APPLICATION OF ITS AT RAILROAD GRADE CROSSINGS

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Lance Allen Schulz
Dr. Ayman Smadi

Upper Great Plains Transportation Institute
North Dakota State University
Fargo, North Dakota

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Disclaimer

ABSTRACT

Rail-highway crossings confront urban areas with several challenges, which include safety and congestion. Many small and medium size metropolitan areas, especially in the Midwest region, were established along rail lines. The population growth, increase in traffic levels, and concentration of rail traffic along fewer lines further complicate these problems. In addition, rail lines block important links in the transportation network when trains are present, impeding traffic flow and, more importantly, emergency response teams.

As urban areas face severe budget cuts and the demand for adequate transportation facilities continues to rise, high cost solutions to separate rail lines from surface roads may be infeasible in many areas. However, several advanced technologies under the Intelligent Transportation System (ITS) have recently been developed to reduce congestion, improve traffic flow, and improve safety.

This paper investigates the application of advanced detection, traveler information, and advanced signal control systems to reduce congestion and incidents at railroad crossings. The study uses a traffic simulation model, TRAF-CORSIM, to evaluate the most effective scenario using ITS to alleviate railroad crossing problems; the Fargo-Moorhead metropolitan area was used as a case study. A typical system layout includes a train detection system that triggers a “train present signal phasing” and provides information to motorists, through Variable Message Signs (VMS), to take alternative routes. The results of the simulation indicate significant improvements in traffic conditions under the proposed ITS scenario.

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CHAPTER 1. INTRODUCTION

The purpose of this study is to investigate Intelligent Transportation System (ITS) technology applied to rail-highway grade crossing corridors. Intelligent Transportation Systems offer promising solutions by combining telecommunications, computers, sensing, and electronic technologies to provide real-time information to both traffic managers and travelers on traffic, weather, navigation, and vehicles (United States Department of Transportation, *The National ITS Program: Where We've Been and Where We're Going*, 1997).

Background

Over the last century, railroads have commanded a vital position in the United States transportation system. In the late 1800s and early 1900s, many cities developed around rail lines, as railroads provided these communities with access to transportation services for industrial and personal use. For this reason, many cities along the rail lines became hubs of commerce in their regions. Where rail lines turned cities into commerce hubs is evident in the larger Midwest cities, such as Kansas City, Omaha, Chicago, and St. Louis, which have thrived as major distribution centers for their regions. However, cities thriving as hubs and distribution centers are also evident in the smaller urban areas and farming states in the region.

Today the situation has changed greatly. Industries originally dependent on rail service have moved to suburban locations or have shifted to other modes of transportation. Also, the logistical just-in-time philosophy, which meets the goal of having the right goods at the right place at the right time, encourages a modal shift to the trucking industry (Ballou, 1992). These shifts have reduced or eliminated some rail operations, resulting in a higher concentration of rail traffic on fewer rail lines. In rural areas, the concerns are similar since rail service eventually moves most agricultural commodities to regional terminal elevators.

The unplanned growth of cities around rail lines has left them divided by the rail lines. In the absence of grade separations, regularly traveled rail lines hamper the transportation network connectivity. The increasing traffic volume on both city streets and high-density rail lines further complicates the problem. Cities that used to experience five or six trains a week are currently experiencing fifty or more trains a day (Western Governors' Association, 1997). This increase is due, in part, to the concentration of rail traffic over fewer lines, the amplified use of the unit trains, and the increase in coal traffic (Tolliver, 1997). Regardless of the reason, there is an increase in train movement through many cities, causing greater congestion, safety incidents, and higher pollution levels at rail-highway grade crossings.

Problem Identification

When a train occupies a grade crossing, motorists can experience a variety of problems including congestion, safety incidents, and higher pollution. An occupied grade crossing creates congestion and delays depending on the length of the train and affected links in the network. The effects of this closure are twofold. First, delays are experienced when cars wait for the train. Second, delays due to congestion in the area of the crossing occur, especially when there is inadequate storage space for vehicles. In these instances, spillback of waiting vehicles occurs on surrounding streets.

Drivers experience delays during these frequent traffic breakdowns or times of interrupted traffic flow. While waiting for a passing train, two types of delays are experienced: stop-time delay and travel-time delay. Stop-time delay is the amount of time a vehicle spends stopped or idling for the train on a given segment of the network. Travel-time delay is the difference between the original travel time and the actual travel time experienced, related to the delay caused by the passing train.

Importance of Research

With the combination of increased train traffic and increasing vehicle levels, more vehicles are being delayed from their destinations due to the impedance of traffic flow at grade crossings. In addition, there is a continuously rising emphasis on the value of travel time for individuals and goods since delays can result in lost productivity and have significant economic implications.

A second concern is the impact that grade crossing closures have on the emergency vehicle response systems. Since an occupied grade crossing acts as a closed road, emergency vehicles are forced to wait for the train to pass or try to maneuver through traffic and make use of an alternative route containing an underpass or overpass. These decisions that are forced upon emergency vehicle response teams can be life threatening.

The third concern is traffic accidents at grade crossings. Drivers' inappropriate behaviors, such as ignoring active warning devices or making a U-turn to avoid the train, cause major hazards at grade crossings. This inappropriate driver behavior creates confusion between other drivers and may result in vehicle conflicts and traffic accidents.

The fourth concern is the air pollution levels at grade crossings. When vehicles are forced to stop and idle at grade crossings, an increase in emission levels is experienced. According to Pisarski, "The short-term affects of relieving congestion are improved air quality" (1990). Improved air quality is achieved by decreasing the amount of time the engine is in operation and allowing traffic to operate at a higher speed.

Traditionally, grade separations, such as overpasses and underpasses between rail lines and surface streets, are used to eliminate the problems associated with grade crossings. In fiscal year 1991, grade separations accounted for nearly one-fifth ($41.7 million) of all state Federal-Aid Highway fund obligations (U.S. General Accounting Office, 1995). The construction of these overpasses and underpasses effectively eliminates the delays associated with grade crossings and the risk of accidents. Since grade separations are very expensive solutions, their use is often limited for streets with low traffic volumes. Given the financial constraints on local and state transportation agencies, this traditional solution is becoming less feasible, especially for routes with low to medium traffic levels. As a result, alternative methods must be sought.

The Intelligent Transportation System (ITS) offers useful options to reduce congestion, improve railroad crossing safety, and decrease pollution in rail corridors through the use of advanced detection, communication and traveler information, and adaptive signal control technologies. However, this potential may not be realized unless ITS user services are recognized as viable options compared to traditional infrastructure improvements and the proper evaluation of their plausibility is carefully considered.

Objectives of Research

The objective of this study is to investigate the use of ITS technologies at grade crossings. The benefit of using ITS will be evaluated and compared by means of key Measures of Effectiveness (MOE) values to the base case (or current policy). The study applies a proposed ITS design to Fargo's Main Avenue corridor to reduce congestion while trains occupy grade crossings. The specific components of ITS that are used include the following:

1) Detect the presence and length of a train through an Advanced Detection System (ADS).
2) Communicate and process information about a train to signal controls and motorists through an Advanced Traveler Information System (ATIS).
3) Modify signal timing plans and encourage motorists to use alternative routes through Advanced Signal Control System (ASCS).

The ADS provides the latest sensing technology that detects an approaching train. A traffic management center (TMC), central computer, or a master signal controller is used as a distribution center networking the ADS and ATIS together, and relaying the detection warning to variable message signs (VMS), which inform drivers of an approaching train. This warning provides time for drivers to divert to an alternative path. The ASCS optimizes traffic signal sequencing during a “train present phase” to allow for less congested traffic levels and a smoother flow of traffic through heavily traveled street and rail corridors.

The decision to use ITS to alleviate some of the problems at grade crossings must be based on a thorough evaluation of the most effective implementation scenarios and the operational and economic impacts associated with them. Specifically, the objectives of this research are summarized as the following:

1) Conduct a literature review of other ITS studies related to highway-rail grade crossings.
2) Develop a case study model of Fargo’s Main Avenue corridor including the Burlington Northern Sante Fe rail line.
3) Analyze and compare the effectiveness of alternative ITS scenarios based on key Measures of Effectiveness (MOE), such as total travel time, total delay time, Level-of-Service, and queue lengths, to the base case by using traffic simulation.
4) Document the results of the research.

Proposed Methodology

This study utilizes the Federal Highway Administration’s (FHWA) Traffic Software Integrated System (TSIS), which includes the simulation program named TRAF-CORSIM, as a tool to compare the differences in the key Measures of Effectiveness (MOE). Measures of Effectiveness are output values from a TRAF-CORSIM simulation. The MOE provide insight into the effects of the applied strategy on different traffic designs, thereby justifying the basis for optimizing that strategy. The MOE that will be computed in this study will relate to congestion. These MOE are average total travel time (seconds per vehicle), average total delay time (seconds per vehicle), Level-of-Service (rating scale), and queue length (vehicles). The MOE will be analyzed by comparing four different scenarios. The first scenario, or base case, is a simulation of the existing conditions: the current geometrics, traffic volume, percentage of trucks, traffic control strategies, and turning movements. The other three scenarios, or ITS alternatives, represent the proposed ITS design. These three ITS scenarios are modeled exactly like the base case except they have different turning movement percentages, to simulate vehicle diversion to the alternative routes once notified of an approaching train, and modified signal timing plans.

Organization

The remainder of this thesis is organized as follows: Chapter 2 provides a review and discussion of previous related studies, and a review of the traffic simulation model which is an integral part of this study. Chapter 3 provides an in-depth look at ITS, an overview of the data requirements for the study, and a discussion and illustration of the methodology used in this study. Chapter 4 is a description of the case study. Chapter 5 summarizes the results of this research demonstrating the proposed ITS technology applied to railroad-highway grade crossings. Chapter 6 is a discussion of conclusions from the results and recommendations for future research.

CHAPTER 2. LITERATURE REVIEW

This chapter consists of an overview of the highway-railroad National ITS Architecture and previous studies that have investigated congestion or accidents associated with highway-railroad grade crossings.

Highway-Railroad National ITS Architecture

There are nine constituents that make up the highway-railroad National ITS Architecture: track circuits, automatic gates, wayside equipment, traffic signals, variable message signs (VMS), surveillance, short range communications, rail operations, and traffic management. All of these components will be used to detect a train, communicate and process information about a train to signal controls and motorists, modify signal timing plans, and encourage motorists to use alternative routes.

Congress formally initiated the national Intelligent Vehicle Highway System (IVHS) Program in the United States with the passing of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. Since railroads do not pertain to the vehicle highway system, a discussion between the railroads and the United States Department of Transportation (USDOT) began to rename IVHS as the Intelligent Transportation System (ITS). This act made it easier for the railroads to have ITS appropriated monies distributed to them for such technologies.

ISTEA was structured to address a number of societal challenges involved in providing accessible transportation. The passing of ISTEA provided research and development departments not only the funding for such research but the opportunity to develop new methods from which transportation engineers could combine with 20th Century technologies in order to solve today's traffic problems.

Application of ITS Technologies to Highway-Railroad Grade Crossings

Questions that come to mind when looking at other grade crossing studies are:

- How bad are the problems associated with grade crossings?
- How did other research describe or estimate these problems?
- What ITS methods or measures have been used to alleviate some of these problems?

Currently, there are few studies that looked specifically at using ITS technology to pre-warn travelers of an approaching train and minimize the congestion at grade crossings. However, there are studies that have looked at using ITS technologies to help prevent accidents between vehicles and trains.

How bad are the problems associated with grade crossings? Concerning highway-railroad grade crossings, the worst problem is often associated with fatalities. If there was one highway-railroad grade crossing incident that shocked the nation, it was the 1995 Fox River Grove crash. This incident, which took the lives of seven students, not only acted as an alarm clock for railroad and transportation officials, but for the country as a whole. This tragedy motivated then Secretary of Transportation, Federico Pena, to deploy funding for a few metro areas to implement several highway-railroad grade crossing ITS elements quickly and to become leaders for other cities. The following studies report research on ITS that alerted travelers of approaching trains or train conductors of a vehicle stuck between the train tracks. At the time of this review, most of the studies were in their conceptual stages. Therefore, many of them did not have results; they only had thoughts of what types of technologies would improve congestion, safety, and air pollution levels at grade crossings.

Los Angeles Metro Blue Line

In 1993, before the Fox River Grove crash, the Los Angeles Metro Blue Line began testing automatic enforcement of lowered gates. This agency was the first one in the country to implement this technology at highway-railroad grade crossings. The objective of the Metro Blue Line was to enhance public safety at more than 100 crossings along this commuter rail line. Los Angeles' automatic enforcement equipment read the license plates of vehicles that drove around lowered gates. The 1993 tests showed that violations decreased by 92 percent at monitored crossings (Urban Transportation Monitor, 1995).

The next innovative design for the Metro Blue Line and the City of Los Angeles Department of Transportation was to pursue signal timing enhancement options. There were two operational changes considered for the signal timing enhancement. The first type of priority was a "green extension," whereby the automobile phases compatible with the light rail phases were held green longer than normally programmed. This enabled approaching light rail trains to be serviced in the current cycle, thus eliminating the need for the light rail trains to stop and wait for the next cycle. The second type of priority was an "early green," whereby the automobile phases that are compatible with the light rail phases are started early, thus reducing the wait incurred by the light rail trains. This type of priority has a lesser benefit to the light rail trains since a stop may still be required, but for a shorter time (Skehan and Pollan, 1997).

These changes were activated in mid 1995 and yielded a street running time savings of approximately 10 percent for the trains over the current signal timing method. The enhancements did not significantly impact the automobile traffic, since the number of occurrences of priority were minimal and did not incur any motorist confusion. Therefore, the Metropolitan Transportation Authority made these changes permanent by late 1995.

Federal Railroad Administration

The Federal Railroad Administration (FRA) tested three independently developed systems that detect the presence of an on-coming train and broadcast that information to a display inside specially equipped vehicles (Polk, 1997). This technology was tested in Pueblo, Colorado. Ultimately, this information would increase safety at rail-highway crossings by decreasing the chances of vehicular and train collisions. The FRA was searching for other railroads to undergo additional testing in emergency vehicles, school buses, and hazardous material haulers at the time of this review.

General Railway Signal and the New York State Department of Transportation

The third study reviewed was a joint study between the General Railway Signal (GRS) and the New York State Department of Transportation (NYDOT). This study looked at three different advanced technology measures to improve safety at rail-highway grade crossings. The first measure is to prevent gates from being lowered if the train has tripped a sensor, but is stopped at a station upstream. Keeping the gate raised would allow the vehicular traffic to flow as it normally would. The second measure is to advise travelers of an on-coming train via Variable Message Signs (VMS). The third measure is to inform conductors if a vehicle is stalled on the railroad tracks. When these technologies are combined, they could potentially minimize congestion, improve safety, and reduce pollution levels at grade crossings. Unfortunately, no results were available at the time of this review (New York State Department of Transportation, 1996).

Minnesota Department of Transportation and 3M

The Minnesota Department of Transportation, the 3M Corporation, Dynamic Vehicle Safety Systems (DVSS), and Hughes Transportation Management Systems developed a partnership to develop a system that warns specially equipped vehicles of an on-coming train via an in-vehicle display. This system has been operational for the last year on some school buses. The system uses 3M's wireless vehicle and roadside communication antennas that can be built into the familiar crossbuck, "RXR" sign, and the front vehicle license plate. Hughes' track side unit picks up a signal from the railroad's train detection electronics and transmits the signal to 3M's antenna-signs. The in-vehicle display, provided by DVSS, will alert drivers using both visual and audible signals (Minnesota Department of Transportation, 1996).

Burlington Northern Santa Fe and Union Pacific Railroads

The fifth study is a project that expands on the Positive Train Separation (PTS) test established by Burlington Northern Santa Fe and Union Pacific railroads. This project was the result of a head-on collision between two trains belonging to each of the railroad companies. The basis of the project is to avoid further head-on collisions by observing and tracking the trains via a Global Positioning System (GPS) located on the locomotives (Intelligent Transportation Society of America, 1995). The Texas Transportation Institute (TTI) is currently developing algorithms to integrate information about train locations and speeds into metropolitan area traffic management systems (TMS), thereby reducing delays for drivers. TTI is similarly concerned with the delays forced on emergency vehicles at highway railroad grade crossings.

Illinois Department of Transportation

The sixth study reviewed involves the Illinois Department of Transportation (IDOT). Similar to the FRA and Minnesota Guidestar, IDOT requested proposals to provide in-vehicle warning systems at highway-railroad grade crossings. IDOT will install over 300 emergency vehicles, school buses, and some passenger cars with in-vehicle warning devices. Trackside equipment will be installed at six highway-railroad grade crossings along the Metro commuter rail line near Chicago. These tests will be conducted over the 1997-1998 school year (Illinois Department of Transportation, 1996).

Wilbur Smith Associates

Salvagin and Taylor (1997) analyzed a corridor approach to railroad crossing consolidation in Columbia, South Carolina. Salvagin and Taylor’s study has close resemblance to this research; however, like many of the studies related to grade crossings, Salvagin and Taylor’s study focused on safety rather than congestion.

The major objective of Salvagin and Taylor’s study was to perform an analysis on closing grade crossings to reduce the number of locations where highway vehicle-train collisions can occur . The study used TSIS’s TRAF-CORSIM to determine approach delays, queuing/stacking of vehicles, optimal signal timing plans, Level-of-Service (LOS), and fuel consumption. The conclusion of their case study was to close three of the five grade crossings within the studied area. These closures diverted traffic to the surrounding roadways and intersections. The surrounding LOS was satisfactory; therefore, no auxiliary roadway mitigation was suggested with the exception of one new parallel roadway (Salvagin and Taylor, 1997).

Preemption at Signalized Intersections

The *Manual on Uniform Traffic Control Devices* (MUTCD) (1988) suggests that preemption be installed when a signalized intersection is located within 200 feet of a railroad grade crossing. There is no explanation in the MUTCD of how a distance of 200 feet was determined. Therefore, some cases may require preemption at intersections that are more than 200 feet from the tracks based on their prevailing queuing characteristics.

The queue length is a function of the approach volume, cycle length, saturation flow rate, and the effective green interval. If the traffic signal is currently present, queue lengths can be measured in the field. However, a decision to use preemption will most likely be made before the traffic signal is installed.

In general, railroad preemption is a signal phase designed to clear the vehicles in the storage space between the railroad tracks and the intersection. This phase is designed to provide enough green time to clear the queue that may accumulate before the train arrives to prevent vehicles from extending over the railroad tracks. A review of this theory will help understand the dynamics of signalized intersections when a train is approaching a grade crossing.

An article by Marshall and Berg (1997), which appeared in the *ITE Journal*, discussed the design guidelines for railroad preemption at signalized intersections and for improving grade crossing safety near intersections. The article presented guidelines for determining when preemption is required and for calculating the timing intervals.

Time and space are factors to consider in the design of railroad preemption. Marshall and Berg concluded that for unsaturated flow conditions, the time in seconds necessary to discharge a queue of vehicles is given by

$$t_o = \frac{q(C-g)}{s-q}, \qquad \textbf{(Equation 2-1)}$$

where

t_o = time (seconds)
q = arrival rate (vph)
C = cycle length (seconds)
g = effective green time (seconds)
s = saturation flow rate (vph)

Assuming an average vehicle spacing of 22 feet, the maximum average distance in feet that the queue will extend back from the stopline can then be calculated as

(Equation 2-2)

This procedure assumes continuous and consistent arrivals and departures. Therefore, the MUTCD provides a nomograph used to determine the maximum number of vehicles that may be expected to arrive at an intersection during one cycle at a preselected probability (or performance) level (Fullerton and Kell, 1982). To determine if preemption is required at an intersection, the expected maximum queue length is compared to the distance between the tracks and the intersection stopline. If the maximum queue length is greater than the available storage space, then railroad preemption is required.

When railroad preemption is required, the next step is to determine the amount of warning time needed and to establish new phase sequencing. These periods are usually referred to as "preemption clearance time" and "preemption period hold." Preemption clearance time involves a call from some track-based, sound-based, or surveillance-based device notifying the controller to terminate the current phase and enter the railroad preemption phase. The preemption period hold phase usually allows green movement to streets running parallel to the railroad tracks, and a red phase is for streets that intersect the railroad tracks (i.e., traffic across the railroad tracks is held). However, the problems of delay and congestion at grade crossings arise when vehicles choose to turn into the storage areas and wait for a train to clear the tracks. This vehicle movement tends to create spillback into the intersections resulting in excessive spillback, blocked intersections, and eventually interrupted or stopped traffic flow.

$$D = \frac{s}{164}\left[\frac{q(C-g)}{s-q}\right]$$

CHAPTER 3. METHODOLOGY AND DATA REQUIREMENTS

This chapter provides an overview of the Intelligent Transportation System (ITS), the methodology of the proposed ITS design, the data required to perform the simulation, and a review of the traffic simulation program (TRAF-CORSIM).

The Proposed Intelligent Transportation System Design

Developing the methodology involved many phases which are categorized into three broad groups: 1) the proposed Intelligent Transportation System Design (ITS Design); 2) methods used to evaluate ITS alternatives (traffic simulation); and 3) acquisition of data. A flowchart schematic of the methodology is shown in Figure 3-1. A case study, which applies the methodology to a rail corridor in Fargo, North Dakota, is presented in Chapter 4.

The first step in developing the methodology was to identify a framework for using ITS elements to reduce/mitigate the problems associated with highway-railroad grade crossings. The second step involved selecting a model to evaluate the base case compared to the proposed ITS design. Since the problem at hand was dynamic and required large amounts of data, the traffic simulation program TRAF-CORSIM was used because of its ability to simulate the effects of traffic control and ITS strategies on operational systems. Data required by TRAF-CORSIM were obtained by the Fargo/Moorhead Council of Governments, the City of Fargo, and the North Dakota Department of Transportation. Data information is discussed later in this chapter. Developing the ITS alternative, running the simulations, and gathering the Measures of Effectiveness (MOE) were the last steps. The proposed ITS design for this study involved three ITS components: 1) Advance Detection System (ADS), 2) Advanced Traveler Information System (ATIS), and 3) Advanced Signal Control System (ASCS).

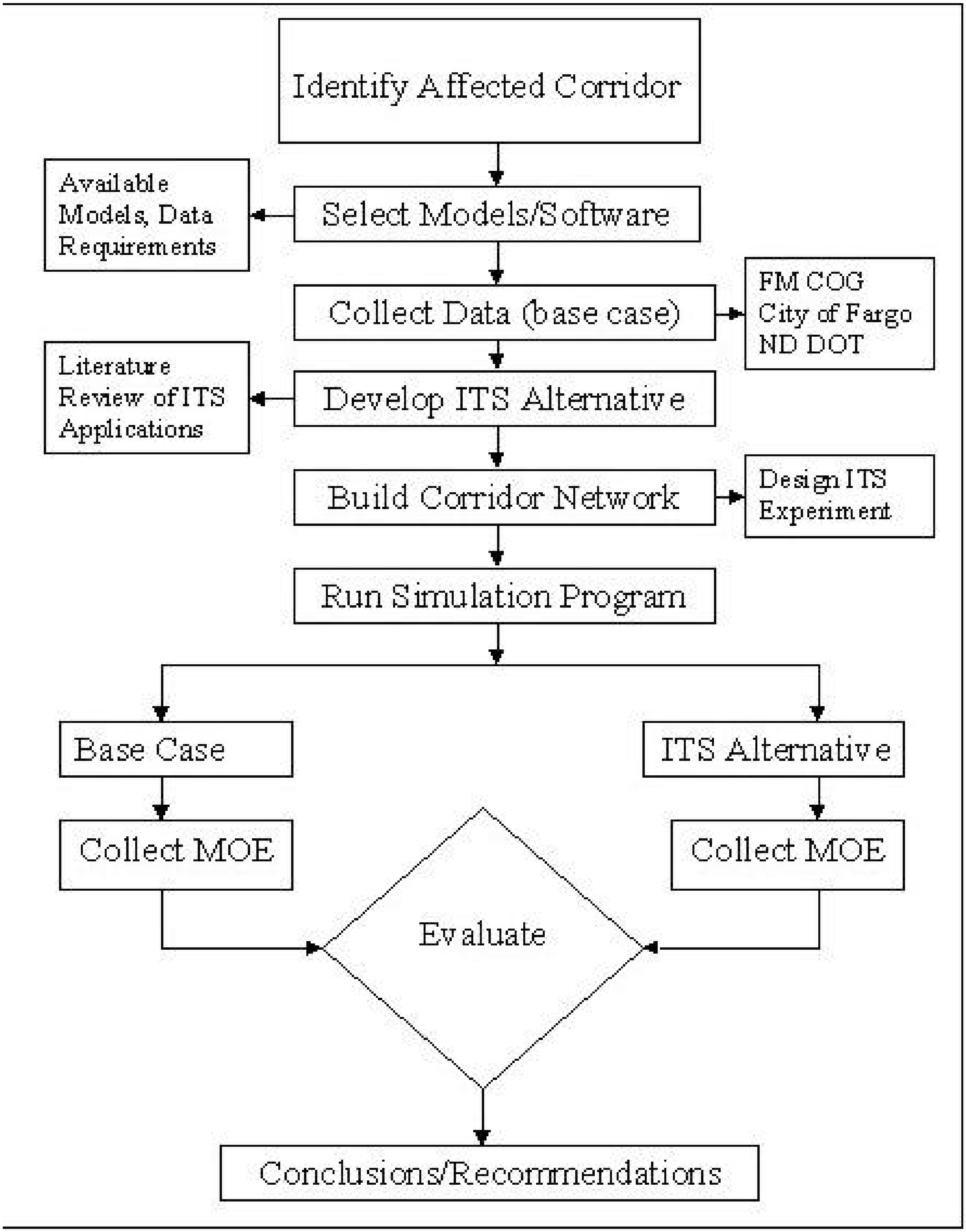


Figure 3-1. Methodology Flow Chart.

Advance Detection System

The Advance Detection System (ADS) uses advanced sensors to detect an approaching train (United Stated Department of Transportation, 1995). There are many different types of technologies available for detection systems. A few of the more popular forms are track-based, surveillance-based, and sound-based. These systems perform two functions on a train's detection: 1) recognize that a train is approaching the detection location and 2) determine the train's length and speed. If you know the length and speed, the total time that a train will occupy a grade crossing can be determined. This temporary grade crossing closure is the time that vehicles are subject to delay.

Advanced Traveler Information System

Advanced Traveler Information Systems (ATIS) convey "real-time" information to drivers through many different forms of communication devices (United States Department of Transportation - Federal Highway Administration, 1995). Some of the more common forms are variable message signs (VMS), radio or television broadcasts, kiosks, or responsive customized signs for a specific situation. The type of information displayed can be traffic conditions, incidents, construction, transit schedules, and weather conditions. For this study, the Advanced Detection System detects a train and relays the relevant information to motorists using variable message signs. The information displayed could include approaching train, expected delay time, and alternative routes. This information allows the drivers to select the best route based on their destinations. Assuming some percent of the drivers will divert to an alternative route, congestion levels throughout the corridor are reduced. The possible transfer of congestion to alternative routes is examined in Chapter 5.

Advanced Signal Control System

The Advanced Signal Control System (ASCS) provides for the integration and adaptive control of surface street systems. The ASCS responsibilities are to improve the flow of traffic; to give preference to public safety, transit or other high occupancy vehicles, and to minimize congestion while maximizing the movement of people and goods (United States Department of Transportation - Federal Highway Administration, 1995). These objectives are accomplished through communications, traffic control, and advanced detection. For this specific study, ASCS is integrated with the ADS, where a train detection activates the ASCS. This activation triggers a railroad preemption phase, allowing vehicles to clear the storage space between the tracks and the intersection. Once the clearing phase has expired, a new phase is activated and allows the optimal sequencing of movements to reduce congestion and spillback into the intersections.

Through the utilization of ASCS, drivers will be encouraged to take alternative paths since the green phase on the signal control lights favor this movement. A phase providing more green time in the direction of an alternative path reduces the number of drivers in the railroad corridor. An illustration of the overall procedure is shown in Figure 3-2.

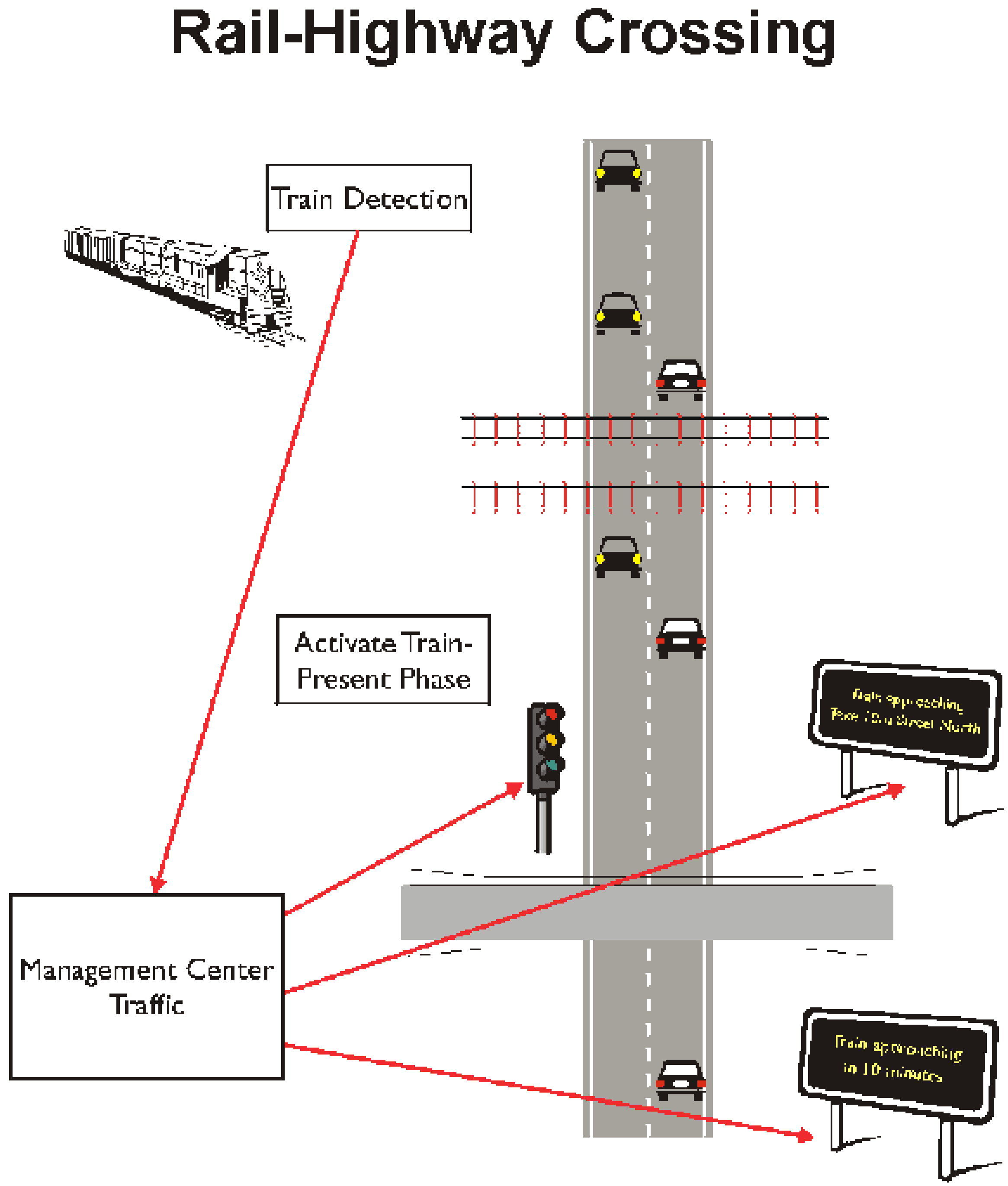


Figure 3-2. Illustration of Intelligent Transportation System implementation.

Traffic Simulation

Traffic simulation is used to evaluate the effectiveness of using ITS compared to the base case. The four scenarios developed for the case study are Case-1 (base case) and Case-25, Case-50, and Case-75 (three ITS cases). Case-1 and the diversion cases are simulated in TRAF-CORSIM, and their MOE are collected to compare the effectiveness of using ITS. As explained in Figure 3-1, comparing the difference of the diversion case MOE to the base case MOE determines if using the proposed ITS design will benefit the traffic flow in terms of total travel time, total delay time, Level-of-Service, and queue lengths. The decision to justify the proposed ITS design from the current practice will consider all MOE results.

Base Case

The base case, referred to as Case-1, replicates the case study's current conditions. The current conditions include the existing traffic volumes (peak PM period volumes were used), turning movements, preemption policy, and signal timing plans.

Diversion Cases (Case-25, Case-50, and Case-75)

The three diversion cases are exact duplicates of the base case except that they include the proposed ITS design. Included in the ITS design are new turning movements that model the drivers' responses to the VMS and optimal signal timing.

Data Requirements

TRAF-CORSIM is used as an analytical tool to calculate the needed MOE. The program requires vast amounts of information relating to the rail line corridor under analysis. The data can be grouped into three different types: geometric data, traffic control data, and volume related data. The data required were obtained from the Fargo-Moorhead Council of Governments (F-M COG), the City of Fargo, and the North Dakota Department of Transportation (NDDOT).

Geometric Data

Included in the geometric data are the topology of the roadway system, the geometries of each roadway component, and the lane channelization. The topology of the roadway system is modeled in the form of a link-node diagram as discussed in the previous chapter. The link-node diagram illustrating the case study network is shown in Appendix A. The geometric data included the length of each link (street) and the number of lanes per link. The lane channelization refers to left-turn only and right-turn only lanes. The geometric data for the case study are shown in Appendix B.

Traffic Control Data

Since simulation models depict current traffic control conditions, detailed information of each intersection is necessary. Such information includes the type of traffic control at each intersection (signalized, stop, yield, or right-of-way) (United States Department of Transportation - Federal Highway Administration, 1997). For signalized intersections, all of the signal-timing information, such as the type of controller (pretimed, semi-actuated, or actuated), phase sequencing, phase timings, phase time minimums, and loop detector locations, is required. Not all detector locations were available from the City of Fargo; therefore, it was suggested to place two detectors for all legs of the intersection. The first detector is six feet long and originates from the stop line. The second detector is placed 200 feet back from the stop line and is also six feet long. If two detectors are not needed, only the first detector is used.

The pretimed controller uses electromechanical dials to control the cycle length. Usually there are three dials allowing multiple signal plans to be implemented. The three different pretimed plans are AM peak, PM peak, and off-peak; some jurisdictions put the signal on “flash” at night (McShane and Roess, 1990). An actuated controller operates in the full-actuated mode when all phases and approaches have detectors and operate in the actuated mode (McShane and Roess, 1990). The concept of a semi-actuated controller is that there is a “main street” that should have the green as much as possible and a “side street” that should be given only enough green to service the relatively low and somewhat unpredictable demand (McShane and Roess, 1990). Therefore, the detectors are placed on the side-street approaches only. The traffic control data for the case study are shown in Appendix C.

Volume Data

Volume data information includes peak hour flows (volume per hour), percent trucks of the total volume, and the turning movement percentages. Peak hour is the single period (five minute, fifteen minute, or actual hour) in the day during which the maximum traffic volume occurs on a given facility. Therefore, peak hour flow is the amount of traffic recorded during the peak period (referred to in vehicles per hour). It is customary to design for peak hour since it is the worst case scenario.

Percent trucks of the total volume is the percentage of trucks compared to the total volume of vehicles. The percentage of trucks is crucial since one truck may be equivalent to 1.5 to 18 passenger cars depending on the facility type (freeway, 2-lane highway, intersection) and section type (level terrain, rolling terrain, mountainous terrain, and percent grade) (McShane and Roess, 1990). Turning movements are the number or percentages of vehicles turning right or left, or making a through movement. The turning movements provide for the distribution of traffic over the network. The volume data for the case study are shown in Appendix D.

Overview of the TRAF System (TRAF-CORSIM)

This section presents the various features of the computer program used to perform the case study analysis. Computer simulation is becoming one of the most important analytical tools for traffic engineers. The TRAF system simulation used in this study consists of an integrated set of simulation models that represent the traffic environment. The TRAF system consists of the following component models:

- NETSIM, a microscopic stochastic simulation model of urban traffic
- FRESIM, a microscopic stochastic simulation model of freeway traffic
- NETFLO 1 & 2, macroscopic simulation models of urban traffic
- FREFLO, a macroscopic simulation of freeway traffic

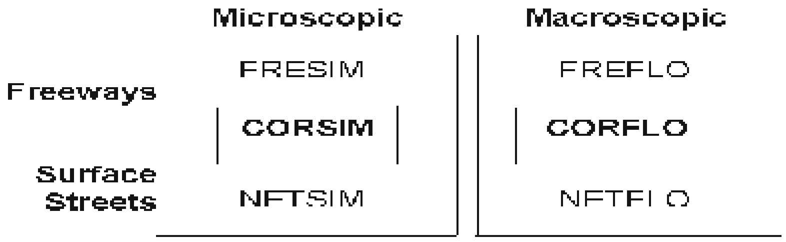


Figure 3-3. **TRAF family of models (United States Department of Transportation - Federal Highway Administration, 1997).**

The naming system for these models is based on a combination of prefixes and suffixes. The prefixes NET and FRE indicate a surface street network and a freeway network, respectively. The suffix SIM and FLO indicate microscopic simulation and macroscopic simulation, respectively. Microscopic models represent movements of individual vehicles, demonstrating the effects of very detailed strategies, such as relocating bus stations or parking restrictions, and influences of driver behavior. Less detailed strategies, such as changes in circulation patterns, can be studied with macroscopic models, which can also be used to gauge the impact of very detailed strategies outside the boundaries of the area in which they are implemented (United States Department of Transportation - Federal Highway Administration, 1997). The combination of NETSIM and FRESIM is named CORSIM, for corridor-microscopic simulation. The NETFLO 1, NETFLO 2, and FREFLO models are integrated into a group for use in analyzing transportation corridors; and the group, named CORFLO, is distributed for corridor-macroscopic simulation.

TRAF-CORSIM is the simulation model used for this study. TRAF-CORSIM simulates traffic flow on urban street networks by representing the movement of individual driver-vehicle combinations stochastically or involving probability. For each vehicle entering the network, a system of links and nodes, vehicle characteristics, and driver characteristics are randomly generated. As the vehicles move from one link to another, their turning movements on the new link is randomly assigned while satisfying the user-specified, link specific turning movement percentages. Random number generation in TRAF-CORSIM is based on a linear recursive procedure, one in which the procedure repeats itself indefinitely. Using a multiplicative congruence technique, a sequence of random numbers is generated by always calculating the next random number from the last obtained number (United States Department of Transportation - Federal Highway Administration, 1997).

Operating as an interval-based scanning model, each vehicle in the network is processed once every second, as are the control devices (i.e., traffic signals). Vehicle motion is governed by a series of car-following, queue discharge, and lane-changing algorithms in response to the traffic control devices.

The time-step record of each vehicle’s performance, as it moves through the network, is updated in a detailed “vehicle array” and a “link array.” The vehicle array contains recorded data, such as cumulative travel time, distance, delay, and number of stops. The link array contains link statistics similar to the vehicle array, but also includes the cumulative number of vehicles and the turning movements processed, as well as the link occupancy and the queue lengths (United States Department of Transportation - Federal Highway Administration, 1997).

Roadway Network

TRAF-CORSIM uses the concept of links and nodes to define the roadway network. Links are one-directional segments of streets or freeways, and nodes are usually the intersection of two or more links. In the case of a two-way street, each one-way roadway segment consists of one directional link. Links are described by their upstream and downstream node numbers, as shown in Figure 3-4. Entry links, exit links, interface links, and internal links have different types of numbering systems. Entry and/or exit nodes must be numbered between 8000 and 8999. Therefore, entry links have an upstream node number in the 8000s. Interface nodes are used as intermittent nodes, joining links together, and must be numbered between 7000 and 7999, so interface links have either an upstream or downstream node in the 7000s. Internal nodes can be numbered from 1 to 750. Internal links must have both upstream and downstream nodes numbered less than 750 (U.S. Department of Transportation - Federal Highway Administration, 1997).

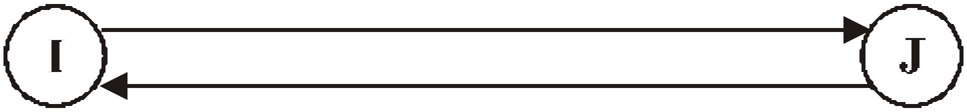


Figure 3-4. **Representation of a link-node diagram. The eastbound link is link (I, J) and has an upstream node number of I and a downstream node number of J. While the westbound link is link (J, I) and goes from upstream node J to downstream node I (U.S. Department of Transportation - Federal Highway Administration, 1997).**

The user specifies the coordinates of each node as well as the length of each link. Links cannot be longer than 4,000 feet without having an interface node in between them. The program also facilitates the user to describe link curvature through optional input data. The user can specify turning movements along volumes from a link in different directions on to adjacent links. The user also has an option to provide turn movement variations within a time period. This comprehensive input about the geometry of the network and traffic volumes enables the user to realistically create the highway network for simulation.

Fleet and Driver Characteristics

TRAF-CORSIM has 16 different types of vehicles, including different operating and performance characteristics that can be specified. There are four different categories of vehicle fleets: private automobiles, trucks, mass transit, and carpool vehicles. The user can reserve lanes for buses and carpools, specifying the percentage of trucks and carpool vehicles on each link. There are default values for acceleration, speed, headway, length, and occupancy of each vehicle type. The default maximum values of acceleration and speed for private automobiles are 5.5 mph/sec and 75 mph, respectively (United States Department of Transportation - Federal Highway Administration, 1997).

Furthermore, a "driver behavior characteristic" is assigned to represent different personality types for varying driver levels of aggressiveness in traffic (United States Department of Transportation - Federal Highway Administration, 1997). The personality varies from passive to aggressive over a scale of 1 to 10. This driver characteristic enables the simulation to account for aggressive drivers, which in some cases are the cause of incidents at highway-railroad grade crossings.

Vehicles are moved according to car-following logic, response to traffic control devices, and response to other demands. Congestion can result in queues that extend throughout the length of a link and block the upstream intersection, thus impeding traffic flow. Such is the case when a train occupies a grade crossing, causing traffic to queue and extend into the intersection.

Simulation of Traffic Control Devices

TRAF-CORSIM can simulate a network of intersections with any type of controls including yield signs, stop signs, pre-time signals, and actuated signals. For pretimed signals, the user can specify any cycle length (max 297 seconds per phase), the number of phases (up to eight), phase sequence, and phase split. For actuated signals, the program can simulate the type 170 or NEMA controller logic up to eight-phase, fully actuated, dual ring controller, including volume-density and phase overlap. Operational characteristics include maximum green time or maximum extension as well as vehicle extension. Since the program knows the position and time of each vehicle and the location of the detectors, it knows when and where a call is placed, and it changes signals accordingly. The ability to simulate different scenarios of sign or signal control strategies plays a major role in evaluating the optimal phase timings to ensure green movement to all directions of traffic.

Limitations of TRAF-CORSIM Modeling

TRAF-CORSIM is mainly used for surface street and/or corridor network analysis. This study will use TRAF-CORSIM for a corridor analysis. As noted in the literature review, TRAF-CORSIM has been used very little to model rail-highway grade crossings. Concerning this study, TRAF-CORSIM has limitations with modeling a grade crossing. The first limitation is that TRAF-CORSIM does not have the capability to model an actual rail line. The second limitation is TRAF-CORSIM's inability to model variable message signs (VMS) or ATIS. However, the program was manipulated to contravene these limitations. A rail line can be modeled as another surface street and treats a grade crossing as a pretimed, signalized street intersection. Traffic is held at this intersection to simulate a train blockage. The maximum duration that TRAF-CORSIM can hold traffic for is 297 seconds, or 4.95 minutes. Trains longer than 4.95 minutes cannot be modeled in the current TRAF-CORSIM version.

Modeling variable message signs is a key part of this study. They provide information at decision points in the network, so motorists can divert to alternative routes. One way to manipulate the program is by using origin-destination (O-D) tables. O-D tables are used in place of turning movement data to distribute the traffic from specific origins to their respective destinations. With the aid of O-D tables, TRAF-CORSIM routes traffic on the path of least resistance. In the event that a road is blocked for a red phase of a timing cycle, the cars will turn to avoid this incident, still arriving at their destination. Since O-D data were not available, turning movements were modified to reflect diversion at appropriate intersections and routes. The new turning movement percentages were based on the percentage of drivers willing to use the information and divert to an alternative path.

CHAPTER 4. CASE STUDY

Fargo, North Dakota, was chosen to demonstrate the ITS methodology presented in this study. Located on the eastern border of North Dakota, Fargo is the largest city in the state. The metropolitan area includes the cities of Fargo and West Fargo, North Dakota; and Dilworth and Moorhead, Minnesota. In 1996, the metropolitan area reached a population of 165,191, an increase of 2.5 percent since 1994 (United States Bureau of Census Data User Services Division, 1996). This growth is a contributing factor to the increased traffic levels that result in congestion. The remainder of this chapter provides a description of Main Avenue's corridor and the proposed use of ITS to relieve some of the problems at grade crossings.

Main Avenue Corridor

Main Avenue is a major arterial for the cities of Fargo, North Dakota, and Moorhead, Minnesota. Main Avenue serves as a trunk line for many employment centers, such as banks, city offices, restaurants, and other businesses. The downtown area containing these businesses makes up the central business district (CBD) for the two cities. Main Avenue also serves as a distributor to the West Acres Shopping Center and other commercial divisions in the metropolitan area.

Main Avenue runs parallel to a major east-west rail line owned and operated by Burlington Northern Santa Fe Railroad (BNSF RR). Currently, this line experiences 60 - 70 trains a day, with train lengths ranging from three to ten minutes (Dahlstrom, 1997). The rail line is very close to Main Avenue and leaves very little storage space for vehicles when a train occupies the grade crossing. The number of vehicles that can be stored in this area is dependent upon vehicle type (i.e., automobiles, buses, semis). If all vehicles are automobiles, the space can store between seven and eight cars. If a semi or bus is in the storage space, there is enough room for only one to two automobiles.

Geometric Characteristics

In Fargo, Main Avenue is a four-lane arterial that extends from 2nd Street in the east to 45th Street in the west, shown in Figure 4-1. However, the area including the proposed use of ITS where the at-grade highway-railroad crossings are located is between 2nd Street and University Drive. This segment of Main Avenue includes three at-grade crossings, located at 4th Street, Broadway, and 8th Street. Within this area are three underpasses, located at 2nd Street, 10th Street, and University Drive. These routes are key to the study since they will be used as alternative routes to divert traffic away from the rail crossings. The study area contains ten intersections, of which six are signalized. The signalized intersections are 2nd Street, 4th Street, Broadway, 7th Street, 8th Street, and University Drive. NP Avenue parallels the BNSF rail line to the north. NP Avenue is an eastbound one-way street from University Drive to 4th Street and bidirectional from 4th Street to 2nd Street. NP Avenue will serve as an alternative route for drivers on the north side of the BNSF rail line when a train is detected.

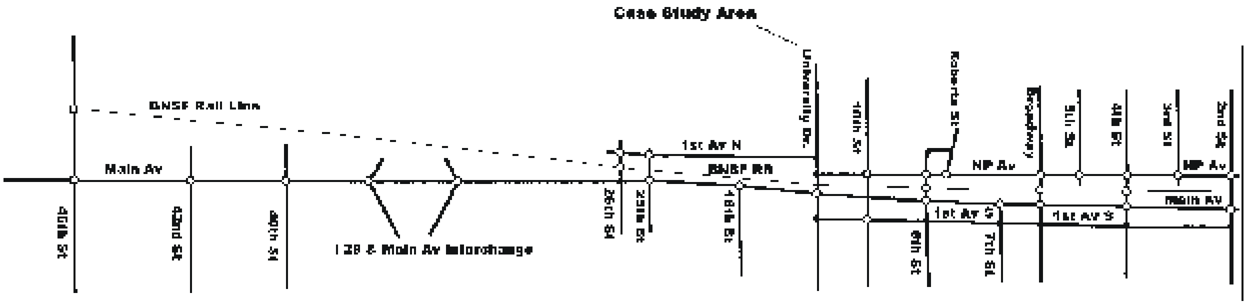


Figure 4-1. Main Avenue and Burlington Northern-Santa Fe Railroad corridor.

On the south side of Main Avenue is 1st Avenue South, a bidirectional street from 4th Street through University Drive. An access road connects 2nd Street to 4th Street. First Avenue South will serve as an alternative route for drivers on the south side of Main Avenue and drivers with destinations outside the downtown Fargo area.

Traffic Volumes

Traveling in an easterly direction, Main Avenue carries an average daily traffic (ADT) of 25,100 vehicles and a peak-hour volume of 1,430 vehicles at the intersection of Main Avenue and University Drive. The turning movements at this location are 80% through movement, and the remaining 20% make a right turn. During average peak-hour traffic conditions, 1,144 eastbound vehicles travel into Main Avenue's corridor under study. Traveling westbound, Main Avenue carries an ADT of 18,000 vehicles and 1,190 vehicles during peak-hour conditions at the intersection of Main Avenue and 2nd Street. The turning movements at this location are 48% through movement, while 29% make a left turn and the remaining 23% make a right turn. Therefore, on average, 571 vehicles travel from the east during peak-hour conditions into Main Avenue's corridor under study.

Traffic conditions in the case study area corridor (between University Drive and 2nd Street) are generally good during off-peak hours. During peak-hour, traffic is slowed and operates at a varying Level-of-Service throughout the study area. When a train occupies a grade crossing during peak-hour traffic, spillback into Main Avenue intersections is widespread; and a breakdown in traffic flow occurs. Based on the description of Level-of-Service ratings, when a train occupies a grade crossing, some traffic commonly operates at Level-of-Service F. Level-of-Service F is defined as greater than 60 seconds of stopped delay time per vehicle (Transportation Research Board, 1994). One explanation in the *Highway Capacity Manual* (HCM) (1994) for a Level-of-Service F is poor progression and long cycle lengths. The current train preemption favors traffic flowing parallel to the railroad tracks and blocks north-south traffic turning on or crossing Main Avenue through an extended red phase in the direction of the rail line. This continuous red phase for north-south travelers, along with vehicles delayed by spillback on Main Avenue into the intersections, may be blamed for the majority of the stopped delay time.

Intelligent Transportation System Design

As stated in the methodology section, this case study uses three ITS elements: 1) Advanced Detection System (ADS) to detect an approaching train, 2) Advanced Traveler Information System (ATIS) to provide information about taking an alternative route to drivers because of an approaching train, and 3) Advanced Signal Control System (ASCS) to activate the traffic controls for a train present phase.

Advanced Detection System

The purpose of the advanced detection system (ADS) is to detect a train via some sensing device and notify a Traffic Management Center (TMC) or a signal control box that a train is approaching the metropolitan area. For this study, the actual method of detection is not included in the proposed ITS design. It is mentioned to recognize that the technology is available.

The proposed ITS design detects eastbound and westbound trains. The eastbound train is detected twice to determine the actual speed of the train when it enters the metropolitan area. The length and speed of the train are needed to calculate how long a train will occupy a grade crossing. The westbound train are only detected once since it slows down to enter Dilworth and Moorhead where BNSF’s switching yard is located.

The maximum speed a train proceeds through the metropolitan area is 40 miles per hour. Information on an approaching train is provided five minutes before occupying its first grade crossing.

The reasoning behind five minutes is explained in Section 4.2.2. By knowing the time before traveler information is provided and the length and speed of the train, a distance from the grade crossing to a detector location can be calculated.

A detection location of 3.33 miles before the first grade crossing was calculated for eastbound trains. Detecting the eastbound train 3.33 miles before the first grade crossing at 8th Street places a detector near the 45th Street crossing. The second detector location is placed exactly one mile upstream to determine the train's exact speed when entering the metropolitan area. The 3.33 mile distance for a westbound train and its first grade crossing at 4th Street places a detector on the east side of Moorhead. Therefore, a detector for a westbound train is placed at the BNSF switching yard. Train detection locations are shown in Figure 4-2.

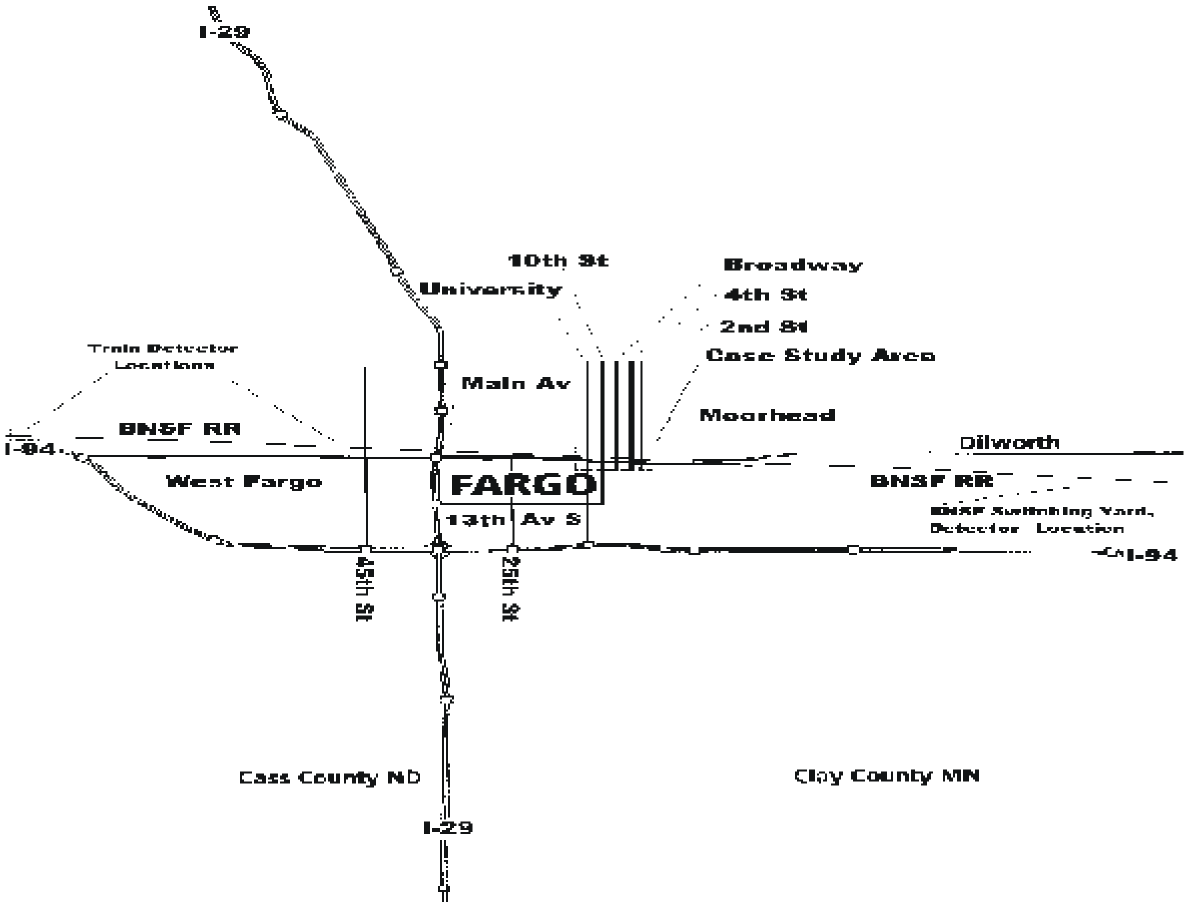


Figure 4-2. **Train Detection Locations within the Fargo-Moorhead Metropolitan Area.**

Advanced Traveler Information System

ATIS provides pre-trip and/or en route travel-related information to drivers. In this case, ATIS will inform drivers of an approaching train and suggest taking an alternative route via an underpass or overpass. This information is displayed on variable message signs. To ensure adequate time for drivers to divert, information that a train is approaching is provided to drivers starting five minutes before and while a grade crossing is occupied. Currently, it takes two and a half minutes to travel from one side of the corridor to the other during uninterrupted traffic flow and off-peak hour conditions. A continuous countdown in minutes may be displayed on the VMS until the train has occupied the grade crossing. The variable message signs will continue to give traveler's information until the train has cleared the tracks.

The variable message signs are placed in strategic locations providing ample time for drivers to divert to an alternative route. Seven variable message signs will be used in this design along with twelve customized railroad signals. The customized railroad signals are Light Emitting Diode (LED) signs portraying a railroad crossing symbol, implying that the grade crossing is closed. One minute before a train occupies the crossing, the customized railroad crossing symbol will flash until the train has cleared the tracks. The seven VMS are located at the following locations:

- 10th Street & 2nd Ave. S.
- 4th Street & 1st Ave. N.
- Broadway & 1st Ave. N.
- University Drive & 1st Ave. N.
- 18th Street & Main Ave.
- 4th Street & 2nd Ave. S.
- 2nd Street & Main Ave.

The theory behind the customized railroad signs is to provide last minute information to drivers caught between the VMS and the railroad tracks. Therefore, placing the LED signs around the railroad corridor intersections will provide these drivers "last chance" information of an approaching train, suggesting that they take an alternative route. The 12 customized railroad signals are located at the corners of the following intersections and illustrated in Figure 4-3.

- 3rd Street and NP Ave.
- 4th Street and NP Ave.
- 5th Street and NP Ave.
- Broadway and NP Ave.
- 8th Street and NP Ave.
- University Drive and NP Ave.
- University Dr. and Main Ave.
- 4th Street and 1st Ave. S.
- Broadway and 1st Ave. S.
- 7th Street and 1st Ave. S.
- 8th Street and 1st Ave. S.
- 10th Street and 1st Ave. S.

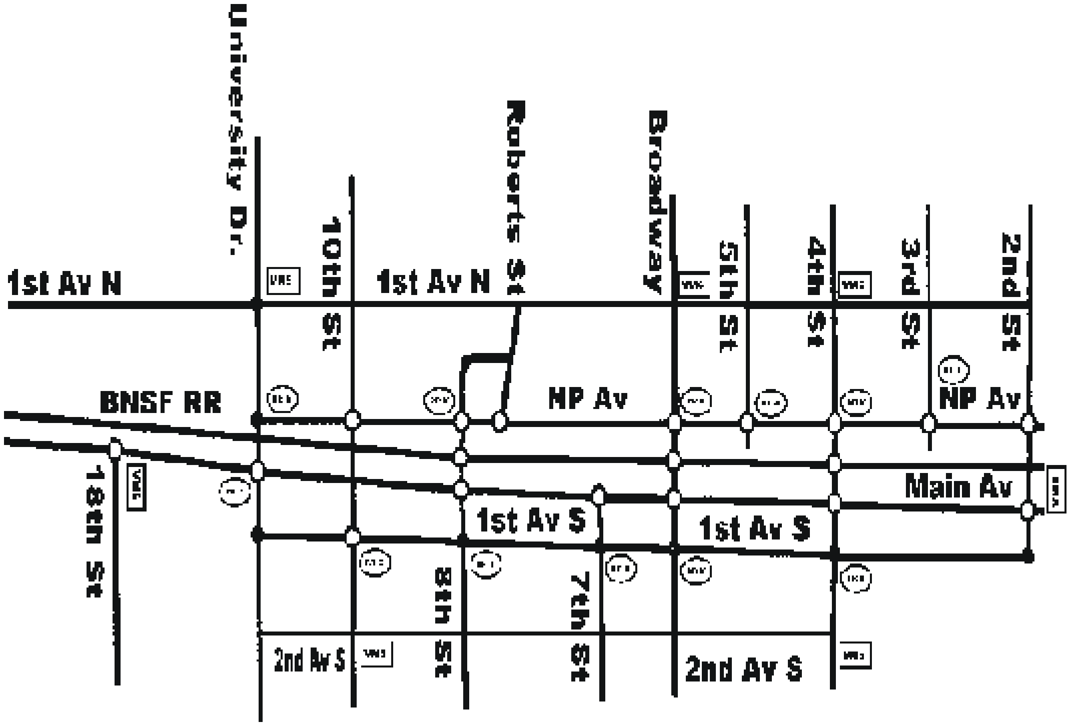


Figure 4-3. **Variable Message Sign and customized train present sign locations.**

Advanced Signal Control System

When the surveillance system detects a train and notifies the central controller, the central controller triggers the ASCS to change the current traffic control cycle to a “train present phase.” The current cycle phasing for a “train present phase” is to give all traffic paralleling the railroad tracks (i.e., Main Avenue traffic) green movement. However, the MOE results show that this practice is not the best. The proposed ITS design provides minimum green time to traffic turning onto or crossing Main Avenue. The minimum green time for a protected left turn onto Main Avenue was calculated by using Greenshields' updated equation defined as follows (McShane, 1990):

$$T = 1.1 + 2.1n \qquad \text{(Equation 4-1)}$$

where

T = minimum green time, seconds
n = maximum number of vehicles in queue, vehicles

Applying this equation results in the following green time for northbound traffic turning onto Main Avenue:

- 4th Street and Main: 25 seconds green, 2 seconds yellow, 1 second red
- Broadway and Main: 25 seconds green, 2 seconds yellow, 1 second red
- 8th Street and Main: 15 seconds green, 2 seconds yellow, 1 second red

The major movement of traffic, Main Avenue traffic, is then given 75 seconds of green time for every minimum green time for northbound traffic turning onto Main Avenue.

Alternative Routes

This study defines an alternative route as a route that uses an underpass and avoids Main Avenue from University Drive to 2nd Street. There are three underpasses in the area under investigation located at 2nd Street, 10th Street, and University Drive. However, University Drive is one-way south, and 10th Street is one-way north. The alternative routes that drivers would take are dependent upon their origins and destinations. The following six origin and destination scenarios are analyzed:

1) Downtown Fargo (CBD) to south Fargo, West Fargo, or I-29.

2) Downtown Fargo (CBD) to Moorhead via Main Avenue bridge.

3) Traveling east on Main Avenue prior to University Drive to downtown Fargo (CBD).

4) Traveling north on 10th Street prior to Main Avenue to downtown Fargo (CBD).

5) Traveling north on 10th Street prior to Main Avenue to Moorhead.

6) Traveling west from Moorhead via Main Avenue bridge to downtown Fargo (CBD).

Downtown Fargo (CBD) to Fargo (south of Main Avenue)

Trip one considers origins within the CBD and destinations south of Main Avenue. If the trip originates north of 1st Avenue North, the driver can take this street to University Drive and use the underpass; however, if the trip originates south of 1st Avenue North or the driver was not informed in time, the only alternative is to drive around the block and use 1st Avenue North and the underpass at University Drive.

Downtown Fargo (CBD) to Moorhead via Main Avenue Bridge

Trip two considers origins within the CBD and destinations in Moorhead via the Main Avenue bridge. Depending on where the trip originates, drivers can travel the street they are on to NP Avenue and continue to 2nd Street using the underpass for their trip into Moorhead. If the drivers receive the information in advance, they can bypass NP Avenue and go straight to 2nd Street using the underpass. An alternative to the underpass, depending on the drivers' destinations, is to continue on 2nd Street and cross the NP Avenue bridge. If the destination is south of Main Avenue, the driver would use the 2nd Street underpass. If the destination is north of Main Avenue, the driver would use the NP Avenue bridge.

Traveling on Main Avenue Prior to University Drive to Downtown Fargo (CBD)

Trip four considers an origin on Main Avenue prior to University Drive with a destination in the CBD. The alternative for this trip is also to turn right onto University Drive, turn left onto 1st Avenue

South, turn left onto 10th Street, and use the underpass. Depending on the destination in the CBD, drivers can take the respective street of their choice.

Traveling on 10th Street Prior to Main Avenue to Downtown Fargo (CBD)

Trip five considers an origin on 10th Street prior to Main Avenue with a destination in the CBD. This trip is exactly like the previous scenario once the driver turns onto 10th Street. The driver continues on 10th Street using the underpass while avoiding a right turn onto Main Avenue where congestion and delays are experienced.

Traveling on 10th Street Prior to Main Avenue to Moorhead

Trip six considers an origin on 10th Street prior to Main Avenue with a destination in Moorhead. A normal route involves a right turn onto Main Avenue; however, due to the congestion and delays, the driver can make a right turn on 1st Avenue South and proceed to the intersection of 2nd Street and Main Avenue crossing the Main Avenue bridge.

Traveling from Moorhead via Main Avenue Bridge to Downtown Fargo (CBD)

Trip seven considers an origin using the Main Avenue bridge with a destination in the Fargo CBD. With advanced warning of an approaching train, a traveler can make a right turn onto 2nd Street using the underpass instead of driving down Main Avenue. Once the drivers have traveled through the underpass, they can take the appropriate street to arrive at their respective destinations.

Motorist Diversion Estimates

Since TRAF-CORSIM does not model traveler reaction to variable message signs, changes in turning movements were calculated to model the effects in traffic conditions when drivers are informed of an approaching train. The assumptions relate to what percentage of drivers will actually divert to an alternative route. Previous studies have determined the percentage of drivers that react to information in major cities while offering little information on smaller-to-medium sized cities. However, preliminary results from a survey conducted in the Fargo-Moorhead metropolitan area indicated that three different diversion percentages could be used: 25, 50, and 75 percent (Krahn and Smadi, 1998). To clarify these values, when using the 25 percent scenario, for example, the model will not divert 25 percent of the total traffic volume traveling through the corridor. The model will divert 25 percent of the volume that uses the grade crossings based on turning movement data. Applying these assumptions to the traffic simulation program will make it react as if the drivers were provided information of an approaching train. There are two major intersections where traffic is diverted: Main Avenue and University Drive, and Main Avenue and 2nd Street. The effects that the three different diversion percentages have on turning movements at the two major intersections are illustrated in **Table 4-1**. **The same three diversion percentages were implemented for NP Avenue traffic**.

Table 4-1. Turning Movement Changes With Different Diversion Percentages

Intersection and Turning Movement	**Case-1**	**Case-25**	**Case-50**	**Case-75**
Main Avenue & University Dr.	**(%)**			
Westbound Left Turn	n/a	n/a	n/a	n/a
Westbound Right Turn	20	27	35	43
Westbound Through Movement	80	73	65	57
Main Avenue and 2nd Street	**(%)**			
Eastbound Left Turn	29	31	32	34
Eastbound Right Turn	23	24	26	27
Eastbound Through Movement	48	45	42	39

CHAPTER 5. CASE STUDY RESULTS

The purpose of this chapter is to discuss the case study results. The first section discusses the validation of the simulation runs based on volume comparisons. The remaining sections summarize the analysis of Measures of Effectiveness (MOE) for the case study under the base case and the ITS scenarios, including average total time, average delay time, Level-of-Service analysis for selected links and specific intersections, and queue length. Finally, the last section discusses the effects of diverting traffic to alternative routes.

Validation of Results

Four cases were simulated to compare the key Measures of Effectiveness (MOE). Each case was simulated 10 times to compute the average MOE. All scenarios have identical geometrics, traffic control devices, and design volumes. The base case (Case-1) is differs from the other three cases (Case-25, Case-50, and Case-75) by their turning movements and the north-south traffic control strategy for the affected intersections. Recall, the different turning movement percentages affect the simulation program to react as if drivers were notified of an approaching train and diverted to their respective alternative paths.

Traffic volume is one way to validate results. If you compare generated traffic volumes to observed ones for the base case, you can assume (in good faith) that the program will give you valid or realistic results. The average peak volume per hour of traffic entering the corridor from the west at the intersection of University Drive and Main Avenue is 1,430 vehicles, while 1,190 vehicles enter from the east at the intersection of 2nd Street and Main Avenue. The diversion scenarios have their respective percentages of traffic entering the corridor and diverting to the alternative routes. The results of simulated volumes are compared to the actual intended volumes in Table 5-1.

Some studies have concluded that TRAF-CORSIM does not always duplicate the intended volume conditions (Wang and Prevedouros, 1997). An examination of the volume that TRAF-CORSIM simulated for the four scenarios in this case study supports this argument. However, the volumes that TRAF-CORSIM did simulate are not that unrealistic in terms of a larger perspective, since the design volume values were determined from an average daily traffic count during peak-hour traffic conditions. Therefore, traffic may vary depending on different road conditions, incidents, and even the day of the week from the volumes that TRAF-CORSIM simulated. The lower amount of simulated traffic results in fewer traffic delays at the grade crossings and their respective intersections for the base case. Therefore, less traffic simulated will underestimate the overall benefits of using ITS at highway-railroad crossings.

The highest value simulated is in Case-25 on the link from 2nd Street to 4th Street. TRAF-CORSIM simulated 636 vehicles per hour when the intended volume was 536. A higher simulated traffic volume will result in longer travel times, longer delay times, longer queue lengths, and a lower LOS. All other volume values were below 10% and did not significantly alter the overall results.

Table 5-1. Design Volumes Compared to the Simulated Volumes

Simulation Run	Case-1			Case-25			Case-50			Case-75		
Street Section	Design Volume (vph)	Simulated Volume (vph)	%	Design Volume (vph)	Simulated Volume (vph)	%	Design Volume (vph)	Simulated Volume (vph)	%	Design Volume (vph)	Simulated Volume (vph)	%
Main & University	1430	1223	-14.5	1430	1366	-4.48	1430	1288	-9.93	1430	1318	-7.83
University - 10th St	1144	1053	-7.95	1044	1132	7.77	930	964	3.53	815	895	8.94
Main & 2nd St.	1190	1105	-7.14	1190	1126	-5.38	1190	1143	-3.95	1190	1127	-5.29
2nd St. - 4th St.	571	604	5.46	536	636	15.72	500	530	5.66	464	495	6.26

* Analysis was performed using a four minute train.

Comparison of Measures of Effectiveness (MOE)

Three different Measures of Effectiveness (MOE) values were collected from the simulation output. MOE values were used to compare the proposed ITS design to the base case. The three MOE collected are 1) total travel time through the corridor in seconds per vehicle, 2) total delay time through the corridor in seconds per vehicle, and 3) vehicle queue lengths at the intersections which contain grade crossings (Main Avenue & 4th Street, Main Avenue and Broadway, and Main Avenue and 8th Street).

In addition to the MOE gathered from the simulation output, a Level-of-Service analysis was also used to compare the benefits of implementing the proposed ITS design. According to the *Highway Capacity Manual* (1994), Level-of-Service (LOS) for a signalized intersection is defined by the average stopped delay time per vehicle and calculated for a given lane group by the following equation:

$$\mathbf{d = d_1 DF + d_2} \qquad \textbf{(Equation 5-1)}$$

$$\mathbf{d_1 = 0.38C\ [1 - g/C]^2/\{1 - (g/C)[Min(X,1.0)]\}} \qquad \textbf{(Equation 5-2)}$$

$$\mathbf{d_2 = 173X^2\ \{X-1) + [(X - 1)^2 + mX/c]^{0.5}\}} \qquad \textbf{(Equation 5-3)}$$

where

d = stopped delay, seconds per vehicle;

d_1 = uniform delay, seconds per vehicle;

d_2 = incremental delay, seconds per vehicle;

DF = delay adjustment for quality of progression and control type;

X = volume to capacity ratio for lane group;

C = cycle length, seconds;

c = capacity of lane group, vehicles per hour;

g = effective green time for lane group, seconds; and

M = an incremental delay calibration term representing the effect of arrival type and degree of platooning.

The Level-of-Service criteria are stated in terms of average stopped delay per vehicle and are shown in Table 5-2. Therefore, comparing the simulation program's calculated stopped delay time per vehicle with the Level-of-Service criteria will determine a Level-of-Service rating for each link of the intersection.

Table 5-2. Level-of-Service Criteria for Signalized Intersections

LEVEL OF SERVICE	STOPPED DELAY PER VEHICLE (SEC)
A	≤ 5.0
B	> 5.0 and ≤ 15.0
C	> 15.0 and ≤ 25.0
D	> 25.0 and ≤ 40.0
E	> 40.0 and ≤ 60.0
F	> 60.0

Source: *Highway Capacity Manual*, 3rd Edition, Washington, DC, 1994.

Total Travel Time Comparison

The total travel time refers to the time it takes to travel through the corridor from University Drive to 2nd Street or 2nd Street to University Drive. Travel times for the ITS scenarios re significantly lower than the base case (Table 5-3). Travel times for westbound traffic are higher than eastbound traffic due, in part, to delays caused by spillbacks where the train is present.

Table 5-3. Total Travel Time for Case-1 Compared to the Diversion Cases

Street Section	Direction Traveling	Case-1 Average Total Travel Time (Secs/veh)	Case-25 Average Total Travel Time (Secs/veh)	Case-50 Average Total Travel Time (Secs/veh)	Case-75 Average Total Travel Time (Secs/veh)
University - 10th	East	34.2	35.1	34.5	34.1
10th - 8th	East	56.8	47.1	44.0	42.6
8th - 7th	East	24.3	23.8	25.5	24.5
7th - Broadway	East	71.9	33.2	30.9	32.3
Broadway - 4th	East	35.7	42.1	43.0	41.4
4th - 2nd	East	77.2	76.2	69.9	71.6
Total Time	East	**300.03**	**257.35**	**247.82**	**246.49**
10th - University	West	51.2	59.1	50.9	47.3
8th - 10th	West	32.5	32.9	33.7	32.9
7th - 8th	West	236.0	122.1	30.2	34.6
Broadway - 7th	West	24.9	29.7	26.6	25.4
4th - Broadway	West	117.7	44.0	39.0	39.1
2nd - 4th	West	67.5	60.6	57.9	56.0
Total Time	West	**529.70**	**348.32**	**238.31**	**235.40**

* Analysis was performed using a four minute train.

Figure 5-1 is a snapshot from TRAFVU (TRAF Visualization Utility), a state-of-the-art graphics post-processor for FHWA’s TRAF-CORSIM microscopic traffic simulation system, illustrating the effect that spillback has on total travel time. This particular snapshot portrays a worse case scenario where drivers would actually block the intersection and on-coming traffic, compared to waiting in the left-turn pocket. This particular snapshot is taken from Case-1, where no ITS components have been implemented. Figure 5-2 is a snapshot taken at the identical time frame from the proposed ITS design when 75 percent of the effected vehicles divert to their respective alternative routes. Note in Figure 5-2, there are only three vehicles in the storage area compared to Case-1 where the storage area was nearly full. Figure 5-2 illustrates the potentials of using ITS to reduce the traffic levels at railroad crossings and the domino effect on delay time and queue length, which increase total travel time.

All diversion cases with the proposed ITS design reduced the total travel time for both eastbound and westbound traffic compared to the base case. For eastbound traffic, the proposed 75 percent diversion ITS design reduced the travel time the most compared to the base case. Average travel times through the corridor were reduced by one minute. The westbound traffic gained significant time savings when the proposed ITS design was implemented.

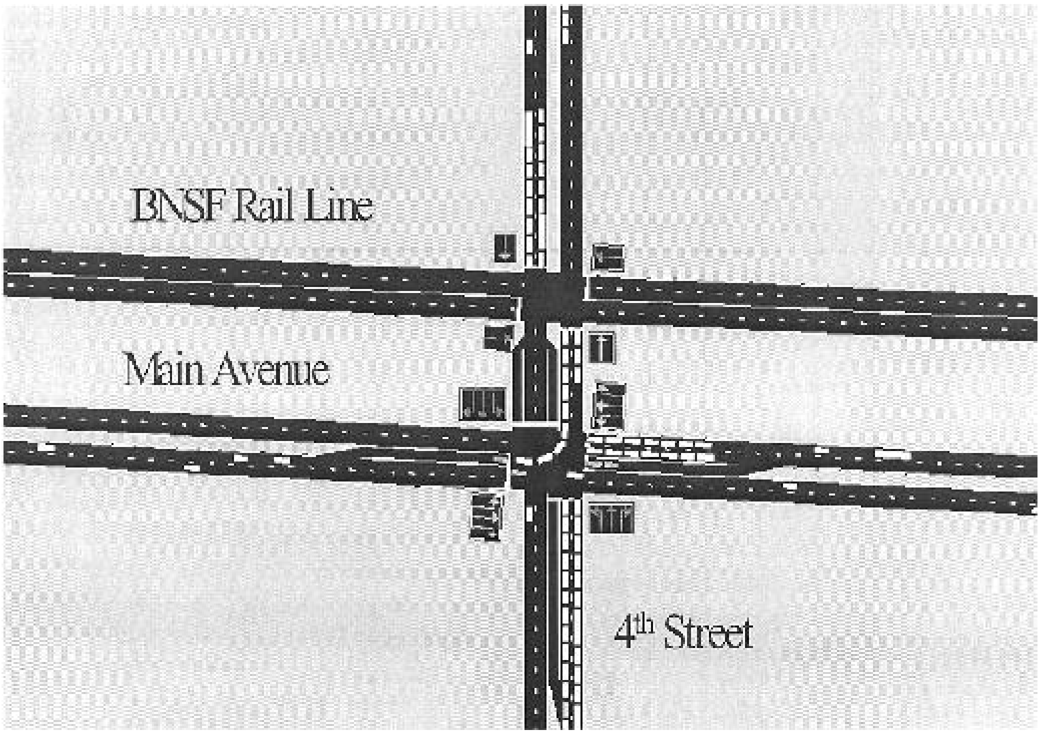


Figure 5-1. Illustration of spillback effect on total travel time for Case-1 (base case).

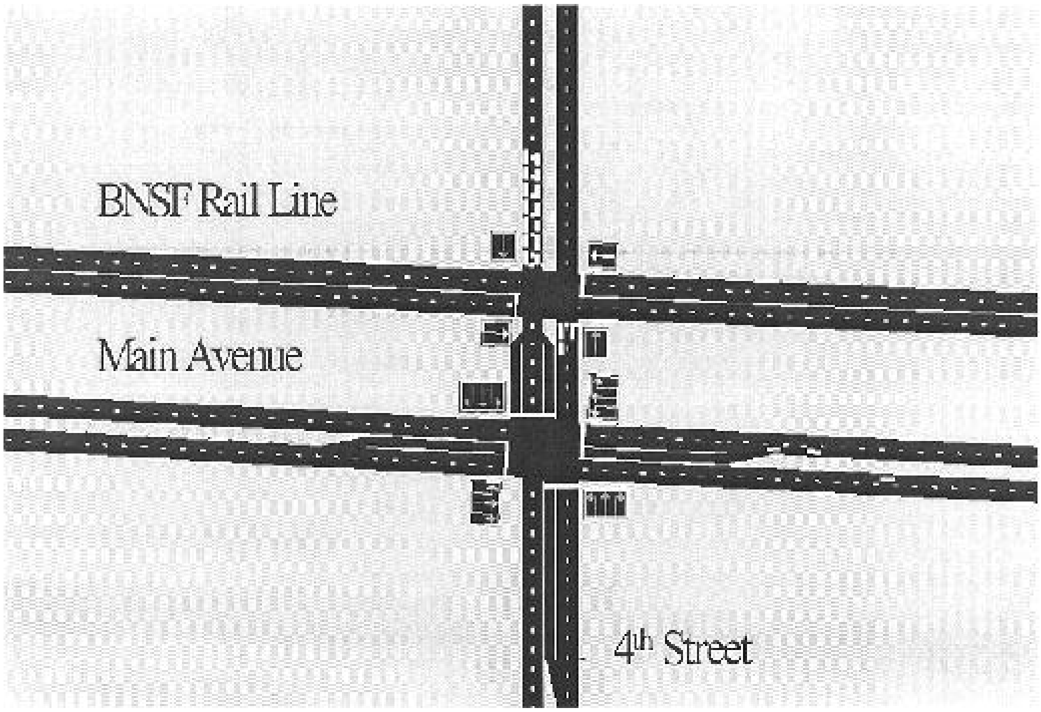


Figure 5-2. **Illustration of no spillback effecting total travel time for Case-75 (ITS design).**

Note the 50 percent and 75 percent diversion scenarios are very close in total travel time values. One explanation is that traffic has approached optimal conditions and is affected by the slightest driving behavior and traffic control sequencing. However, the 75 percent case did reveal better results where total travel time was reduced from 530 seconds to 235 seconds. The 75 percent case resulted in average total travel time savings of 294 seconds or 4.91 minutes.

The proposed ITS design reduced the total travel time through the corridor for every diversion case. On certain links where travel time was not reduced, there were no more than a few seconds added to the initial total travel time. On these links, this minor increase in travel time was the result of providing a minimum green movement to traffic waiting to turn onto or crossing Main Avenue, instead of penalizing them with a continuous red light until the train clears the tracks.

Total Delay Time

Delay time is a MOE that may represent many different types of delay including stopped delay, approach delay, travel-time delay, time-in-queue delay, or percentage of vehicles stopping. However, for this study, the delay calculated from the simulation program is stopped time delay in terms of seconds per vehicle. The average total stopped delay was gathered for each link in the corridor and summed to determine the total average delay time through the corridor. The total delay time results are shown in Table 5-4.

Except eastbound traffic for Case-25, the average total delay time was reduced in all diversion scenarios. The 30-second increase from Case-1 to Case-25 for eastbound traffic is attributed to providing a minimum green movement for traffic turning on or crossing Main Avenue. Since this case only has 25 percent diversion of traffic from the grade crossing, traffic experienced spillback attributing to the delay time. However, in the cases where 50 percent and 75 percent of the traffic is diverted, there is a reduction of approximately 50 seconds of delay. Unlike Case-1 and the 25 percent diversion case, the remaining average total delay time of approximately 80 seconds through the corridor for these cases can be attributed to the green movement for traffic turning on and crossing Main Avenue and not spillback. Spillback is less likely to affect eastbound lanes as much as the westbound lanes because of left-turn lanes. However, the eastbound vehicles making left turns into the grade crossing storage areas are frequently stranded in turning pockets when the grade crossing storage area is full. This phenomenon is less likely to happen when 50 percent and 75 percent of the vehicles divert to alternative routes. For westbound traffic, all cases experienced a decrease in average total delay time. Similar to the total travel time results, the 75 percent diversion case for westbound traffic had the largest decrease in average total delay time compared to the base case with approximately 296 seconds, or 4.92 minutes, of savings. Note that this value is close to the same value as the decrease in total travel time through the corridor. Therefore, if 50 percent of the drivers respond favorably to VMS, significant benefits should be expected.

Table 5-4. Total Delay Time for Case-1 Compared to the Diversion Cases

Street Section	Direction Traveling	Case-1 Average Total Delay Time (Seconds)	Case-25 Average Total Delay Time (Seconds)	Case-50 Average Total Delay Time (Seconds)	Case-75 Average Total Delay Time (Seconds)
University - 10th	East	4.1	5.0	4.4	4.0
10th - 8th	East	26.8	16.1	14.4	12.7
8th - 7th	East	9.3	8.8	10.6	9.5
7th - Broadway	East	56.9	18.2	15.9	17.5
Broadway - 4th	East	5.7	12.1	13.0	11.4
4th - 2nd	East	32.3	31.3	25.0	26.6
Total Time	East	**135.06**	**165.92**	**83.17**	**81.68**
10th - University	West	21.2	29.7	20.8	17.3
8th - 10th	West	2.6	2.9	3.7	2.9
7th - 8th	West	221.0	110.1	15.2	18.6
Broadway - 7th	West	9.9	14.7	11.6	10.4
4th - Broadway	West	87.8	14.0	9.0	9.1
2nd - 4th	West	22.6	15.6	13.0	11.0

Total Time	West	**364.98**	**186.91**	**73.31**	

* Analysis was performed using a four minute train.

Level-of-Service (LOS) Analysis

As described earlier, Level-of-Service (LOS) can be related to delay time calculated by the simulation program for the signalized intersection. There are six categories of Level-of-Service ranging from A to F. The analysis performed was not an intersection analysis but a

Level-of-Service rating comparison determined from the average total delay time produced by the computer simulation program. The LOS results for the Main Avenue corridor are shown in Table 5-5.

When evaluating the delay time as a LOS rating, notice that all sections except one improved their LOS rating. The base case had LOS ratings ranging between B and F, which were improved by the proposed ITS design with LOS ratings ranging between B and D. One exception was on the link between 7th Street and 8th Street for the 25 percent diversion case where the LOS was F. Except the Broadway to 4th Street section, the other two sections, 8th Street to 7th Street and Broadway to 7th Street, had LOS ratings of B; however, these sections are not actual grade crossing entrances. It is not surprising that the Broadway to 4th Street section has a LOS rating of B. This section has a left and right turn pocket, and the grade crossing storage area has two lanes. Therefore, this section should have a higher LOS rating compared to the Broadway grade crossing storage area, which only has one lane for the grade crossing storage area and no left or right turn pockets. Similarly, 8th Street has a left turn pocket, but the grade crossing storage only has one lane.

The section of 4th Street to 2nd Street is the east end of the corridor and was the only section to have a LOS rating fall to D after it achieved a LOS C for the 50 percent diversion case. The reason why the LOS fell is explained by the amount of traffic diverting to the alternative routes creating more left turn delays at 2nd Street. Other than this section, all diversion cases improved their LOS when compared to the base case.

A LOS analysis for signalized intersections was also performed. Synchro, a complete software package for modeling and optimizing traffic signal timings was used for this analysis

Table 5-5. Level-of-Service Ratings for Case-1 Compared to the Diversion Cases

Street Section	Direction Traveling	Case-1 Average Level of Service (LOS)	Case-25 Average Level of Service (LOS)	Case-50 Average Level of Service (LOS)	Case-75 Average Level of Service (LOS)
10th - 8th	East	D	C	B	B
8th - 7th	East	B	B	B	B
7th - Broadway	East	E	C	C	C
Broadway - 4th	East	B	B	B	B
4th - 2nd	East	D	D	C	D
7th - 8th	West	F	F	C	C
Broadway - 7th	West	B	B	B	B

4th - Broadway	West	F	B	B
2nd - 4th	West	C	C	B

* Analysis was performed using a four minute train.

(Trafficware, 1997). Synchro provides a complete implementation of the 1994 Highway Capacity Manual for calculating delays and Level-of-Service. An overall intersection LOS demonstrates how the proposed ITS design effects total intersection delays compared to selected links, as did the previous LOS analysis.

The Level-of-Service ratings for all base case scenarios, except the intersection of 7th Street and Main Avenue, were F. The intersection of 7th Street and Main Avenue had a LOS rating of A for Case-1 and remained at A after the implementation of the proposed ITS design. This high LOS is reflective of the insignificant amount of left turn traffic, where most intersection delays accumulate influencing the LOS rating. At the remaining five signalized intersections, the LOS ratings improved significantly when the proposed ITS design was implemented. The results of Synchro's LOS analysis are shown in Table 5-6. Notice the diversion intersections, 2nd Street and Main Avenue, and University Drive and Main Avenue, remain at LOS F. There is no improvement in the LOS at these intersections because of the number of left turn vehicles. In all other cases, the intersection LOS improved from a LOS rating of F to B. Referring to Table 5-2, these improvements decrease intersection delay from greater than 60 seconds to between 5 and 15 seconds. This reduction in intersection delay is a significant amount of savings and is noticed in the previous average delay time analysis.

Table 5-6. Intersection Level-of-Service Analysis Results

INTERSECTION	Case-1	Case-25	Case-50	Case-75
2nd Street & Main	F	F	F	F
4th Street & Main	F	C	B	B
Broadway & Main	F	B	B	B
7th Street & Main	A	A	A	A
8th Street & Main	F	C	B	B
University & Main	F	F	F	F

* Analysis was performed using a four minute train.

Queue Length Comparison

For this study, queue length is defined as the number of vehicles lined up at the intersection. At grade crossings, spillback and traffic control signal timings have a major influence on the severity of queue length. Queue length comparisons will illustrate the benefit that the proposed ITS design has on traffic turning on or crossing Main Avenue from the north and south compared to the base case. These affected links are defined as “traveling north” and “traveling south” in the results. The “traveling north” links are on the south side of Main Avenue trying to turn left or right onto or cross Main Avenue. The “traveling south” links are the lanes on the north side of Main Avenue paralleling the storage area lanes. The “traveling south” queue lengths are not that important since train preemption will grant a clearing phase before the train occupies the grade crossing to reduce the chance of a vehicle being stopped on the tracks. The maximum queue length results comparing the current practice with the proposed ITS diversion cases are shown in Table 5-7. Note that there are two lanes represented for each case. In simplifying the results, “Lane 1” is defined as the curb lane and, where applicable, the right turn pocket; “Lane 2” is the through lane and, where applicable, the left turn pocket.

Table 5-7. Maximum Queue Lengths for Case-1 Compared to the Diversion Cases

Intersection	**Case-1 Queue Length (Vehicles)**		**Case-25 Queue Length (Vehicles)**		**Case-50 Queue Length (Vehicles)**		**Case-75 Queue Length (Vehicles)**	
Lane #	1	2	1	2	1	2	1	2
Main & 4th Street								
Traveling East	2	1	5	5	7	6	5	6
Traveling West	8	6	5	5	3	4	4	3
Traveling North	17	11	3	0	2	0	1	0
Traveling South	5	7	2	3	2	3	1	2
Main & Broadway								
Traveling East	14	15	13	10	11	9	11	10
Traveling West	15	12	5	6	3	4	2	3
Traveling North	18	n/a	8	n/a	3	n/a	2	n/a
Traveling South	8	n/a	7	n/a	3	n/a	1	n/a
Main & 8th Street								
Traveling East	9	29	13	14	13	3	10	1
Traveling West	28	1	34	0	14	0	10	1
Traveling North	18	n/a	2	n/a	2	n/a	1	n/a
Traveling South	8	n/a	6	n/a	6	n/a	4	n/a

* Analysis was performed using a four minute train.

Case-1 queue length results explain the impact that a passing train has on traffic breakdown and overall congestion. Queue length values range from 1 to 29 for the base case compared to 0 to 11 for the 75 percent diversion case. For these values, if a snapshot was taken from TRAF-CORSIM comparing the base case to the ITS alternatives, it would illustrate excessive queue lengths, and the storage areas would be filled with severe spillback into the intersections (Figure 5-1). Since, the northbound links are penalized with a red phase the entire time a train is present, they are among the longest queue lengths. The difference in the base case queue length values compared to the proposed ITS diversion case queue length values are a result in the reduction of traffic volumes into the corridor and the non-penalizing minimum green phase provided to traffic turning onto or crossing Main Avenue. As expected, the 75 percent diversion case returned the lowest queue lengths. However, the 50 percent diversion case returned results that are very similar. As mentioned earlier, a conclusion to the similarities is that these two cases are approaching the best case scenario for relieving congestion and reducing the high queue length values. There are two cases for the 25 percent diversion where queue lengths are longer than the current practice. The result is a “trade-off” for providing a minimum green phase to traffic turning onto or crossing Main Avenue and momentarily stopping the Main Avenue traffic. However, with a higher percentage of traffic diversions, as in the 50 and 75 percent cases, the minimum green movement significantly reduces the queue lengths.

Statistical t-Test

$$t = \frac{\bar{X}_1 - \bar{X}_2 - d}{\sqrt{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}} \sqrt{\frac{n_1 n_2 (n_1 + n_2 - 2)}{n_1 + n_2}}$$

To examine the statistical significance of the differences in the MOE relative to the base case, a two sample t-Test was performed. The two sample t-Test is used for applications where sample sizes are small (in this case, n_1 and n_2 are both 10 since there were ten simulation runs for each case) with $n_1 + n_2 - 2$ degrees of freedom. The t-Test is calculated as follows (Johnson, 1994):

$$\bar{X}_i = \frac{\sum_{i=1}^{n} x_i}{n}$$

$$s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n - 1}}$$

(Equation 5-4)

where

δ = 0

X = the sample mean and is calculated as follows:

(Equation 5-5)

s = the standard deviation of *n* observations as the square root of their variance, defined by the following equation:

(Equation 5-6)

A 0.05 level of significance (95% probability) was used to test whether the difference between the means of the base case (Case-1) and the proposed ITS cases (Case-25, Case-50, and Case-75) show statistically significant evidence between their mean values. The t-Test is set up as follows:

1) *Null hypothesis*: $\mu_1 - \mu_2 = 0$; μ_1 = case-1 and μ_2 = a respective diversion case.

   Alternative hypothesis: $\mu_1 - \mu_2 > 0$, or $\mu_1 > \mu_2$.

2) *Criterion*: Reject the null hypothesis if $t > 1.734$, where 1.734 is the value of $t_{0.05}$ for $10 + 10 - 2 = 18$ degrees of freedom.

3) *Decision*: If t exceeds 1.734, the null hypothesis must be rejected at level $\alpha = 0.05$. It can be concluded that there is statistical evidence showing that the Case-1 average total times, delay times, or queue lengths is larger than the ITS scenario average total times, delay times, or queue lengths demonstrating an improvement in traffic conditions.

The majority of the diversion cases showed statistically significant improvements compared to the values of Case-1. Results of the total travel time t-Test are shown in Table 5-8. Recall that the critical t value is 1.734. In some cases where the total travel time for a diversion case was less than the base case but the t value was not greater than 1.734, the values imply that the 10 different diversion case values were too close to the base case values to show statistically significant improvement.

Similar to the average total travel time, the total delay time t-Test values show evidence that the diversion case average delay times are less than the base case average delay times. Results of the total delay time t-Test values are shown in Table 5-9. Again, notice the 50 percent and 75 percent case links show more statistical evidence than the 25 percent case. For the links that did not show significant evidence, the values were too close to the base case average delay time values to show statistical evidence.

The statistical t-Test also shows an improvement in the queue lengths for most links in the proposed ITS diversion cases. Results of the queue length t-Test values are shown in Table 5-10. As noticed in actual values of queue lengths, the 50 percent and 75 percent diversion cases have the most statistically significant links and display similar improvements in their actual values. For the cases where the t-Test was not significant, the queue length values were not much higher, if higher at all, than the base case queue length values.

Table 5-8. Total Travel Time t-Test Values

Street Section	Direction Traveling	Case-25 t-statistic value	Case-50 t-statistic value	Case-75 t-statistic value
University - 10th	East	-5.367	-1.638	0.850
10th - 8th	East	1.912	2.524	2.786
8th - 7th	East	1.135	-2.390	-0.456
7th - Broadway	East	1.891	2.001	1.936
Broadway - 4th	East	-6.184	-8.411	-5.733
4th - 2nd	East	0.321	2.919	1.753
10th - University	West	-1.915	0.113	1.388
8th - 10th	West	-0.943	-2.805	-1.124
7th - 8th	West	3.578	7.753	7.550
Broadway - 7th	West	-3.332	-1.735	-1.735
4th - Broadway	West	2.949	3.152	3.147
2nd - 4th	West	1.308	1.830	2.201

* Analysis was performed using a four minute train.

* Shading denotes statistically significant sections.

Table 5-9. Delay Time t-Test Values

Street Section	**Direction Traveling**	**Case-25 t-statistic value**	**Case-50 t-statistic value**	**Case-75 t-statistic value**
University - 10th	East	-5.614	-1.497	0.657
10th - 8th	East	2.070	2.437	2.772
8th - 7th	East	1.157	-2.421	-0.439
7th - Broadway	East	1.891	2.004	1.927
Broadway - 4th	East	-6.143	-8.388	-5.672
4th - 2nd	East	0.305	2.931	1.784
10th - University	West	-2.087	0.117	1.384
8th - 10th	West	-0.759	-2.669	-0.833
7th - 8th	West	3.441	7.753	7.582
Broadway - 7th	West	-3.332	-0.620	-1.735
4th - Broadway	West	2.953	3.155	3.152
2nd - 4th	West	1.315	1.828	2.202

* Analysis was performed using a four minute train.

* Shading denotes statistically significant sections.

Table 5-10. Queue Length t-Test Values

Intersection	**Case-25 t-statistic value**		**Case-50 t-statistic value**		**Case-75 t-statistic value**	
Lane #	1	2	1	2	1	2
Main & 4th Street						
Traveling East	-4.110	-5.206	-6.406	-7.113	-4.118	-7.156
Traveling West	1.769	1.066	3.452	1.705	2.364	2.058
Traveling North	25.536	6.821	25.899	6.821	30.268	6.821
Traveling South	7.799	10.286	7.799	9.576	10.585	11.126
Main & Broadway						
Traveling East	2.705	18.437	0.738	1.456	0.759	1.292
Traveling West	2.175	1.726	4.689	2.983	4.954	3.317
Traveling North	4.054	n/a	8.376	n/a	8.683	n/a
Traveling South	0.609	n/a	33.068	n/a	45.316	n/a
Main & 8th Street						
Traveling East	-6.427	15.310	-2.496	22.901	-0.735	24.474
Traveling West	-4.270	0.614	6.975	4.583	10.226	-1.964
Traveling North	8.866	n/a	63.180	n/a	78.243	n/a
Traveling South	5.206	n/a	15.057	n/a	28.500	n/a

* Analysis was performed using a four minute train.
* Shading denotes statistically significant sections.

Diversion Effects on Alternative Routes

Since the proposed ITS design has decreased travel time, delay time, queue lengths, and improved LOS ratings through the corridor, an evaluation of the diversion impacts on alternative routes was performed. There were no MOE gathered for the diversion routes because of the massive amounts of data collection required. However, TRAFVU was used to graphically view the effects of diverting traffic to 1st Avenue South and NP Avenue (alternative routes).

Currently, when trains occupy the grade crossings, traffic on alternative routes flows freely until spillback extends to the surrounding intersections as it does on Main Avenue. However, this rarely happens since the storage areas on the north side of the tracks are two to three times longer than the south side storage areas. Figure 5-3 is a snapshot from TRAFVU for Case-1. This figure displays queuing in the storage area along with drivers waiting to make a left turn into the storage area from NP Avenue.

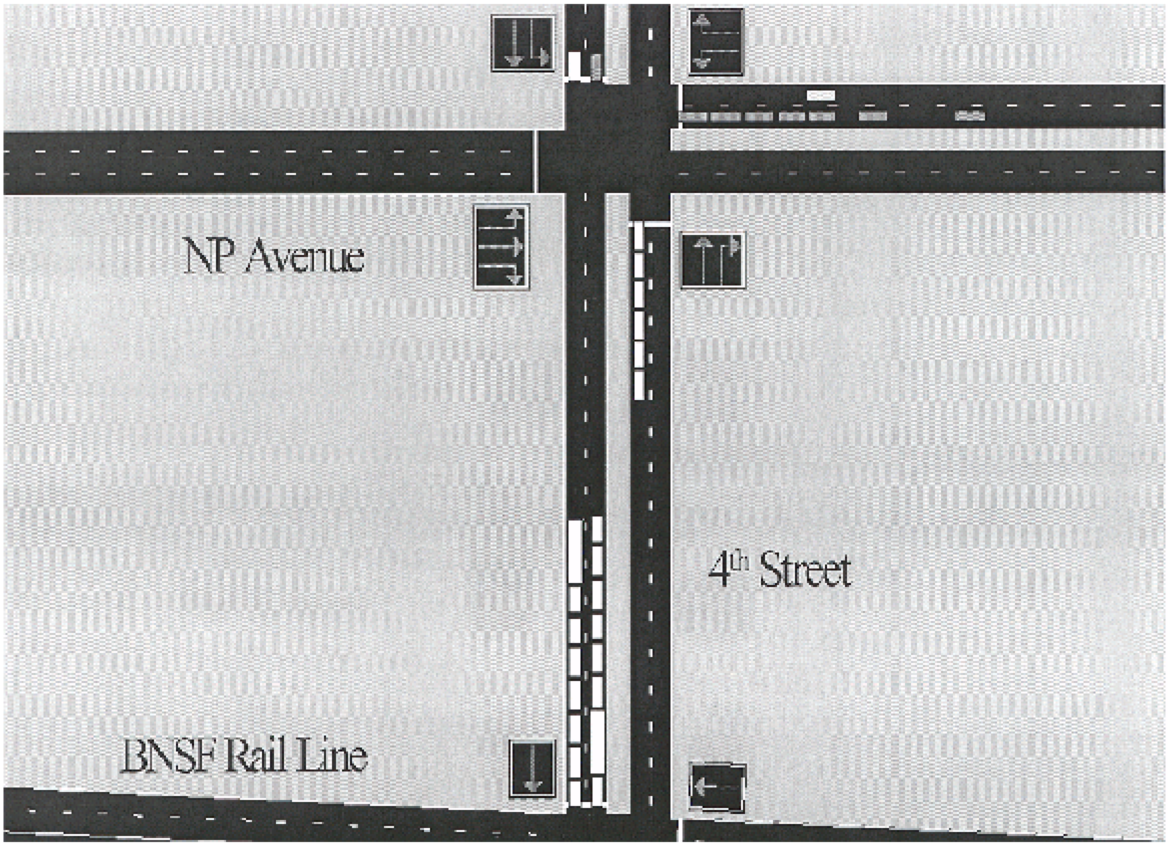
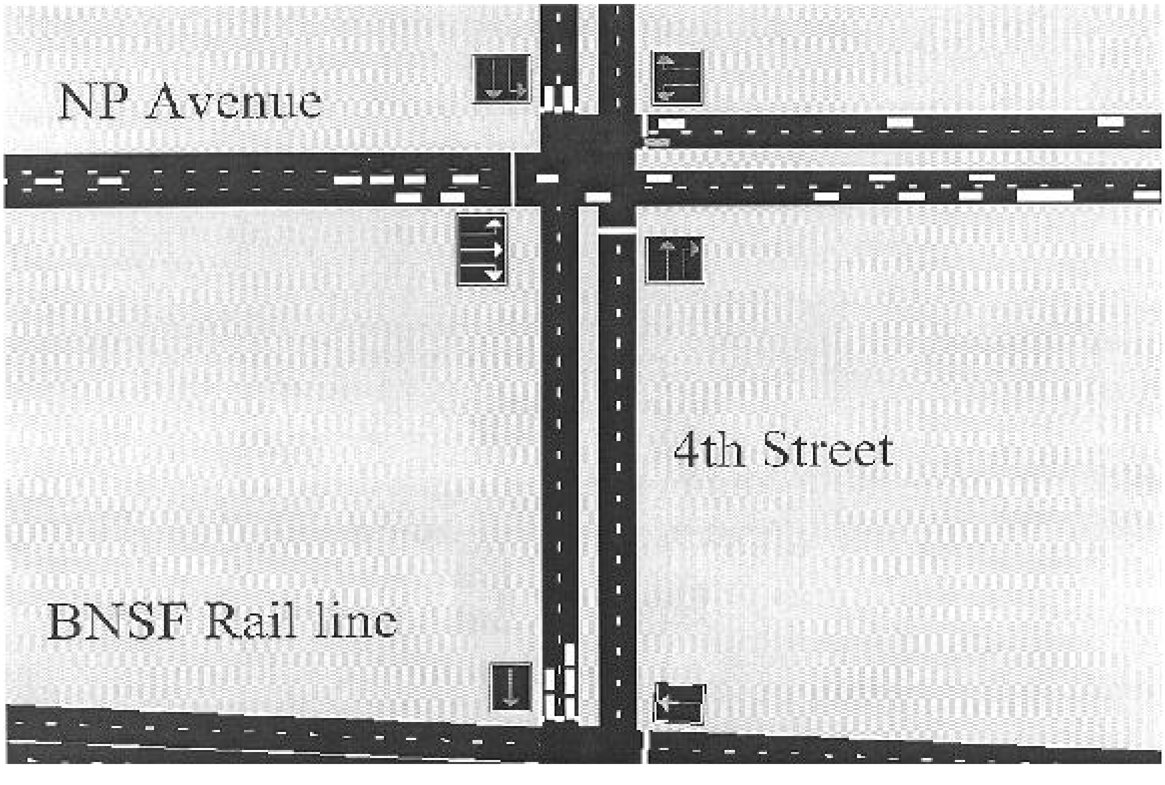


Figure 5-3. **Illustration of traffic flow for Case-1 when a train is present.**

In the 25 percent diversion case, there are little changes or problems in traffic levels on the alternative routes. No major problems with traffic levels are expected since there are very few vehicles diverted in this scenario. On NP Avenue and 4th Street, traffic flow is temporarily interrupted due to spillbacks into the intersection, however, spillback is also experienced in the base case. Not enough people use the underpass, but they continue to use the grade crossing, causing the storage areas to fill and spill into the intersections. Therefore, the 25 percent diversion of traffic does not cause a transfer of congestion to 1st Avenue South or NP Avenue.

In the 50 percent diversion case, more traffic is diverted to NP Avenue and 1st Avenue South. However, this diversion did not seem to cause any significant congestion on the alternative routes. In actuality, this scenario resulted in a smoother flow of traffic along NP Avenue and 1st Avenue South since less vehicles were spilling back into the intersections. Smaller queue lengths were observed in storage areas, which reduce the chance of spillback and traffic breakdowns. The smaller queue lengths are illustrated in Figure 5-4, a snapshot from TRAFVU for the 75 percent diversion case. Figure 5-4 shows that traffic is moving, and the number of vehicles using the grade crossing is reduced. Shorter queues at the intersection of University Drive and Main Avenue were observed since this is a right turn movement to reach 1st Avenue South.

Figure 5-4. Illustration of 75 percent diversion effect on alternative routes.



In the 75 percent diversion case, nearly 615 vehicles per hour are diverted at the intersection of University Drive and Main Avenue. At the intersection of 2nd Street and Main Avenue, approximately 405 vehicles per hour are diverted to 1st Avenue South, and 321 vehicles per hour make a right turn to use the 2nd Street underpass. This volume of traffic seems like a large amount of traffic being diverted, but a train does not occupy a grade crossing for an entire hour. Therefore, assuming the worst case scenario that a train would occupy a grade crossing for 10 minutes, only 103 vehicles would divert at University Drive and Main Avenue, and 68 and 54 vehicles would make left and right turns at 2nd Street and Main Avenue, respectively. Through the animation program, it was observed that traffic still operates under free flow conditions. There is no spillback into intersections on NP Avenue, allowing traffic to flow freely and reach the 2nd Street underpass. On 1st Avenue South, traffic also flows in a free flow condition, except at the intersection of 10th Street and 1st Avenue South where queuing is observed since this is another diversion point for vehicles to use the 10th Street underpass and reach the downtown area without waiting for a train to clear a grade crossing. Similar to the queuing at 2nd Street and Main Avenue, this queuing is a trade-off between waiting for a green light and waiting five to ten minutes for a train. Therefore, if the alternative routes are currently well below their capacity, the added traffic will not cause major problems, and the trade-off is on the plus side.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

The purpose of this chapter is to summarize the research findings. The objective of the research was to investigate the benefits of using appropriate ITS technologies at railroad grade crossings. These reductions in total travel time are credited to the use of ITS whereby information of approaching trains was provided reducing the amount of spillback into the intersections where vehicles are often stopped, prolonging their total travel time. The benefits were assessed by comparing key Measures of Effectiveness (MOE) such as total travel time, total delay time, queue length, and Level-of-Service (LOS) ratings throughout the specified Main Avenue corridor (University and Main Avenue to 2nd Street and Main Avenue). To analyze the key MOE, the methods developed in this paper were tested in a case study. The case study was modeled and simulated using TRAF-CORSIM, a traffic simulation program. There were four different cases simulated, including a base case scenario reflecting current conditions and three cases for ITS alternatives reflecting various driver response rates. This chapter is divided into two sections: Benefits of Using ITS for Rail-Highway Grade Crossings and Recommendations.

Benefits of Using ITS for Rail-Highway Grade Crossings

Three MOE were analyzed to demonstrate the benefits of using ITS: total travel time, total delay time, and queue length. A Level-of-Service rating analysis for specific links and certain intersections was also performed.

Total travel times were reduced in the ITS cases for the three selected driver response rates (Case-25, Case-50, and Case-75). For eastbound traffic, the 25, 50, and 75 percent diversion cases reduced the total travel times from 300 seconds to 257, 248, and 246 seconds, respectively. For westbound traffic, the 25, 50, and 75 percent diversion cases reduced total travel times from 530 seconds to 348, 238, and 235 seconds, respectively. Since the proposed ITS design benefitted total travel times in all cases, it was concluded that the proposed ITS design significantly benefits drivers and, most of all, emergency response vehicles in reaching their destination when applied to grade crossings .

Total delay times were also reduced using the proposed ITS design. An exception was eastbound traffic when 25 percent of drivers diverted. It was mentioned in Chapter 4 that this increase in delay time was due to allocating allowed green time to vehicles turning onto or crossing Main Avenue while the train was present. However, when 50 and 75 percent of the affected vehicles were diverted, a significant decrease in total delay time was observed. The most impressive decrease in delay time was for westbound traffic when 75 percent of the effected vehicles were diverted. In this case, the delay time decreased from the original 365 seconds to 69 seconds.

Related to delay time is Level-of-Service (LOS). In nearly every case, the LOS rating improved when the proposed ITS design was implemented. The only exception was on the 4th to 2nd link where it achieved a LOS rating of C for the 50 percent diversion case and then returned to D in the 75 percent diversion case. When analyzing the actual delay time values, it was noticed that there was a one-and-a-half second increase in delay time which was attributed to the increase in the amount of traffic trying to divert to alternative routes. In most cases, the LOS rating improved by two-to-three ratings. When LOS were calculated for the total intersection, an increase in the ratings was obtained in every case compared to the current LOS ratings.

The last MOE used to compare the benefits of using ITS applications at railroad grade crossings was queue length. Queue lengths refer to the number of vehicles in line at any given leg of an intersection. There were only two instances where queue lengths did not decrease from the base case values. The seldom increase in queue lengths is attributed to the minimum green time provided for vehicles turning onto or crossing Main Avenue, whereby Main Avenue traffic is stopped every 70 seconds. In the ITS case with the highest driver response (Case-75), average queue length values at certain intersections were reduced from 17 to 1, 18 to 1, 15 to 2, and 12 to 3. These significant reductions in queue length values are attributed to the use of ITS where drivers are informed to take alternative routes. In the higher diversion cases, 50 and 75 percent, fewer vehicles turning into the grade crossing storage areas reduce the chance of causing spillback and breakdowns in traffic flow. Therefore, it is concluded that greater benefits of ITS are achieved when at least 50 percent of the motorists respond favorably to the information and change their routes.

In conclusion, this study has illustrated the usefulness and benefits of applying ITS technology at railroad grade crossings. The Main Avenue corridor was used in a case study demonstrating the application of this technology. Significant improvements were experienced in total travel times, total delay times, Level-of-Service ratings, and queue lengths under various applications of ITS. While the exact dollar amount of savings related to user benefits was not calculated, the benefits of the proposed ITS design can be converted to a dollar amount to compare user savings to the cost of the ITS system. These benefits will only continue to have higher significance with the expected growth in traffic levels for the metropolitan area.

Recommendations

Further research is required in the area of traffic simulation to enhance the modeling effects of ITS applications at railroad grade crossings. This study simplified two of the three network components to model and simulate their effects on traffic when a train occupies a grade crossing. The first simplified component was the graphical modeling of the BNSF rail line and the control to reflect the actual maximum delay of a train occupying a grade crossing. The second simplified component was the manipulation of turning movements in order to model drivers’ responses to ATIS.

Since no cost-benefit analysis was performed, there is the possibility of future research to determine the actual dollar value associated with implementing this ITS application. This research would require many dollar values associated with drivers' opportunity cost and all costs associated with ITS. At the minimum, the cost of an ITS strategy applied to highway-railroad grade crossings would include communication costs, variable message costs, and smart intersection controllers.

The future of Intelligent Transportation System applications and technologies looks very promising. The continuing advancements in computer technology, sensing technology, and signal control systems will enhance and encourage more applications for ITS.

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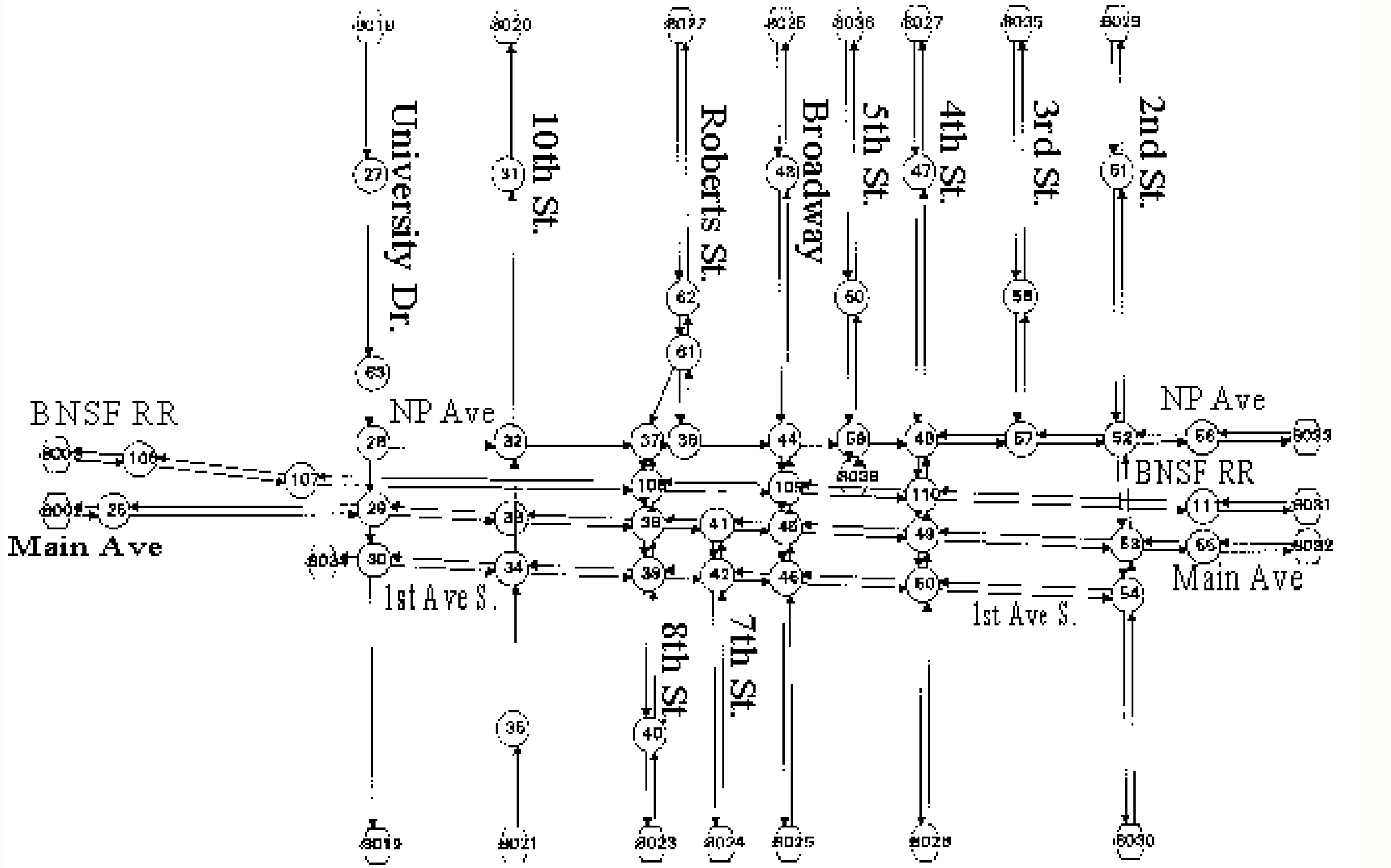
APPENDIX A

NETWORK LINK-NODE DIAGRAM


University Dr.
10th St.
Roberts St.
Broadway
5th St.
4th St.
3rd St.
2nd St.
NP Ave
BNSF RR
Main Ave
1st Ave S.
8th St.
7th St.
NP Ave
BNSF RR
Main Ave
1st Ave S.

Not To Scale

Figure A-1. Link-Node diagram for the case study network.

APPENDIX B

GEOMETRIC DATA

Table B-1. Geometric Data Including Link, Length, and Lane Information

Link	Length (FT)	Lanes		
		Full	Left Pocket	Right Pocket
25,29	2363	2	0	1
29,25	2362	2	0	0
29,30	363	2	0	0
29,33	1322	2	0	0
33,29	1322	2	1	0
33,38	1321	2	0	0
38,33	1321	2	0	0
49,53	1982	2	1	1
53,49	1982	2	1	0
53,54	362	2	0	0
54,53	362	2	0	0
109,44	343	2	0	0
44,109	343	2	0	0
109,45	160	2	0	0
45,109	160	2	0	0
48,110	408	2	0	0
110,48	408	2	0	0
110,49	167	2	1	1
49,110	167	2	0	0
32,31	2645	3	0	0
44,43	2645	1	0	0
43,44	2645	1	0	0

Table B-1. cont.

Link	Length (FT)	Lanes		
		Full	Left Pocket	Right Pocket
52,51	2645	2	0	0
51,52	2645	2	1	1
45,49	1321	2	1	0
49,45	1321	2	0	0
38,41	660	2	0	0
41,38	660	2	0	0
41,45	660	2	0	0
45,41	660	2	0	0
53,55	740	2	0	0
55,53	740	2	1	1
42,41	363	2	0	0
41,42	363	2	0	0
46,45	363	1	0	0
45,46	363	1	0	0
50,49	363	2	0	0
49,50	363	2	0	0
35,34	1671	2	1	1
40,39	1673	2	0	0
39,40	1673	2	0	0
39,38	363	2	0	0
38,39	363	2	0	0
34,32	764	3	0	0
28,32	1320	3	1	0

Table B-1. cont.

Link	Length (FT)	Lanes		
		Full	Left Pocket	Right Pocket
50,46	1321	2	0	0
46,50	1321	2	0	0
46,42	660	2	0	0
42,46	660	2	0	0
42,39	660	2	0	0
39,42	660	2	0	0
39,34	1321	2	0	0
34,39	1321	2	0	0
34,30	1322	2	0	0
30,34	1322	2	0	00
52,56	800	2	0	0
59,48	660	3	0	0
61,37	265	2	0	0
36,61	55	1	0	0
61,36	55	1	0	0
37,36	260	3	1	0
36,44	1060	2	0	0
61,62	450	2	0	0
62,61	450	1	0	0
27,63	1807	2	0	0
63,28	838	2	0	0

APPENDIX C

TRAFFIC CONTROL DATA

Table C-1. 2nd Street and Main Avenue Traffic Controls

Phase	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Function								
Min. Green	3.0	12.0	3.0	12.0	3.0	12.0	3.0	12.0
Passage	2.0	5.0	2.0	5.0	3.0	5.0	2.0	3.0
Max. No. 1	20.0	40.0	20.0	30.0	20.0	40.0	20.0	30.0
Max. No. 2	0	0	0	0	0	0	0	0
Yellow	3.0	3.2	3.0	3.0	3.0	3.2	3.0	3.0
Red	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Added Initial	0	2.0	0	2.0	0	2.0	0	2.0
Max. Initial	0	20.0	0	20.0	0	20.0	0	20.0

Table C-2. 4th Street and Main Avenue Traffic Controls

Phase	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Function								
Min. Green	0	10.0	0	10.0	0	10.0	0	10.0
Passage	0	0	0	0	0	0	0	0
Max. No. 1	0	26.0	0	22.0	0	26.0	0	22.0
Max. No. 2	0	0	0	0	0	0	0	0
Yellow	0	3.2	0	3.0	0	3.0	0	3.0
Red	0	2.8	0	3.0	0	1.0	0	3.0
Added Initial	0	0	0	0	0	0	0	0
Max. Initial	0	0	0	0	0	0	0	0

Table C-3. Broadway and Main Avenue Traffic Controls

Phase	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Function								
Min. Green	0	10.0	0	10.0	0	10.0	0	10.0
Passage	0	0	0	0	0	0	0	0
Max. No. 1	0	28.0	0	20.0	0	28.0	0	20.0
Max. No. 2	0	0	0	0	0	0	0	0
Yellow	0	3.2	0	3.0	0	3.2	0	3.0
Red	0	2.8	0	3.0	0	2.8	0	3.0
Added Initial	0	0	0	0	0	0	0	0
Max. Initial	0	0	0	0	0	0	0	0

Table C-4. 7th Street and Main Avenue Traffic Controls

Phase	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Function								
Min. Green	0	10.0	0	10.0	0	10.0	0	10.0
Passage	0	0	0	0	0	0	0	0
Max. No. 1	0	29.0	0	19.0	0	29.0	0	19.0
Max. No. 2	0	0	0	0	0	0	0	0
Yellow	0	3.2	0	3.0	0	3.2	0	3.0
Red	0	2.8	0	3.0	0	2.8	0	3.0
Added Initial	0	0	0	0	0	0	0	0
Max. Initial	0	0	0	0	0	0	0	0

Table C-5. 8th Street and Main Avenue Traffic Controls

Phase	1	2	3	4	5	6	7	8
Function								
Min. Green	0	10.0	0	10.0	9.0	10.0	0	10.0
Passage	0	0	0	0	0	0	0	0
Max. No. 1	0	31.0	0	17.0	9.0	19.0	0	17.0
Max. No. 2	0	0	0	0	0	0	0	0
Yellow	0	3.2	0	3.0	3.0	3.2	0	3.0
Red	0	2.8	0	3.0	0	2.8	0	3.0
Added Initial	0	0	0	0	0	0	0	0
Max. Initial	0	0	0	0	0	0	0	0

Table C-6. University Drive and Main Avenue Traffic Controls

Phase	1	2	3	4	5	6	7	8
Function								
Min. Green	0	20.0	0	29.0	9.0	20.0	0	29.0
Passage	0	0	0	0	0	0	0	0
Max. No. 1	0	20.0	0	29.0	9.0	20.0	0	29.0
Max. No. 2	0	0	0	0	0	0	0	0
Yellow	0	3.2	0	3.0	3.0	3.2	0	3.0
Red	0	2.2	0	2.3	0	2.2	0	2.3
Added Initial	0	0	0	0	0	0	0	0
Max. Initial	0	0	0	0	0	0	0	0

APPENDIX D

VOLUME AND TURNING MOVEMENT DATA

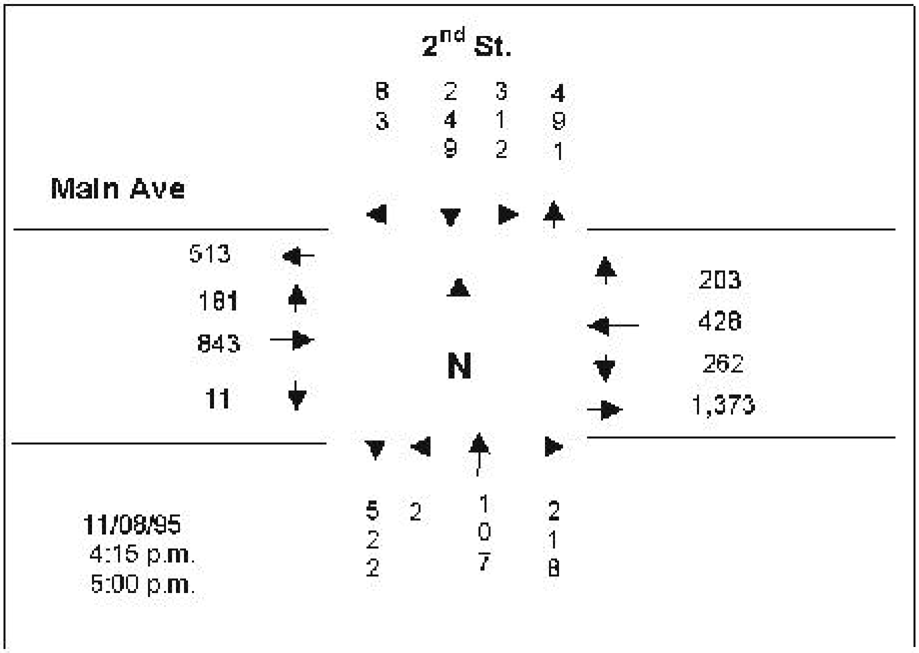


Figure D-1. Turning movement and volumes for 2nd Street and Main Avenue.

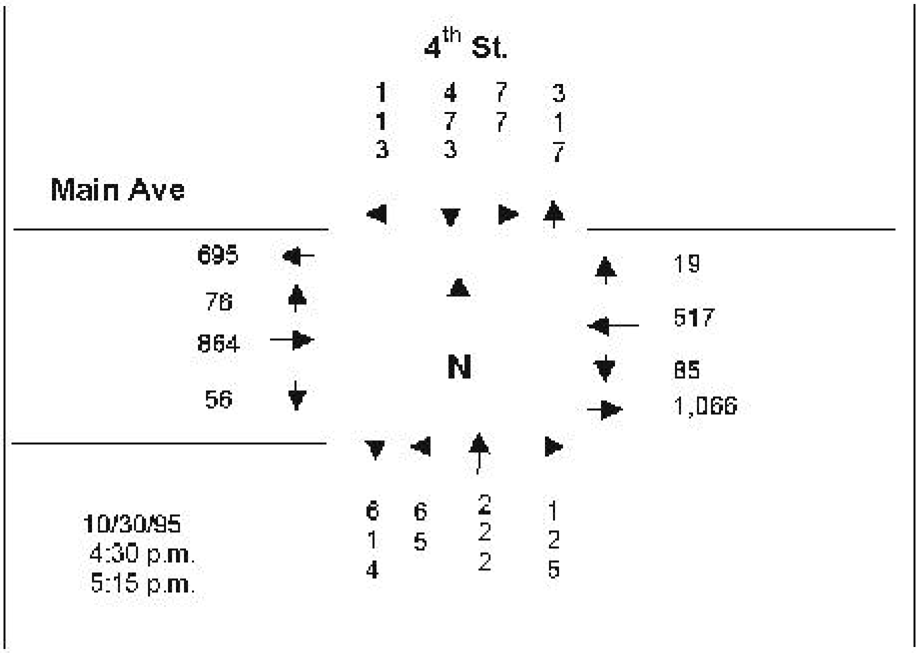


Figure D-2. Turning movement and volumes for 4th Street and Main Avenue.

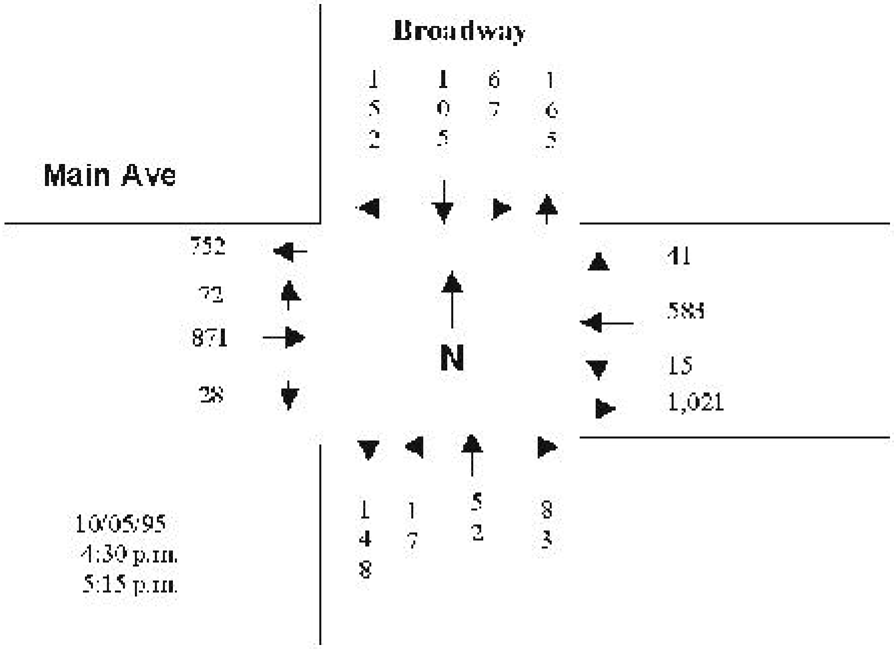


Figure D-3. Turning movement and volumes for Broadway and Main Avenue.

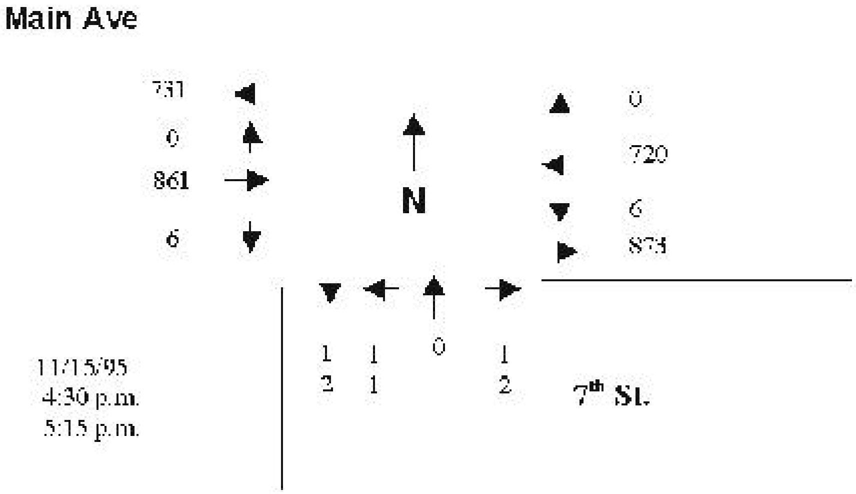
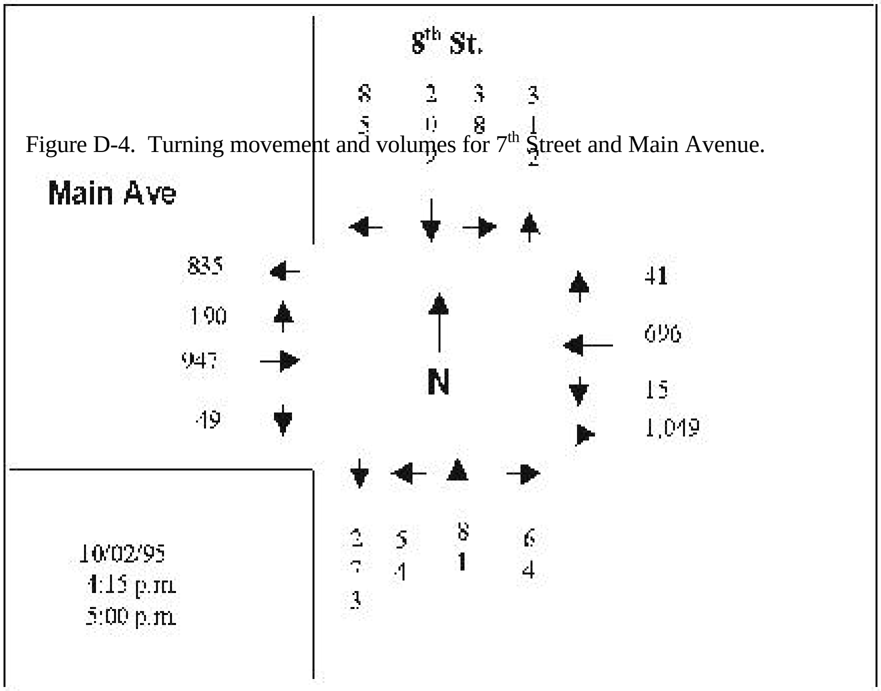


Figure D-4. Turning movement and volumes for 7th Street and Main Avenue.



10/02/95
4:15 p.m.
5:00 p.m.

Figure D-5. Turning movement and volumes for 8th Street and Main Avenue.

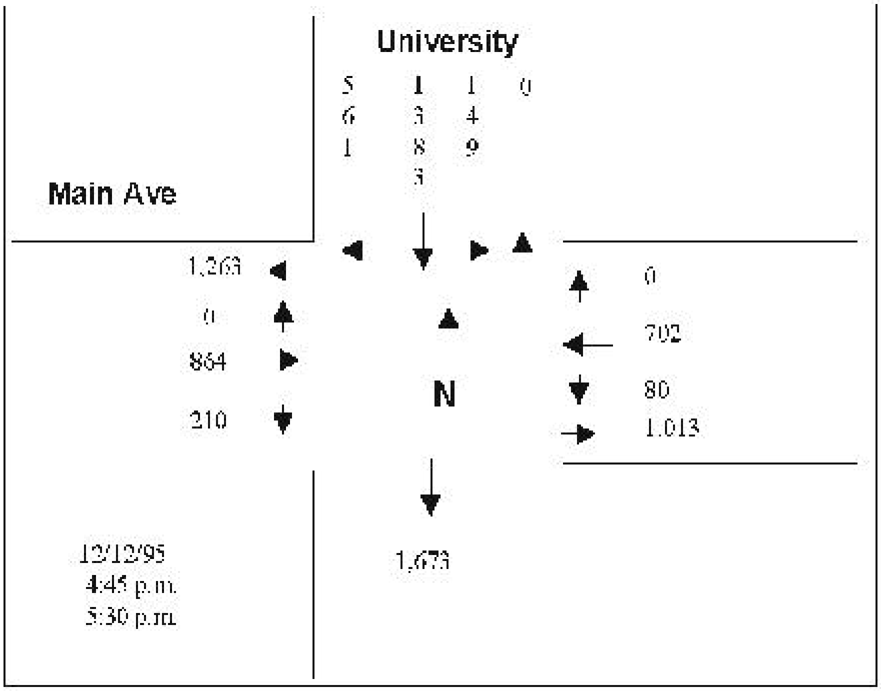


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Figure D-6. Turning movement and volumes for University Drive and Main Avenue.