.00	62.00
7:09:16 PM	7:09:20 PM	59.88	61.50
7:09:21 PM	7:09:25 PM	59.94	63.33
7:09:26 PM	7:09:30 PM	60.38	62.60
7:09:31 PM	7:09:35 PM	60.27	63.50
7:09:36 PM	7:09:40 PM	59.93	62.40
7:09:41 PM	7:09:45 PM	60.15	61.50
7:09:46 PM	7:09:50 PM	61.18	63.20
7:09:51 PM	7:09:51 PM	60.87	61.50



t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	60.23194101	62.15641026
Variance	0.152427649	1.722478632
Observations	13	13
Pearson Correlation	-0.004605677	
Hypothesized Mean Difference	0	
df	12	
t Stat	-5.061123204	
P(T<=t) one-tail	0.000139646	
t Critical one-tail	1.782287548	
P(T<=t) two-tail	0.000279292	
t Critical two-tail	2.178812827	

Variable 1: Radar

Variable 2: Autoscope

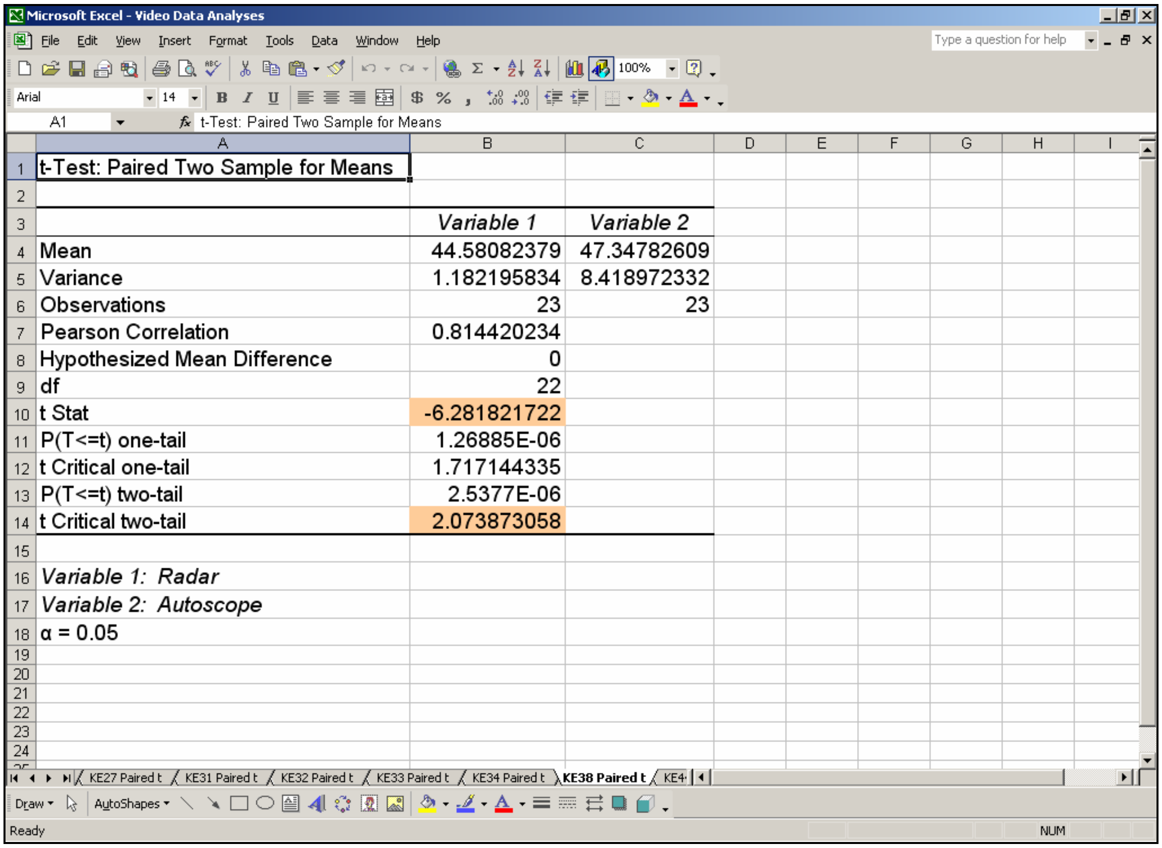
α = 0.05

Paired t-test Output from Excel for Train KE34

Autoscope Speed Detector Data paired with Calibrated Radar Data, Train KE38

Time		Average Speed (mph) From Times X1 to X2 Inclusively	
X1	X2	From Calibrated Radar	From Autoscope Speed Detector
7:39:42 PM	7:39:46 PM	42.71	40.00
7:39:47 PM	7:39:51 PM	42.78	(40.00)
7:39:52 PM	7:39:56 PM	42.83	43.00
7:39:57 PM	7:40:01 PM	43.18	48.00
7:40:02 PM	7:40:06 PM	43.48	(48.00)
7:40:07 PM	7:40:11 PM	43.61	47.00
7:40:12 PM	7:40:16 PM	44.00	(47.00)
7:40:17 PM	7:40:21 PM	44.03	(47.00)
7:40:22 PM	7:40:26 PM	44.14	(47.00)
7:40:27 PM	7:40:31 PM	44.44	47.00
7:40:32 PM	7:40:36 PM	44.68	(47.00)
7:40:37 PM	7:40:41 PM	44.76	(47.00)
7:40:42 PM	7:40:46 PM	45.05	(47.00)
7:40:47 PM	7:40:51 PM	45.17	(47.00)
7:40:52 PM	7:40:56 PM	45.08	(47.00)
7:40:57 PM	7:41:01 PM	45.15	50.00
7:41:02 PM	7:41:06 PM	45.51	50.00
7:41:07 PM	7:41:11 PM	45.88	(50.00)
7:41:12 PM	7:41:16 PM	45.69	50.00
7:41:17 PM	7:41:21 PM	45.94	50.00
7:41:22 PM	7:41:26 PM	45.80	(50.00)
7:41:27 PM	7:41:31 PM	46.13	(50.00)
7:41:32 PM	7:41:34 PM	45.32	(50.00)

(###) – Value copied from previous interval to replace void in Autoscope data set



t-Test: Paired Two Sample for Means		
	Variable 1	*Variable 2*
Mean	44.58082379	47.34782609
Variance	1.182195834	8.418972332
Observations	23	23
Pearson Correlation	0.814420234	
Hypothesized Mean Difference	0	
df	22	
t Stat	-6.281821722	
P(T<=t) one-tail	1.26885E-06	
t Critical one-tail	1.717144335	
P(T<=t) two-tail	2.5377E-06	
t Critical two-tail	2.073873058	

Variable 1: Radar

Variable 2: Autoscope

α = 0.05

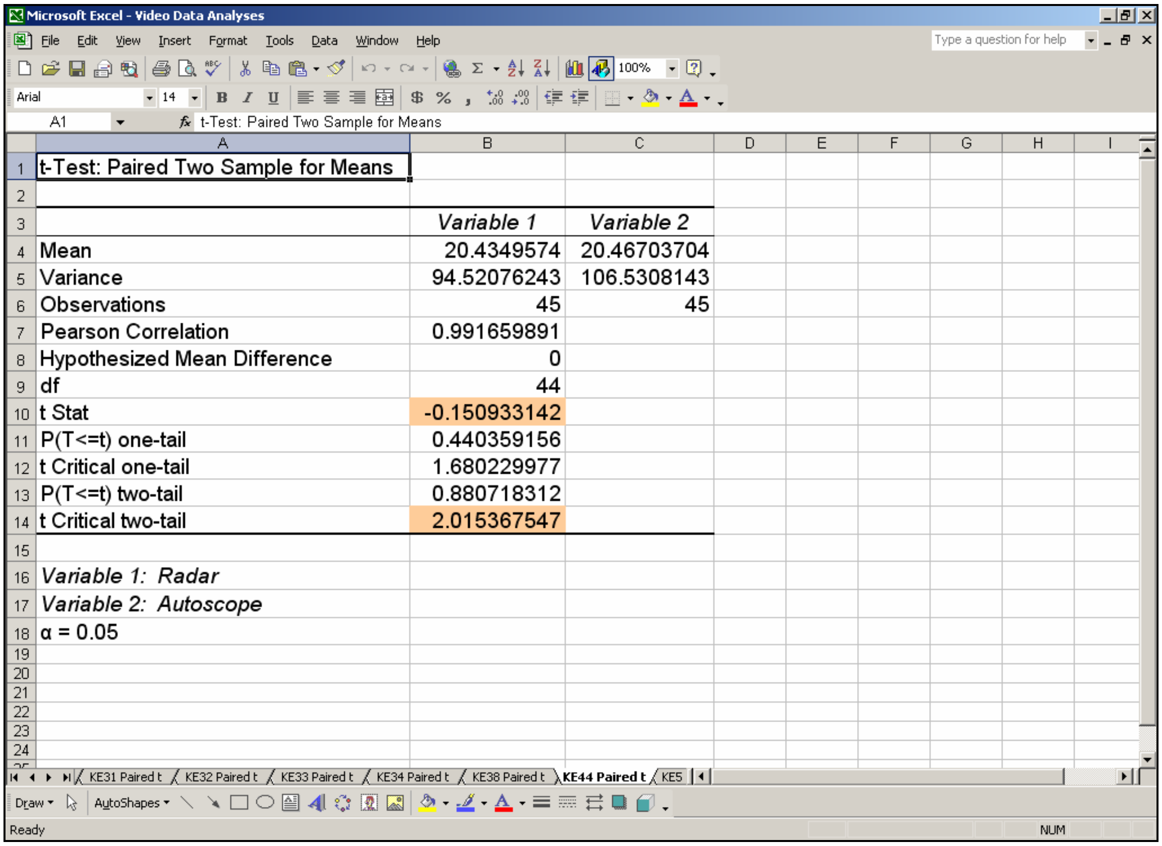
Paired t-test Output from Excel for Train KE38

Autoscope Speed Detector Data paired with Calibrated Radar Data, Train KE38

Time		Average Speed (mph) From Times X1 to X2 Inclusively	
X1	X2	From Calibrated Radar	From Autoscope Speed Detector
8:26:25 PM	8:26:29 PM	2.89	0.00
8:26:30 PM	8:26:34 PM	3.93	3.50
8:26:35 PM	8:26:39 PM	5.11	5.00
8:26:40 PM	8:26:44 PM	6.02	5.00
8:26:45 PM	8:26:49 PM	7.27	(5.00)
8:26:50 PM	8:26:54 PM	7.79	7.67
8:26:55 PM	8:26:59 PM	8.60	8.00
8:27:00 PM	8:27:04 PM	9.72	8.67
8:27:05 PM	8:27:09 PM	10.62	9.00
8:27:10 PM	8:27:14 PM	11.38	10.67
8:27:15 PM	8:27:19 PM	11.72	12.33
8:27:20 PM	8:27:24 PM	12.80	14.00
8:27:25 PM	8:27:29 PM	13.31	15.00
8:27:30 PM	8:27:34 PM	14.46	15.00
8:27:35 PM	8:27:39 PM	15.05	15.33
8:27:40 PM	8:27:44 PM	15.79	16.00
8:27:45 PM	8:27:49 PM	16.10	16.20
8:27:50 PM	8:27:54 PM	16.86	17.67
8:27:55 PM	8:27:59 PM	17.22	18.00
8:28:00 PM	8:28:04 PM	18.22	19.00
8:28:05 PM	8:28:09 PM	18.63	19.50
8:28:10 PM	8:28:14 PM	19.41	20.00
8:28:15 PM	8:28:19 PM	20.41	21.00
8:28:20 PM	8:28:24 PM	20.55	20.50
8:28:25 PM	8:28:29 PM	21.31	21.00
8:28:30 PM	8:28:34 PM	22.56	21.00
8:28:35 PM	8:28:39 PM	23.35	23.00
8:28:40 PM	8:28:44 PM	24.23	22.33
8:28:45 PM	8:28:49 PM	25.04	22.50
8:28:50 PM	8:28:54 PM	25.60	25.00
8:28:55 PM	8:28:59 PM	26.68	24.33
8:29:00 PM	8:29:04 PM	27.58	28.00
8:29:05 PM	8:29:09 PM	28.36	28.33
8:29:10 PM	8:29:14 PM	29.08	30.00
8:29:15 PM	8:29:19 PM	29.68	28.50
8:29:20 PM	8:29:24 PM	30.64	30.00
8:29:25 PM	8:29:29 PM	31.39	36.00
8:29:30 PM	8:29:34 PM	31.99	34.67
8:29:35 PM	8:29:39 PM	32.66	34.75
8:29:40 PM	8:29:44 PM	32.95	33.50
8:29:45 PM	8:29:49 PM	33.62	34.20
8:29:50 PM	8:29:54 PM	34.00	(34.20)
8:29:55 PM	8:29:59 PM	34.71	34.50
8:30:00 PM	8:30:04 PM	35.40	35.67
8:30:05 PM	8:30:07 PM	34.90	37.50

(###) – Value copied from previous interval to replace void in Autoscope data set

Note – Radar data unavailable before 8:26:25 PM



t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	20.4349574	20.46703704
Variance	94.52076243	106.5308143
Observations	45	45
Pearson Correlation	0.991659891	
Hypothesized Mean Difference	0	
df	44	
t Stat	-0.150933142	
P(T<=t) one-tail	0.440359156	
t Critical one-tail	1.680229977	
P(T<=t) two-tail	0.880718312	
t Critical two-tail	2.015367547	

Variable 1: Radar

Variable 2: Autoscope

α = 0.05

Paired t-test Output from Excel for Train KE44