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Signal Coordination Strategies
Final Report

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Prepared for:
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Executive Summary

This report summarizes the findings from the *Signal Coordination Strategies* study conducted in Grand Forks, North Dakota during 2002. The Washington Street corridor (5th Ave N to 32nd Ave S) in Grand Forks was used as a case study for evaluating two potential coordination (interconnect) strategies using three time periods (AM, MID, and PM). The Washington Street corridor currently includes two interconnect segments: a north segment from 2nd Ave N, to 5th Ave N and a south segment from 17th S to 32 Ave S. Additionally, two intersections (Demers and 13th Ave S) located in the middle section of the corridor currently operate on an isolated basis.

The objectives of this study were to provide information and guidance on traffic signal optimization tools, traffic signal coordination strategies, and communication strategies for traffic signal interconnects. An evaluation of Synchro, TEAPAC, PASSER, and TRANSYT provided significant insights into the capabilities and limitations of these models. Synchro was found to be the most user-friendly model among those evaluated, due largely to its graphical interface and optimization routines. The user can easily import background images and create the network in a relatively short amount of time. The input process is simplified using automated minimum values and parameters. The optimization features are also easy to use and can be automatically or manually selected. In addition, Synchro was the only model among those evaluated that estimates the actuated-green time, providing a distinct advantage over the other models. This is feature is especially useful for determining the offsets since the maximum green time available is not typically used.

Traffic simulation analyses were conducted to evaluate the performance of traffic signal timing plans developed by the four signal optimization programs, as well as the effectiveness of the two coordination strategies. Three simulation models (CORSIM, SimTraffic, and Vissim) were used to limit the bias between comparisons. The results indicate that the Synchro model generally provided the lowest overall network delay, mainly contributed to the reduction in side-street delay. The TEAPAC model ranked second in the network delay comparisons.

The comparison between the two coordination strategies did not result in any conclusive evidence for either strategy. Depending on the time of day, one strategy provided slightly more benefits over the other strategy, however, the savings obtained were minimal or insignificant. A recommendation was made to implement the one-system coordination strategy since the cycle length differences between the two systems only averaged five seconds and a common cycle length would provide progression not realized in a segmented system.

Three alternative communication technologies (wireless, cable, and fiber) were reviewed for interconnecting two additional traffic signals to the existing corridor segments. After reviewing potential communication costs, it was recommended to add Demers Ave to the existing north interconnect and to connect 13th Ave S to the south interconnect. It was further recommended to use fiber between 17th Ave S and 2nd Ave N (using the previously installed innerduct) and wireless between Demers Ave and 2nd Ave N. Several factors were taken into consideration for this recommendation, including hardware requirements and existing infrastructure. A fiber installation to connect the two intersections would cost approximately $29,306, while the fiber/wireless combination would cost approximately $9,200, not considering labor costs for installation of components in the traffic controller cabinet. The use of fiber and wireless technologies would resulting in a savings of more than $20,000. It should also be mentioned that these recommendations did not take into account potential future uses of communications along the corridor, such as adding video monitoring or other ITS technologies.

Finally, updated traffic signal timing plans were developed for the corridor after additional traffic data collection was conducted in the Spring of 2003. The plans developed earlier in the projects used older data at some locations and Grand Forks transportation officials wanted to capture current traffic levels. These plans are summarized in Appendix C of this report.

Once the new traffic signal plans were implemented and traffic in the area had a chance to acclimate, field travel time studies were conducted to estimate the impacts on traffic delays in the corridor. The new plans generally improved traffic operations in the corridor, resulting in delay reductions as high as 40% for one of the busy intersections. The results from the filed travel time study are summarized in Appendix D.

1.0 Introduction

This study was conducted for the Grand Forks/East Grand Forks Metropolitan Planning Organization by the Advanced Traffic Analysis Center of North Dakota State University. The purpose of the study was to use a case study approach to develop best practices for traffic signal coordination which may be used as a reference for future coordination efforts in Grand Forks/East Grand Forks as well as other areas. The Washington Street corridor, from 5th Ave N to 32nd Ave S in Grand Forks was selected as the case study location.

The coordinated operations of adjacent signalized intersections on a main corridor can potentially improve traffic operations and significantly reduce traffic delay. However, developing coordinated traffic signal operation plans through interconnect systems requires careful and detailed analysis that would take into consideration traffic patters, intersection spacing, communications cost for connecting intersections, as well as possible benefits (i.e., reductions in traffic delay). In general, engineers must balance benefits to the favored movement (main approach) to possible negative impacts on side streets.

As a result, several tools are available to traffic engineers to support detailed evaluations of alternative coordination plans. These tools may be classified into traffic signal optimization and traffic simulation. Although optimization tools share the general concept for estimating the appropriate measures of effectiveness (MOE), they each vary with the level of priority they place on various MOE. As a result, there has been an increasingly growing emphasis on using analysis tools which can evaluate the developed timing plans under various conditions and scenarios before they are implemented in the field. Traffic simulation models are used to create these scenarios and quantify the impacts through estimates of numerous MOE. Microscopic traffic simulation models can provide added insights by modeling interactions of individual vehicles with the road network and traffic signal control strategies.
The framework for adequate corridor analysis is then comprised of a two-step approach: develop appropriate traffic signal timing plans using an optimization model then evaluate the performance of these plans using traffic simulation. The focus of this study is on choosing the right optimization tool, specifically for addressing traffic signal timing plans for coordinated signalized intersection operations.

1.1 Overview and Problem Description

Small to medium size cities are sometimes faced with the challenge of maintaining signalized corridors that have been developed with less than ideal access management, intersection spacing, or have simply developed greater than originally anticipated. In some instances, corridors develop in a manner contrary to metropolitan or regional planning efforts. Coordination of signalized intersections with inconsistent spacing is challenging at best, especially with competing directional traffic flows and heavy demand on the side streets. Agencies may find it difficult to design or maintain multiple coordination plans for various traffic patterns and may resort to a limited set of timing plans or use one cycle length throughout the day. Confronted with limited resources, small to medium size cities often develop timing plans in conjunction with initial traffic signal installations that may remain unchanged for several years, despite significant changes in traffic patterns. The lack of new timing plans can greatly increase network delay. While this may not hold true in the case study location, the information gained from the case study experience may be beneficial to other agencies.

There is also the issue of selecting an appropriate analysis framework, including the right analysis tools. Part of the difficulty of keeping signal timing plans updated is the availability of effective analysis tools. With the availability of numerous traffic analysis software packages, there is a need for information to determine appropriate signal timing software for coordination.

1.2 Objectives

The main objective of this study is to analyze signal optimization software and provide a recommendation on the best software to use for signal analysis purposes. This study investigates the methods for designing and evaluating signal timing and coordination plans for a closed-loop corridor with mixed intersection spacing. Specifically, the following items will be the salient findings of the study:

- Functionality of signal optimization programs (pros/cons, requirements, limitations)
- Effectiveness of traffic signal timing plans produced by various models
- Effective communications options, such wireless, cable, and fiber optic

1.3 Methodology

This study evaluates four traffic signal optimization programs in the areas of: ease of operations, data requirements, and effectiveness of results. A case study is used to explore the performance of these models in developing coordination strategies for a corridor with mixed signal operations. The evaluation framework included the consideration of possible interconnect scenarios and accounts for traffic patterns by including three peak periods. Three traffic simulation programs will evaluate the signal optimization programs and coordination strategies in terms of arterial, side-street, and network delay. The main steps of this study are shown in Figure 1.1.

Several signal timing analysis software packages or signal optimization tools were investigated, including Synchro, TEAPAC, PASSER, and TRANSYT. These models provided signal timing plans for multiple time periods, as well as two coordination strategies: 1) coordination of all intersections along the corridor with a common cycle length, and 2) partitioning the corridor into two coordinated segments.

The performance of the plans developed from the optimization tools was evaluated using traffic simulation. Three traffic simulation models, including CORSIM, SimTraffic, and VISSIM, were used to estimate key MOE that would indicate which optimization model produced better plans (i.e., reduced traffic delay).

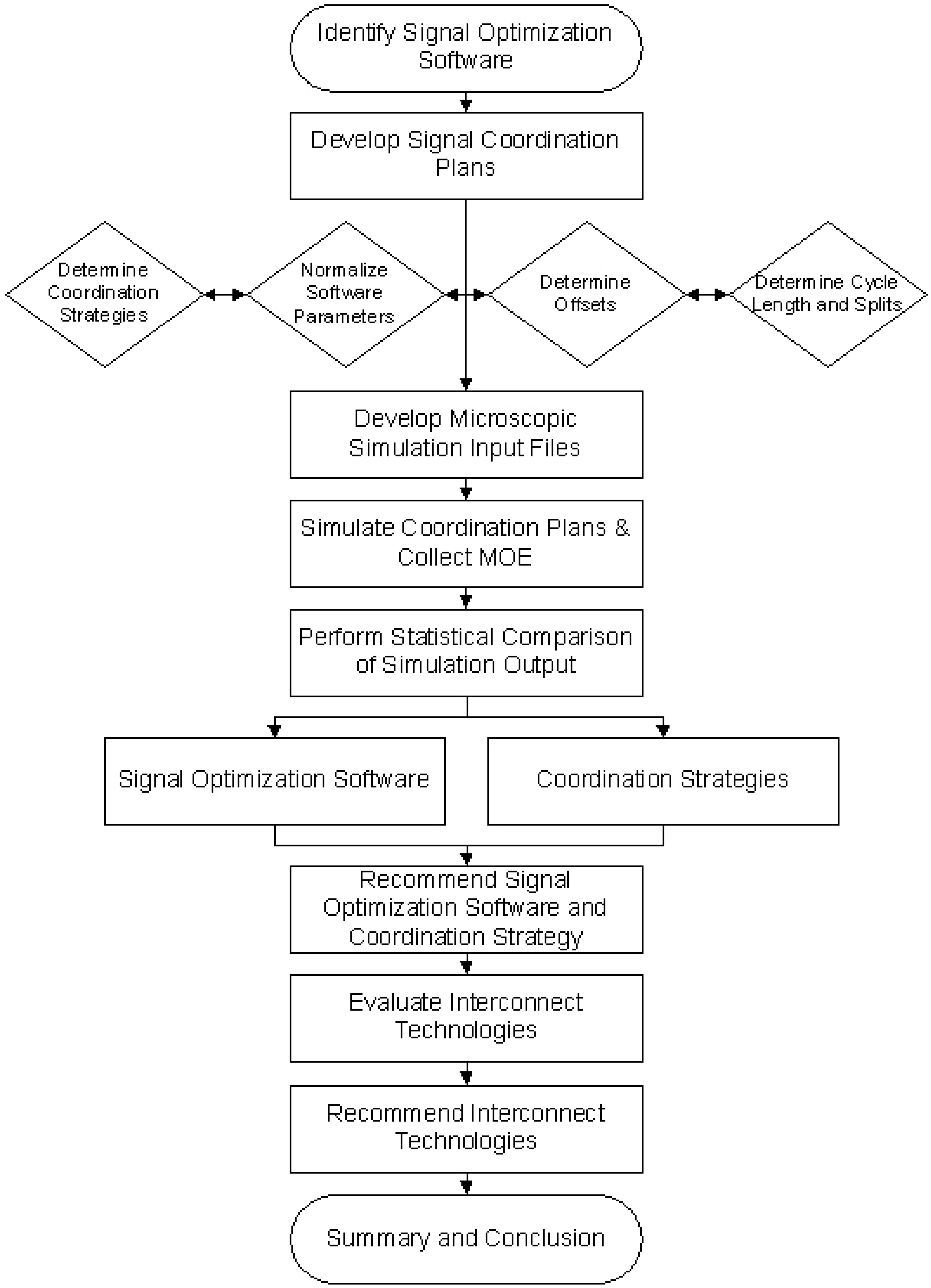


Figure 1.1. Case Study Methodology

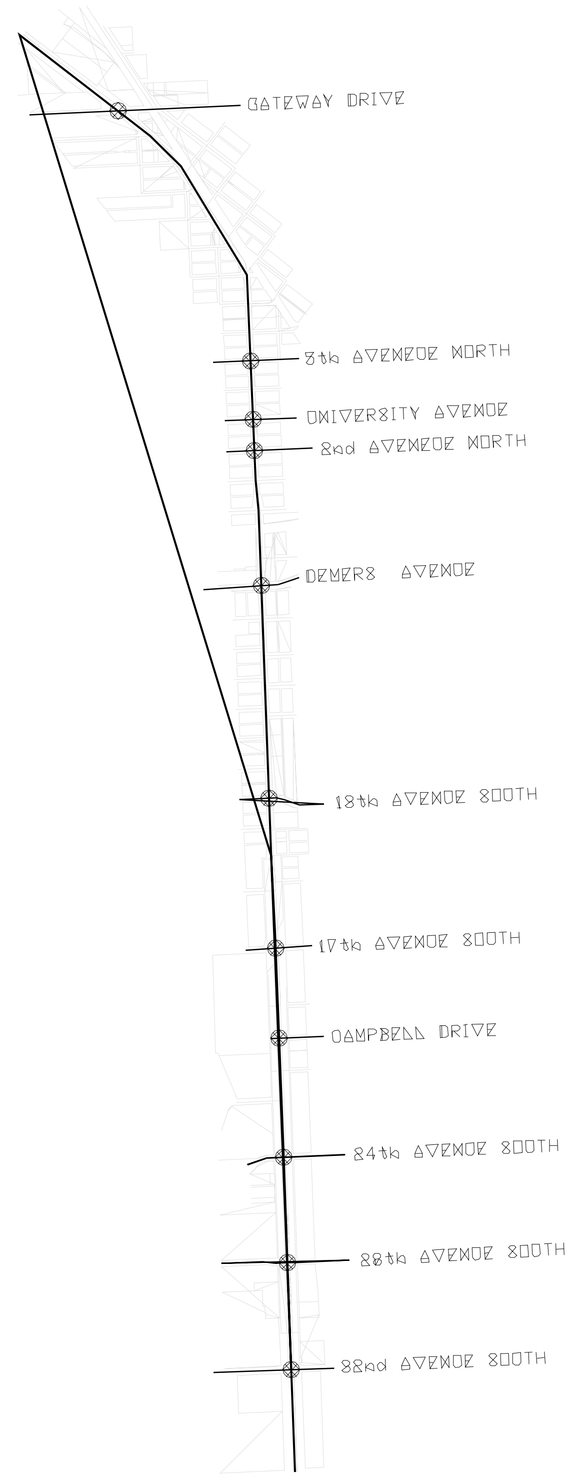


Figure 1.2. Case Study Area

1.4 Study Area

The City of Grand Forks, ND has identified South Washington Street as a potential corridor for signal timing and coordination enhancements. The City of Grand Forks, ND has a population of approximately 50,000. Figure 1.2 illustrates the study area.

South Washington Street is a north-south corridor with non-typical intersection spacing. The surrounding areas from 13th Ave South to 32nd Ave South have moderate commercial development. The areas to the north of this area are light commercial and residential areas.

The study area consists of 11 signalized intersections with two separate interconnected areas. Currently, the signalized intersections operate under morning and evening timing plans, with the remaining time operating in an actuated-uncoordinated mode. Gateway Dr is a coordinated corridor and a major east-west thoroughfare.

The most recent traffic signal improvements to this corridor were implemented in 2000 and were consistent with plans provided by the North Dakota Department of Transportation. The traffic counts used for developing the Year 2000 improvements were from 1993-1995 and may have under-represented conditions of the corridor. In addition, there has been significant commercial and residential development along the south end of the corridor since that time.

1.5 Report Organization

Chapter 2 of this study describes the four signal optimization tools (Synchro, TEAPAC, PASSER, and TRANSYT), as well as discusses the required input, analysis time, and benefits/limitations of each model. Chapter 3 discusses the coordination strategies (one- and two-system interconnect) and the summary results of the signal optimization analyses. Chapter 4 provides an overview of the three simulation models (CORSIM, SimTraffic, and VISSIM). Chapter 5 provides the results of the simulation analyses. Chapter 6 reviews communication media to interconnect traffic signals. Chapter 7 provides the study recommendations.

2.0 Signal Optimization Tools

This chapter summarizes the general process for applying each of the four signal optimization tools. Typically, the process can be summarized as follows:

- Develop network/corridor representation/model
- Input general parameters (geometry, traffic counts, etc)
- Determine coordination strategy
- Optimize cycle lengths
- Optimize cycle splits
- Optimize offsets

Traffic counts were obtained by the City of Grand Forks for this analysis. Peak-hour factors were calculated for each signalized approach and used as the proxy for coordination volumes. The traffic volumes were not weighted or balanced throughout the corridor due to the multiple access points between signalized intersections.

The approach applied in this research was to use as many vendor-defined variables when evaluating the signal optimization tool. It was intended to provide the necessary data for the models and let the model determine the best signal timing plan.

2.1 Software Summary

This section provides an overview of four signal optimization tools, Synchro, TEAPAC, PASSER, and TRANSYT (note Appendix A for signal program contact and version information). In addition, it compares the models' optimization functions, input requirements, and limitations.

2.1.1 SYNCHRO

Synchro utilizes a graphical user interface to build the network or corridor. A background image file is imported in several common image formats from which a network is created. Synchro's user-friendly interface eases development of networks once the background image has been imported.

Synchro is capable of optimizing cycle lengths, splits and offsets. In addition, Synchro can partition networks. This feature was used to determine two plausible scenarios for interconnect systems. Synchro utilizes the HCM 2000 methodology, however, it differs from other signal analysis models that uses this methodology. The differences are primarily attributed to Synchro's incorporation of five percentile flow scenarios (10^{th}, 30^{th}, 50^{th}, 70^{th}, and 90^{th}). These scenarios are to replicate traffic variations within the peak 15 minute period. For example, if 100 cycles were observed, the traffic volume observed would be equal to or less than the 90^{th} percentile flow. Synchro estimates the actuated effective green time for each percentile flow and displays control delay as a volume weighted average of the five percentile scenarios.

Synchro provides optimization function for cycle lengths, splits, and offsets. Synchro determines network cycle lengths using a performance index (PI), which take into account signal delay, queue penalty, and vehicle stops. Split optimization is achieved by serving the critical flows then dividing the remaining green time equally among the even phases. Offset optimization calculates the delay between intersections based on the arrival patterns from neighboring intersections. Several iterations are performed to determine the offsets that provide the lowest delay.

Synchro includes many import and export features which allow for integration with other signal optimization and simulation tools. This reduces the time necessary for model network construction for other software tools.

2.1.2 TEAPAC

TEAPAC consists of a suite of traffic analysis programs that use a common interface to perform multiple traffic engineering and planning analyses. The TEAPAC programs that were used in this document include SIGNAL2000, NOSTOP, PREPASSR, and PRETRANSYT. Several methods can be used to develop coordination plans, however, the methods used in this section were based on the suggestions by the TEAPAC developer. The major steps in developing the corridor and performing the coordination analysis are as follows:

1. SIGNAL2000 is applied at individual intersections and requires an input file to be created for each intersection. SIGNAL2000 is primarily used to evaluate and optimize phasing and split times. It follows the procedures and calculations defined in the HCM 2000. The default optimization strategy in SIGNAL2000 is to minimize delay for each critical movement. Delay for non-critical movements will be equal to this value or better. The user may modify the default strategy by setting a target LOS and having the excess green allocated to desired movements. This analysis used the default optimization feature of TEAPAC while allocating the green time for each phase. It should be noted that the split times were designed to accommodate the pedestrian and vehicle minimum times for each intersection.

2. NOSTOP is a fairly simple signal progression program that maximizes bandwidth. Based on the specified cycle length range, the program provides insight into the most efficient cycle length for the corridor. Next, the user must then select the most appropriate cycle length based on efficiency while keeping in mind the delay implications, e.g., a very large cycle length will cause more delay. Then, the selected cycle length will be input back into SIGNAL2000 and the splits will be optimized. It is a good idea to re-evaluate the new timings in NOSTOP to see if the optimal cycle length changed. Therefore, the cycle length analysis is an iterative process that requires engineering judgement. Based on this study, the cycles evaluated ranged from 80-120 seconds with 5 second increments.

3. PRETRANSYT is a pre- and post-processor for the TRANSYT-7F program. PRETRANSYT eliminates the need to code data directly into TRANSYT-7F and extracts relevant output from the model. Since the cycle length and splits were optimized using NOSTOP and SIGNAL2000, PRETRANSYT optimizes offsets and uses the default objective function, which minimizes delay and stops. To construct a PRETRANSYT network, TEAPAC combines the individual intersection SIGNAL2000 files.

2.1.3 PASSER

PASSER (Progression Analysis and Signal System Evaluation Routine) II-90 was developed by the Texas Transportation Institute in 1990. The program provides bandwidth optimization for corridors and can also be used to simulate existing signal system operations. PASSER strictly maximizes bandwidth efficiency by finding the highest value of summing the thru green band divided by twice the cycle length. PREPASSR, which is another TEAPAC program, was used to construct the PASSER II-90 model. PREPASSR was developed to serve as a pre- and post-processor for PASSER. Since PASSER II-90 was developed in 1990, it is a DOS based program and uses the HCM 1985 delay model. PASSER was used to optimize the splits (accommodated pedestrian and vehicle minimums), cycle lengths (80-120 seconds with 5 second increments), and offsets.

2.1.4 TRANSYT

TRANSYT-7F was originally developed by the Transport Research Laboratory in the United Kingdom, however, version 7 was transferred to U.S. standards for the Federal Highway Administration (FHWA), creating the “7F”. Recently, McTrans developed a T7F9 shell program that uses several components, however, the core model of the program is TRANSYT-7F, which uses the HCM 2000 delay model. Additional components that were used in this analysis include CYCOPT and genetic algorithm (G.A.) optimization. TRANSYT-7F is a signal timing analysis program that provides simulation and optimization capabilities. The simulation feature of TRANSYT-7F does not provide animation but it is used internally to model platoon dispersion, queue spill back, and spillover for evaluating existing conditions and optimization strategies.

TRANSYT-7F is capable of optimizing cycle length, phasing sequence, splits, and offsets. A wide variety of objective functions are also available with the model. This study used the traditional optimization function, which minimizes delay and stops.

Traffic networks may be constructed using the TRANSYT-7F model by entering values in several tables or by exporting networks from SYNCHRO or PRETRANSYT programs. For this study, the TRANSYT-7F network was provided by PRETRANSYT. An incremental optimization process was used to design the proposed signal plans, which included the following:

1. CYCOPT was used to select the optimal cycle length for the network. The cycle length ranged from 80-120 seconds with a five-second increment.

2. TRANSYT-7F was used to perform split optimization. The new T7FACT component, which is supposed to provide traffic-actuated split times, was not used since it provided higher performance index value than the original TRANSYT-7F engine. More research is needed to evaluate T7FACT. Similar to the other models, the split times were designed to accommodate the pedestrian and vehicle minimum times for each intersection.

3. The genetic algorithm optimization was used to optimize offsets. This feature ensures that the model will not provide local optimal solutions but global optimal solutions during the hill climbing technique.

2.2 Software Input and Analysis Times

In terms of input time, the Synchro model takes full advantage of the windows operating system, thus easier and more efficient to use than the other three models. The graphical user interface has appropriate windows that allow the user to progress through the input in an orderly fashion. As with any software, there is a learning curve which must be overcome. Based on sufficient experience, it was determined that Synchro's learning curve was far less than those of TEAPAC, PASSER, and TRANSYT.

It is difficult to calculate the time needed to develop each model since TEAPAC was used to develop the PASSER and TRANSYT input files. When comparing the data input time for Synchro and TEAPAC for an experienced user, Synchro is a least 25 percent more efficient. However, this time significantly increases if changes need to be made to the network. In Synchro, the modification only needs to occur once since all of the information is stored in one file. However, since TEAPAC combines individual intersection information into one network file, multiple files have to be modified.

2.3 Benefits/Limitations

A signal analysis tool must have one or more attribute to make it a marketable product, while reducing the number of negative aspects. The following section describes the most prominent benefits and limitations of each program.

2.3.1 SYNCHRO

The major benefit of Synchro is the ability to develop and optimize a network within the same graphical interface. This interface reduces input time and eliminates the need to maintain multiple files during analysis. In addition, Synchro provides the ability to import and export data between many different traffic software programs, making it desirable for pre-processing to TRANSYT or the simulation model, CORSIM.

The ability to designate and manipulate zones or partitions also made the model desirable, especially for this analysis. The user was able to optimize one zone independent of the other zone. Another nice feature of the Synchro model is the report generation option. The user can define network, arterial, or intersection levels, as well as limit the measures of effectiveness to the lane level.

Synchro does have limitations, however, such as not having the option for different coordination optimization methods. The percentile method works well for reducing the overall network delay but does not allow the user to allocate additional green time or capacity to the coordinated movement. In several of the timing plans, large splits will be noticed for side-street movements. These large splits occur because excess capacity is evenly split between all the phases. Thus the side-street split does not necessarily reflect the effective actuated green time.

2.3.2 TEAPAC

The major benefit of TEAPAC is the interface between several traffic analysis models allowing the user to input data into a common file format that can be used by several models. TEAPAC provides insight and advice on which models to use based on the goals of the analysis, e.g. to maximize bandwidth or minimize delay.

Although TEAPAC is beneficial to share data between models, the program does have some shortcomings. The lack of a graphical interface could potentially result in more errors when constructing networks and modifying input parameters. Configuring the models and mapping to the various programs may cause some initial problems to develop, especially if the user does not have reasonable computer experience. The user normally only encounters these issues, however, during the initial program setup.

SIGNAL2000 has several positive attributes for capacity analysis and optimization. First, it strictly follows the methodology in the HCM 2000. In addition, SIGNAL2000 is capable of designing intersection timings based on default and user defined optimization strategies. One disadvantage of the model is the lack of an effective graphical interface.

2.3.3 PASSER

The PASSER II-90 has been successfully used to optimize bandwidth since 1990. However, it is in need of updating to the current HCM methodology. (Note: since the time of this study's signal analysis, PASSER 2000 has been released.) In addition, the input parameters of the program need to be enhanced, such as entering lost time per phase instead of the global input value. Modifications to more accurately analyzing actuated phasing would also be beneficial.

2.3.4 TRANSYT

The TRANSYT-7F program has undergone some recent enhancements, including a more user-friendly input editor, and several components to provide more accurate results compared to the standard TRANSYT-7F engine. The more prominent components or modules of the T7F9 shell program includes the following:

- TRANSYT-7F - Traffic simulation and signal optimization tool
- CYCOPT - Thorough cycle length optimization
- T7FACT - Actuated control methodology
- G.A. Optimization - Genetic algorithm optimization

Although TRANSYT-7F documentation has been around for many years, documentation for the T7F9 shell program and the remaining modules is limited. A more user-friendly manual needs to be constructed and insight to the recommended practices and procedures would be helpful.

2.4 Input Requirements

The following inputs were common to each signal optimization tool:

- Traffic volume
- Peak hour factor
- Traffic composition
- Lane configuration
- Distance between intersections (center to center or stopline to stopline)
- Type of controller (pretimed or actuated)
- Cycle Lengths (initial)
- Phase sequence
- Minimum Green
- Clearance times (yellow/red)
- Offset

The next sections will add to these minimum input requirements. It should be noted that not all inputs are readily available. Some input variables, such as arrival type and lost time, require some judgement to be made by the user.

2.4.1 Synchro

In addition to the minimum inputs above, Synchro requires the following inputs:

- Minimum split
- Total lost time
- Detector location and length
- Passage time
- Right-turn-on-red (RTOR)

2.4.2 TEAPAC

In addition to the minimum inputs above, TEAPAC requires the following inputs:

- Arrival type
- Start up lost time

2.4.3 PASSER

In addition to the minimum inputs above, PASSER II-90 requires the following inputs:

- Left-turn sneakers per phase
- Phase total lost time (global value, including clearance times)

2.4.4 TRANSYT

In addition to the minimum inputs above, TRANSYT-7F requires the following inputs:

- Start-up lost time
- Extension of effective green
- Left-turn sneakers per phase
- Unit extension (T7FACT)
- Detector length (T7FACT)

3.0 Coordination Plans

This section summarizes the coordination plans developed using the four signal optimization tools: Synchro, TEAPAC, PASSER, and TRANSYT. Each model was used to develop three time-of-day plans for the morning, midday, and evening peak periods. In addition, two interconnect systems were investigated. The one-interconnect system consists of the complete corridor (5th Ave N to 32nd Ave N), while the two-system interconnect consists of two interconnect areas 5th Ave N to Demers Ave and 13th Ave S to 32nd Ave S. These two systems will be referred to as a one- and two- system interconnect.

The time periods differed mainly in traffic volumes increasing in the south-bound movement throughout the day. The morning period includes the highest northbound movement, however, the northbound movement maintains a heavy traffic pattern during the midday and pm periods. Other than these two observations, there were no other major traffic patterns that could be observed. Since the traffic volumes are maintained in the northbound direction, it is difficult to provide coordination plans that service time-of-day patterns. Given the traffic characteristics, the models were not forced to provide specific directional coordination.

The original intent of the study was to evaluate the corridor from Gateway Dr to 32nd Ave S. After initial evaluations of the corridor, it was determined to eliminate Gateway Dr from the analysis due the long distance to the next nearest intersection at 5th Ave N. Therefore, the first strategy was to coordinate the signals between 5th Ave N and 32nd Ave S. The second strategy divided the corridor into two segments. The most logical separation point occurred between Demers Ave. and 13th Ave S.

Synchro can automatically determine the best combination of intersections (partitioning), while forcing each intersection to operate in coordination. In other words, no intersection was allowed to operate in free mode. Several tests were conducted in the Synchro software by altering the inputs, but the dividing point between the two areas remained consistent. Since the other models do not have Synchro's functionality, each partition was analyzed separately.

The resulting two interconnect systems consist of all the intersections from 5th Ave N to 32nd Ave S and two segmented areas divided between Demers Ave and 17th Ave S. Figures 3.1 and 3.2 illustrate the two interconnect systems.

3.1 One System Interconnect

This section provides a summary of the one-system interconnect strategy for the three time periods and four signal optimization tools. This strategy includes the complete analysis corridor (10 intersections) between 5th Ave N and 32nd Ave S (approximately 6300 ft). *Technical Memorandum I* provided the complete signal timing of the four optimization models, which include the cycle length, phase split time, and offset.

The main differences between the plans of the four models relates to the cycle lengths and left-turn split times. The cycle lengths for the one-system interconnect were between 95 seconds and 105 seconds. The AM and midday plans reflect similar characteristics, whereas the pm plans were generally at 100 second cycle lengths. Table 3.1 summarizes the cycle lengths determined by each signal optimization tool for the one-system interconnect.

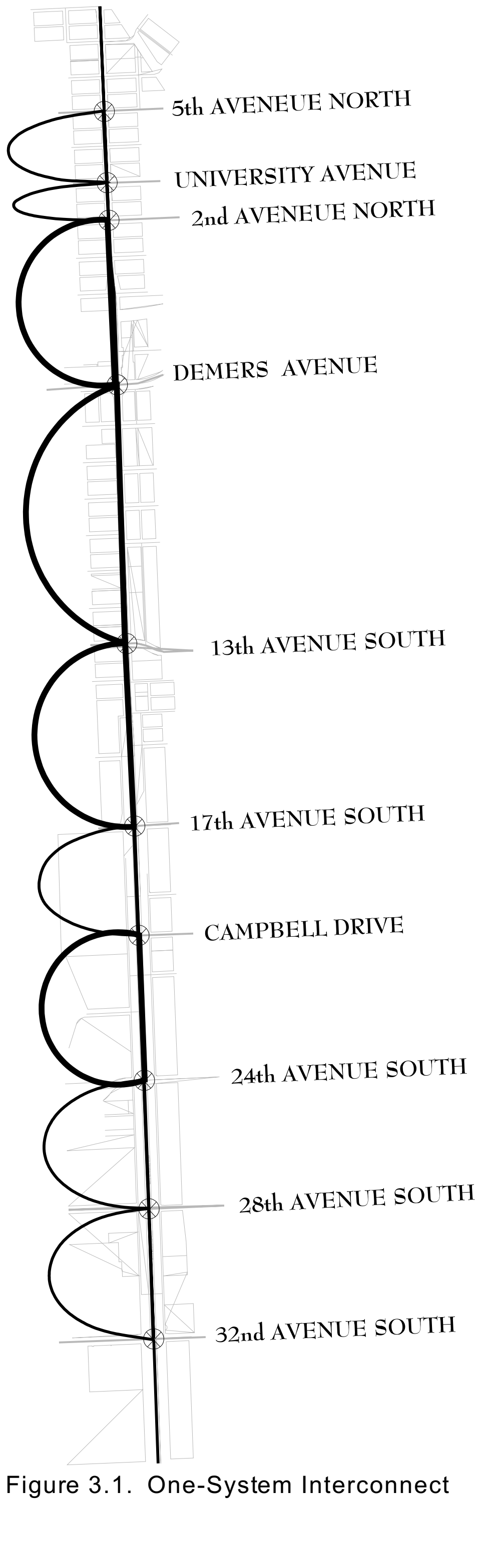


Figure 3.1. One-System Interconnect

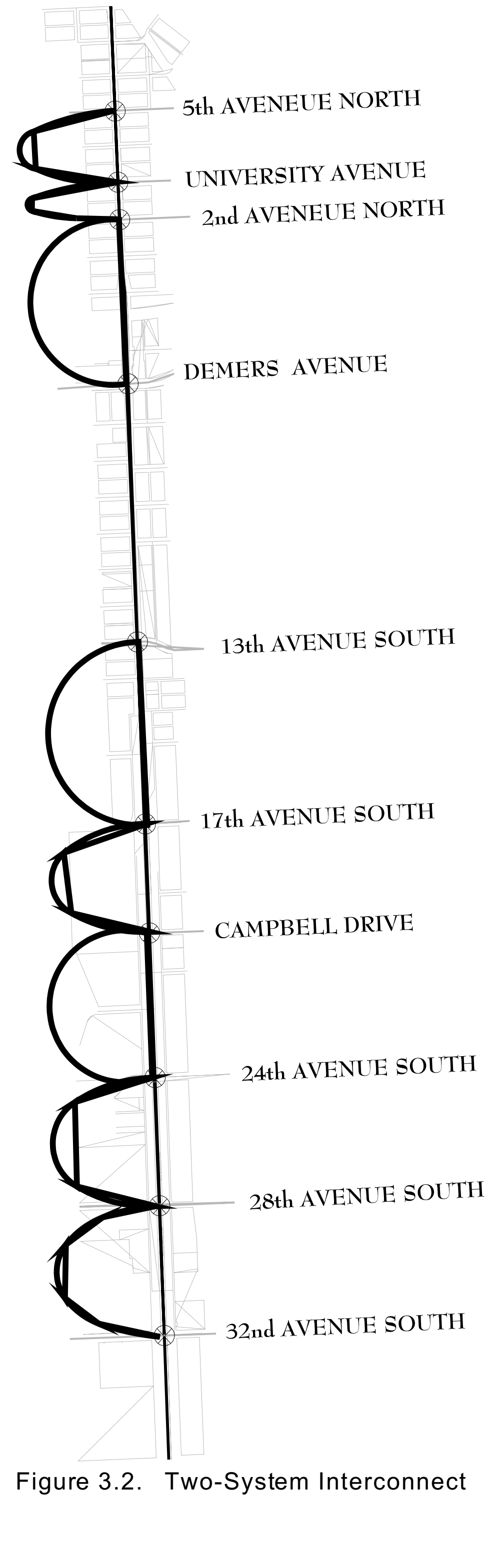


Figure 3.2. Two-System Interconnect

Table 3.1. Summary of Cycle Lengths, One System Interconnect.

	Interconnect 5th - 32nd		
	AM	MID	PM
Synchro	95	95	100
TEAPAC	95	95	100
PASSER	110	105	105
TRANSYT	100	100	100

3.2 Two System Interconnect

This section provides a summary of the two-system interconnect strategy for the three time periods and four signal optimization tools. This strategy increases the existing two interconnects by connecting Demers Ave to the 5th Ave N to 2nd Ave N (approximately 1750 ft) interconnect and connecting 13th Ave S to the 17th Ave S to 32nd Ave S interconnect (approximately 1900 ft). *Technical Memorandum I* provided the complete signal timing of the four optimization models, which include the cycle length, phase split time, and offset.

The two-system interconnect resulted in differing cycle lengths for each interconnect, which ranged from 85-120 seconds. There is no common pattern that is recognized between the signal optimization tools and time periods. Table 3.2 summarizes the cycle lengths determined by each signal optimization tool for the two-system interconnect.

The left-turn split times also differed between the models. Synchro allowed for a minimum green split to be entered. This split designation allowed for low volume left turns to receive a larger green time if demand was present. The other optimization tools did not allow for this input and often resulted in small maximum splits, often 2 or 3 seconds for the left-turn movement.

Table 3.2. - Summary of Cycle Lengths, Two System Interconnect.

	Interconnect 5th - Demers			Interconnect 13th - 32nd		
	AM	MID	PM	AM	MID	PM
Synchro	95	90	95	100	85	90
TEAPAC	110	115	105	95	95	100
PASSER	115	120	120	110	110	105
TRANSYT	95	95	95	100	105	95

3.3 Coordination Plan Summary

The cycle lengths were mainly 95 - 100 seconds when evaluating the one-system interconnect. In comparison, the cycle lengths ranged from 85 -120 when evaluating a two-system interconnect. Synchro maintained generally conservative cycle length values, as expected due to the desire to lower overall network delay. The PASSER model, however, provided cycle lengths as high as 120 seconds while trying to minimize arterial delay.

4.0 Simulation Tools

This chapter provides an overview of the microscopic traffic simulation tools and information on software input and analysis time. The summaries will provide an overview of some of the capabilities and limitations of the simulation tools.

4.1 Simulation Overview

A simulation model's internal logic, such as car-following logic and lane-changing logic involve a series of detailed calculations and are general proprietary. In addition, a simulation model's functionality, features, and capabilities/limitations are extensive. Therefore, the following sections will briefly discuss some of the main components and features of each model without providing all details. For more detailed information on CORSIM, SimTraffic, and VISSIM, review their user manuals or contact their distributors (note Appendix B for simulation contact and version information).

4.1.1 CORSIM

CORSIM (CORridor SIMulation) was developed in the mid-1970's by the Federal Highway Administration. It serves as the microscopic simulation model of the TRAF software suite and is capable of modeling surface streets, freeways, and basic transit operations. CORSIM incorporates two, microscopic, stochastic models that operate on a one-second time step: 1) NETSIM, which models street networks, and 2) FRESIM, which models freeway networks.

TSIS (Traffic Software Integrated System) provides an interface and environment for executing CORSIM. A graphical user interface named TRAFED is provided with TSIS to develop CORSIM networks, however, several other programs, such as Synchro and PRENETSIM (a TEAPAC component) can also create CORSIM networks. Once the CORSIM input files are simulated using TSIS, TRAFVU (TRAF Visualization Utility), which is a program within the TSIS environment, is used to view the simulation animation.

The model's networks are based on a link-node representation. Each link represents a one-directional segment connecting an upstream and downstream node. Nodes represent link intersections and points of origins or destinations.

Several types of traffic control are available with CORSIM, including yield signs, stop signs, and traffic signals. CORSIM models pre-timed and actuated signals internally. CORSIM can also interface to traffic signal controllers, NEMA or Type 170, using an add-on controller interface device.

CORSIM provides 2D animation and several types of numerical output. The output can be link-specific, aggregated for multiple links, or network-wide, and includes volume, travel time, delay time, control delay, queue time, queue length, speed, emissions, etc.

4.1.2 SimTraffic

SimTraffic was developed in the mid-1990's by the Trafficware Corporation. This microscopic simulation model is integrated into the Synchro program and is capable of simulating cars, trucks, and pedestrians. SimTraffic incorporates most of the vehicle and driver characteristics found in CORSIM and is capable of modeling both arterials and freeways.

Data must first be inputted into Synchro to perform a simulation analysis with SimTraffic. Therefore, it provides the user with both signal analysis and simulation analysis capabilities through one input source. Similar to CORSIM, SimTraffic's networks are based on a link-node representation.

SimTraffic is capable of simulating several types of traffic control, including yield signs, stop signs, and traffic signals (pre-timed and actuated). SimTraffic can also interface to NEMA traffic signal controllers using a the TS2 interface.

In addition to 2D animation, SimTraffic provides several types of numerical output. The user can select a variety of MOE reports, aggregated into arterial or network reports. Examples of the output include travel time, delay time, queue length, speed, emissions, etc.

4.1.3 VISSIM

The VISSIM simulation model was developed in Germany by PTV AG. It is a microscopic simulation model capable of simulating traffic operations in urban areas with special emphasis on public transportation and multi-modal transportation. Therefore, the model can simulate cars, heavy vehicles, pedestrians, bicyclists, heavy rail, and light rail transit.

VISSIM consists of two different programs: 1) the traffic simulator, and 2) signal state generator. The traffic simulator is a microscopic simulation model comprising of car-following logic and lane-changing logic. The simulator is capable of simulating up to ten times per second. CORSIM and SimTraffic differ by simulating only one time per second. The signal state generator is signal control software that polls detector information from the traffic simulator on a discrete time step basis and updates the signal state every second.

The largest difference between VISSIM and other microscopic simulation models is its departure from a node-link structure. VISSIM's networks are based on links and connectors. This structure allows flexibility when constructing complex intersections or lane alignments, such as round-abouts, curvatures, short links, and underpasses. This type of modeling allows greater representation of actual network conditions by creating connections which represent the actual flow of traffic, instead of computer generated connections.

VISSIM simulates a variety of traffic control types, including yield signs, stop signs, and pre-timed or actuated traffic signal control. Pre-timed traffic signal control is handled by an internal logic whereas the actuated traffic signal control is handled by the external signal state generator, VAP. VAP, or vehicle actuated program, allows users to completely define their specific signal control. Users can code, using a language similar to BASIC, actuated signal control operations or analyze advanced features, such as transit priority, railroad preemption, adaptive control strategies, and emergency vehicle preemption. VISSIM can also interface to traffic signal controllers type NEMA, 170, or 2070.

VISSIM provides several forms of output. In terms of animation, the user can specify either 2D or 3D graphics. Numerical output files are user-customized and include volume, speed, travel time, delay time, queue length, emissions, number of stops, etc.

4.2 Software Time Requirements

The time needed to construct the simulation model depends on several factors, including the user's experience with the model, the type of traffic control used for the analysis, and the availability of a pre-processor to construct networks. Similar to other programs, a learning curve must be overcome to be a proficient user and simulation models typically have a steeper curve than other traffic analysis models.

Each of the simulation models have dissimilar processes when developing networks. In some instances, as previously described, the network is developed by a pre-processor or converter from another software program. This greatly reduces the time needed for network development and maintains consistency between models. Some networks are developed from a graphical background, while others are simply input by coordinates. There are also several other methods that differ between the models, such as traffic control, speed control, and yielding control. Some models have built in features, while others require user input.

Using detailed traffic control, such as actuated signal control, requires additional input values. Further, user experience is helpful when converting between a signal optimization tool and a simulation network. Some parameters must be altered to ensure proper comparison between the models, such as the coordination parameters, forceoffs and permissive windows. For example, the CORSIM model calculates the permissive window differently than the VISSIM model.

The CORSIM model was easily created by using the Synchro program. The export feature allows for automatic creation of the network file (.trf) which can be read into the TSIS shell. Only small errors were encountered when exporting the CORSIM files. Some examples of the errors include the following:

- detector placement
- turning lane distances
- phasing sequence

Since SimTraffic is an integrated product of Trafficware, a simple export feature is provided for simulation ease. Some input parameters are needed from the user to control the simulation. Otherwise, the process is fairly straight-forward.

VISSIM networks were by far the most difficult to create, providing no pre-processor for network development. This process was described in the previous section. Traffic control inputs also required a large amount of user time. VISSIM does not provide a pre-processor for developing actuated control logic. Therefore, each signal timing plan was calculated by hand and input into the VISSIM logic files. While this is promised to be an input feature in future releases, it is not currently provided by any other third party. It is estimated that the VISSIM input time took approximately eight times longer to create a network than the input time required for the other two simulation models. It should be noted, however, that developing networks in CORSIM without the aid of a pre-processor, would take a similar amount of input time.

4.3 Simulation Network Development

This section will provide information on the development of the network models using the three simulation tools. First, information is provided on the individual models, followed by general input requirements and simulation parameters.

The simulated traffic volumes were held consistent between the three simulation models. The volumes were adjusted with the peak hour factors (PHF) to simulate the peak rate of flow. When the volumes between intersection were not balanced, source-sink values were used at centroid locations. The source/sink values adjust the link volumes to conform with the field counts at each intersection. Volume discrepancies are evident since several driveways or unsignalized intersections are between the signalized intersections, thus the volume received at an intersection may differ from the volume sent to the intersection based on the adjacent intersection count.

4.3.1 CORSIM

The CORSIM simulation files were developed using the export feature in Synchro. To ensure consistency in calculating the permissive periods, force offs, and yield points, the signal plans from TEAPAC, PASSER, and TRANSYT were entered into Synchro program then exported to CORSIM. Some minor adjustments were made to the exported CORSIM files within TSIS, such as defining link aggregation for summarizing numerical output and modifying detector placement. The adjustments were reflected in all of the simulation plans.

4.3.2 SimTraffic

The SimTraffic simulation files were developed using Synchro. For the signal plans developed using Synchro, the user only needs to select the SimTraffic ANIMATION button within Synchro. As stated in the CORSIM section, the signal plans of the other three programs were entered into Synchro prior to being simulated in SimTraffic.

By entering the the signal plans from TEAPAC, PASSER, and TRANSYT into Synchro, the SimTraffic models were constructed automatically. Transferring the Synchro files to SimTraffic is a seamless transition since the error checking is performed in Synchro.

4.3.3 VISSIM

The VISSIM simulation files were developed without any assistance from other tools, as previously mentioned. VISSIM's user interface allows for background images to be imported in .bmp format. Once the background image has been scaled, the network is developed manually. VISSIM does have the capability to import network files from another PTV software suite program, VISUM. VISUM is a planning model similar to TranPlan or EMME/2. Once the model was created, the other network elements were added to the model, such as traffic characteristics (volumes, speed limits, turning movements), signal control, and data collectors. This process took much longer time than the other two models.

Since VISSIM does not have an interface to Synchro or the other models, the signal control was manually entered into text files. Each signal timing plan required calculations to obtain the correct input parameters required by the VAP files.

4.4 Input Requirements

The major inputs for the simulation model are similar to the signal optimization models and can be classified into roadway geometry, traffic composition, and traffic control. Roadway geometry includes the spacial location, width, and number of travel lanes. Traffic composition characteristics include volume, turning movements, and the percentage of heavy vehicles. Traffic control input includes the type of control, such as unsignalized, pre-timed, or actuated signalized control. All of the intersections analyzed in this study were actuated signal controllers. The required signal input for most of the models includes phase sequence, cycle length, minimum green time, clearance and change intervals, passage time, permissive period, force off, and offset or yield point.

4.5 Simulation Parameters

Each simulation model contains a variety of parameters that may or may not be defined by the user. Some of these parameters are used to calibrate the model for a particular study while others are used to simulate unique or unusual situations. Some examples of simulation parameters include vehicle length, acceleration rates, speed curves, startup lost time, etc. This analysis used the default parameters for each simulation model to compare the performance of signal optimization tools. The goal of the simulation comparisons was to evaluate the changes between the signal plans, therefore, care was taken to ensure the roadway geometry and traffic compositions were consistent.

Each simulation run had a one hour duration, in addition to a seed time period, that allowed traffic to reach equilibrium in the network. Since the simulation models are stochastic in nature, variations in the numerical output occur between each simulation run. Therefore, the average numerical output for 30 simulation runs was used for each simulation analysis. This provides statistical significance for the comparisons.

4.6 Simulation Limitations

Traffic simulation programs attempt to represent the field conditions of an analysis network. To accomplish this task, the models use a variety of parameters (similar to signal analysis programs) related to driving behavior and vehicle parameters. Driver behavior data is used to provide various types of

drivers to the traffic stream, such a aggressive and passive drivers, and includes but is not limited to the following:

- Free-flow speed
- Queue discharge headway

- Gaps for lane changing and turning maneuvers
- Driver reaction to green indication, yellow indication and traveler information

Vehicle data represent the vehicle characteristics and operational performance of the traffic stream. Examples of vehicle data include the following:

- Traffic composition (percentage of each vehicle type or class)
- Vehicle length
- Maximum acceleration/deceleration rate

Each simulation model provides default driver and vehicle parameters based on previous research to produce typical/acceptable results. These parameters should vary from place to place for several reasons, including driver demographics, road conditions, etc. Therefore, it is recommended to calibrate these parameters to produce valid output, such as travel time, volume, and queue length that correlates with the local conditions.

Since the field data were gathered several months prior to this study, the calibrate/validation process could not be performed. Furthermore, this study was unique in terms of evaluating various signal optimization programs using various traffic simulation models rather than field conditions. In addition, since only the signal plans were modified between the simulation scenarios, the percent change between different plans would probably be observed in the field but the actual values, such as delay time, may or may not match observed conditions.

5.0 Simulation Results

This chapter provides results from the three simulation models. Results are provided for both interconnect systems, referred to as one-system and two-system. The results obtained were aggregated for the side-streets, arterial, and the total network.

Three simulation models were used to limit the bias between comparisons. By using three independent models with similar network characteristics, a better representation is given on the performance of the signal timing plans developed using the signal optimization tools. Each simulation tool is capable of providing detailed performance data or measures of effectiveness (MOE). Since each simulation model has a different method of calculating their respective MOEs. For example, CORSIM calculates stopped delay whenever the vehicles travel less than 3 fps, SimTraffic calculates stopped delay whenever vehicles travel less than 10 fps, whereas VISSIM calculates stopped delay for vehicles with velocity equal to zero. Since each model collects total delay when traveling below the desired free flow speed, this MOE was chosen for the comparison. This comparison will reduce bias by using only one model, however, each model is expected to differ due to unique modeling methods.

Based on the results, VISSIM's delay times were consistently lower than those obtained by CORSIM and SimTraffic. This difference can be mainly explained by the measurement process. Delay is calculated whenever vehicles are within collection zones, which are user-defined. The delay measurement zones were placed consistently throughout the model, mainly 200 meters upstream from each stop line location. The other two models differ in this process by using internal coding for collecting delay. While VISSIM's measurement points are 200 meters upstream from the stop line location, CORSIM and SimTraffic measurement points are from stop line to stop line. Also, the different models have similar but unique driver-vehicle combinations that can affect the overall performance of the model.

Each of the values from the simulation output have been averaged using 30 random number seeds. This high number of simulation runs provides the greatest statistical significance of the values obtained. Several studies have looked at the statistical significance of multiple simulation runs, a general rule of thumb is to disregard values that include less than 10 random number seeds. Each simulation period was simulated for one hour, not including a five-minute seed time of the network to reach equilibrium.

Statistical analyses were performed among the four signal optimization program for each simulation model and time period. The analysis focused on the arterial and total network delay time values to determine if the differences between the signal analysis programs are significant at a 95% confidence.

5.1 One System Interconnect

Three related sets of MOE are summarized for the corridor, including side-street, arterial, and network delay. All three MOE are summarized in average vehicle hours.

5.1.1 Side-Street Delay

Side-street delay is measured for each approach on the avenues that bisect Washington Street. This MOE illustrates which signal optimization tool provides the greatest benefits to side-street traffic. Tables 5.1 illustrates the results from the simulation for the AM, MID, and PM periods. The bolded values indicate the lowest delay values.

Table 5.1. Side-Street Total Delay, One System Interconnect

	Total Delay, veh-hr			
	SYNCHRO	TEAPAC	PASSER	TRANSYT
AM Peak Period				
CORSIM	55.1	**54.7**	65.9	62.8
SimTraffic	**56.8**	57.2	72.5	122.4
VISSIM	**60.2**	60.8	73.7	74
MID Peak Period				
CORSIM	**59.2**	60.6	67.3	66.4
SimTraffic	**64.1**	66.8	76	114.6
VISSIM	**65.3**	80.9	87.7	96.2
PM Peak Period				
CORSIM	**77.5**	78.6	85.1	83.1
SimTraffic	**90.1**	114.3	204.2	190.7
VISSIM	**82.6**	106.4	104.1	120.6

Synchro provided the greatest benefits to the side-street traffic for all but one scenario. TEAPAC provided the greatest benefits during the CORSIM, AM period and was normally the ranked second to Synchro in the other scenarios. In some instances the values were low for all of the signal optimization tools. In other instances, large differences can be seen. Based on the PM period, it appears that SimTraffic has difficulties modeling congested conditions since some delay values are double those of CORSIM or VISSIM.

5.1.2 Arterial Delay

Arterial delay is measured for the northbound and southbound movements along Washington Street. Similar to the side-street delay measurements, these values were aggregated into vehicle-hours. Arterial delay provides insight into the tools that try to minimize the coordinated delay times and maximize green-band for the coordinated phases. Per the discussion in *Technical Memorandum I*, PASSER is expected to provide the best results. Table 5.2 summarizes the arterial delay values for the AM, MID, and PM time periods. The shaded values indicate the lowest delay values.

Table 5.2. Arterial Total Delay, One System Interconnect

	Total Delay, veh-hr			
	SYNCHRO	TEAPAC	PASSER	TRANSYT
AM Peak Period				
CORSIM	58.3[a]	63.5	**57.5**[b]	**58.0**[a,b]
SimTraffic	65.4	69.2[a]	**61**	67.7[a]
VISSIM	42.5[a]	43.8	42.1[a]	**39.9**
MID Peak Period				
CORSIM	57.9	60.5	59.5	**52.1**
SimTraffic	67.6[a]	66.8[a]	65	**60.9**
VISSIM	**46.7**[a,b]	47.3[a]	**46.1**[b]	54.8
PM Peak Period				
CORSIM	79.3	87.9	81.8	**76.9**
SimTraffic	95.3	102.7	**93.1**	110.8
VISSIM	**66.9**[†]	**65.6**[†]	**65.5**[†]	**67.9**[†]

[†] All comparisons statistically insignificant at a 95% confidence interval

[a-b] Matching letters are statistically insignificant at a 95% confidence interval

Although the results are not as conclusive when compared to the side-street delay, PASSER and TRANSYT provided the lowest arterial delay values. Only one Synchro timing plan during the PM period provided the lowest arterial delay value, which was slightly lower than the PASSER plan for the same time period.

5.1.3 Network Delay

Network delay is an aggregation of the side-street and arterial delay from the previous two sections. Table 5.3 summarize the delay times for the AM, MID, and PM time periods. The shaded values indicate the lowest delay values.

Table 5.3. Network Total Delay, One System Interconnect

	Total Delay, veh-hr			
	SYNCHRO	TEAPAC	PASSER	TRANSYT
AM Peak Period				
CORSIM	**113.4**	118.2	123.4	120.8
SimTraffic	**122.3**	126.4	133.5	190.1
VISSIM	**102.7**	104.5	115.8[a]	113.9[a]
MID Peak Period				
CORSIM	**117.1**	121.1	126.8	118.5
SimTraffic	**131.8**[a]	**133.5**[a]	140.9	175.5
VISSIM	**112**	128.3	133.8	150.9
PM Peak Period				
CORSIM	**156.8**	166.5[a]	166.9[a]	160
SimTraffic	**185.4**	217	297.3[a]	301.5[a]
VISSIM	**149.6**	172.0[a]	169.6[a]	188.5

[a] Matching letters are statistically insignificant at a 95% confidence interval

In all but one case, Synchro provided the lowest overall network delay. Each simulation model consistently reported the same patterns for delay, hence Synchro's coordination plan was the most efficient given the one-system interconnect characteristics.

5.1.4 Summary of Results

PASSER and TRANSYT programs provided similar results in terms of arterial and network delay time. As expected, PASSER provided the low arterial delay values. In addition, the TRANSYT model provided low arterial delay. However, the two models typically ranked third and fourth for side-street and network delay time.

The TEAPAC analysis incorporated several different components to design the coordination plans. During the optimization process, several steps and iterations were performed to develop plans to improve the performance of the total network. The TEAPAC signal plans typically provided the second lowest network delay times each simulation model and time period.

Synchro provided the most benefits in terms of side-street, arterial, and network delay time. Synchro is the only model that estimates the actuated-green time, providing a distinct advantage over the other models. This is feature is especially useful for determining the offsets since the maximum green time available is not typically used.

5.2 Two-System Interconnect

Similar to the one-system interconnect, this section will summarize the results for the two-system interconnect plans. The two-system interconnect includes the 5th Ave N to 13th Ave S interconnect and 13th Ave S to 32nd Ave S interconnect.

5.2.1 Side-Street Delay

Tables 5.4 illustrates the results from the simulation for the AM, MID, and PM periods. The bolded values indicate the lowest delay values.

Table 5.4. Side-Street Total Delay, Two System Interconnect

	Total Delay, veh-hr			
	SYNCHRO	TEAPAC	PASSER	TRANSYT
AM Peak Period				
CORSIM	**54**	58.5	66.7	59.7
SimTraffic	**56.5**	60.7	73.6	76.5
VISSIM	**59.2**	64.9	75.6	69.2
MID Peak Period				
CORSIM	**56.1**	66.7	72.5	66.6
SimTraffic	**60.2**	67.7	73.9	126.5
VISSIM	**62.1**	85.2	128.6	103.1
PM Peak Period				
CORSIM	79.3	79.9	90.9	**78.5**
SimTraffic	**91.7**	116	188.4	222.6
VISSIM	**85**	106.6	121.7	110.8

Synchro provided the greatest benefits to the side-street traffic. TRANSYT and TEAPAC also provided low delay values for the side-street approaches. Overall, the three simulation models produced similar results; however, large variations were observed during the PM period. Congested conditions can create problems, especially when green time values for the side-street and left-turn phases are used. If the green time allocated is not adequate or borderline for the peak rate of flow, some vehicles may not be served in one cycle length.

5.2.2 Arterial Delay

Tables 5.5 illustrates the results from the simulation for the AM, MID, and PM periods. The bolded values indicate the lowest delay values.

Table 5.5. Arterial Total Delay, Two System Interconnect

	Total Delay, veh-hr			
	SYNCHRO	TEAPAC	PASSER	TRANSYT
AM Peak Period				
CORSIM	**56.5**[a]	61.4	59.7	**56.9**[a]
SimTraffic	64.1[a]	68.2	63.5[a]	**61.9**
VISSIM	42.6	38.7	41	**37.8**
MID Peak Period				
CORSIM	61.3	59.6	62.9	**57.7**
SimTraffic	73.3[a]	**65.9**[b]	71.6[a]	**66.2**[b]
VISSIM	46.9	45.3	**42.9**	55.2
PM Peak Period				
CORSIM	79.6	84.3	85.5	**77.5**
SimTraffic	93.4[a,b]	95.0[a,c]	94.5[b,c]	**86.3**
VISSIM	70	**64.1**	67.6	65.5

[a-c] Matching letters are statistically insignificant at a 95% confidence interval

TRANSYT provided the lowest arterial delay values in all but two instances. It should be pointed out that each of the remaining three models provided the lowest arterial delay in at least one case.

5.2.3 Network Delay

Table 5.6 summarize the delay times for the AM, MID, and PM time periods. The shaded values indicate the lowest delay values.

Table 5.6. Network Total Delay, Two System Interconnect

	Total Delay, veh-hr			
	SYNCHRO	TEAPAC	PASSER	TRANSYT
AM Peak Period				
CORSIM	**110.6**	119.9	126.4	116.6
SimTraffic	**120.6**	128.9	137.2[a]	138.4[a]
VISSIM	**101.8**	103.6	116.6	106.9
Mid Peak Period				
CORSIM	**117.3**	126.3	135.4	124.3
SimTraffic	**133.5**[a]	**133.6**[a]	145.5	188.4
VISSIM	**109**	130.5	171.5	158.3
PM Peak Period				
CORSIM	158.9	164.2	176.4	**156.1**
SimTraffic	**185.1**	211	282.9	308.8
VISSIM	**155**	170.7	189.3	176.3

[a] Matching letters are statistically insignificant at a 95% confidence interval

In all but two cases, Synchro provided the lowest overall network delay. TEAPAC provided the second lowest network delay for every case.

5.2.4 Summary of Results

PASSER ranked third and fourth for the side-street and overall network benefits, respectively. It was expected that PASSER would rank high for the arterial benefits, however, it only finish first on one case and typically ranked third for the other cases.

TRANSYT ranked third and first for the side-street and arterial benefits, respectively. The model ranked first in one case of the network benefits, but ranked third overall.

TEAPAC ranked second overall for the three MOE comparisons. The suited ranked first on two arterial cases and one overall network case.

Synchro provided the most network benefits by ranking first in all but one case. Although the arterial benefits were not vary consistent ranging from first to fourth, the side-street benefits were large enough to obtain the top network ranking.

5.3 Interconnect Comparison

The following sections will discuss the simulation results comparing the one-system and two-system interconnect. To reduce the bias between the two types of systems, results of the three simulation will be compared. Since Synchro was chosen to be the most beneficial model, the summary will primarily focus on this tool.

5.3.1 CORSIM Analysis

Tables 5.7 - 5.9 illustrate the percentage changes for the arterial and network delay between the one-system and two-system interconnects for the three time periods. The bolded values indicate the Synchro percent differences.

Table 5.7. CORSIM Interconnect Comparison, AM Peak Period

AM Peak Period	Arterial Total Delay (veh-hr)				Network Total Delay (veh-hr)			
	SYNCHRO	TEAPAC	PASSER	TRANSYT	SYNCHRO	TEAPAC	PASSER	TRANSYT
Two-System	56.5	61.4	59.7	56.9	110.6	119.9	126.4	116.6
One-System	58.3	63.5	57.5	58.0	113.4	118.2	123.4	120.8
Percentage Difference	**3.2%**	3.5%	3.7%	1.9%	**2.6%**	-1.4%	-2.4%	3.6%

Table 5.8. CORSIM Interconnect Comparison, MID Peak Period

MID Peak Period	Arterial Total Delay (veh-hr)				Network Total Delay (veh-hr)			
	SYNCHRO	TEAPAC	PASSER	TRANSYT	SYNCHRO	TEAPAC	PASSER	TRANSYT
Two-System	61.3	59.6	62.9	57.7	117.3	126.3	135.4	124.3
One-System	57.9	60.5	59.5	52.1	117.1	121.1	126.8	118.5
Percentage Difference	**-0.1**	1.5%	-5.4%	-9.7%	**-0.2%**	-4.1%	-6.4%	-4.6%

*shaded values indicate statistically insignificant at a 95% confidence interval

Table 5.9. CORSIM Interconnect Comparison, PM Peak Period

PM Peak Period	Arterial Total Delay (veh-hr)				Network Total Delay (veh-hr)			
	SYNCHRO	TEAPAC	PASSER	TRANSYT	SYNCHRO	TEAPAC	PASSER	TRANSYT
Two-System	79.6	84.3	85.5	77.5	158.9	164.2	176.4	156.1
One-System	79.3	87.9	81.8	76.9	156.8	166.5	166.9	160.0
Percentage Difference	**-0.3%**	4.3%	-4.4%	-0.8%	**-1.3%**	1.4%	-5.4%	2.5%

*shaded values indicate statistically insignificant at a 95% confidence interval

Arterial delay was generally lower for the one-system interconnect, except for the TEAPAC model. When comparing the network delay, the results favored the one-system interconnect for the MIDpeak but AM and PM peaks were split between the one- and two-system interconnect.

The timing plans developed by the Synchro program favored the one-system interconnect on two of the three peak periods. The results make it difficult to determine the most effective interconnect, since the plans do not provide obvious delay time savings.

5.3.2 SimTraffic Analysis

Tables 5.10 - 5.12 illustrate the percent change for the arterial and network delay between the one-system and two-system interconnects for the three time periods. The bolded values indicate the Synchro percent differences.

Table 5.10. SimTraffic Interconnect Comparison, AM Peak Period

AM Peak Period	Arterial Total Delay (veh-hr)				Network Total Delay (veh-hr)			
	SYNCHRO	TEAPAC	PASSER	TRANSYT	SYNCHRO	TEAPAC	PASSER	TRANSYT
Two-System	64.1	68.2	63.5	61.9	120.6	128.9	137.2	138.4
One-System	65.4	69.2	61	67.7	122.3	126.4	133.5	190.1
Percentage Difference	**2.1%**	1.6%	-4.0%	9.3%	**1.4%**	-1.9%	-2.7%	37.3%

*shaded values indicate statistically insignificant at a 95% confidence interval

Table 5.11. SimTraffic Interconnect Comparison, MID Peak Period

MID Peak Period	Arterial Total Delay (veh-hr)				Network Total Delay (veh-hr)			
	SYNCHRO	TEAPAC	PASSER	TRANSYT	SYNCHRO	TEAPAC	PASSER	TRANSYT
Two-System	73.3	65.9	71.6	66.2	133.5	133.6	145.5	188.4
One-System	67.6	66.8	65	60.9	131.8	133.5	140.9	175.5
Percentage Difference	**-7.7%**	1.3%	-9.2%	-8.0%	**-1.3%**	-0.1%	-3.1%	-6.8%

*shaded values indicate statistically insignificant at 95% confidence interval

Table 5.12. SimTraffic Interconnect Comparison, PM Peak Period

PM Peak Period	Arterial Total Delay (veh-hr)				Network Total Delay (veh-hr)			
	SYNCHRO	TEAPAC	PASSER	TRANSYT	SYNCHRO	TEAPAC	PASSER	TRANSYT
Two-System	93.4	95	94.5	86.3	185.1	211	282.9	308.8
One-System	95.3	102.7	93.1	110.8	185.4	217	297.3	301.5
Percentage Difference	**2.0%**	8.1%	-1.5%	28.4%	**0.2%**	2.8%	5.1%	-2.4%

*shaded values indicate statistically insignificant at a 95% confidence interval

A consensus cannot be made for the arterial delay comparisons. Three out of four signal programs had the one- and two- system interconnect as the most efficient for the MID and PM periods, respectively. The AM period was evenly split between the two systems.

The network delay comparison also yielded inconsistent results. The AM peak was split between the two systems, while the MID and PM peak had insignificant differences between the two systems for all four models.

The Synchro program favored the two-system interconnect on two of the three peak periods. The AM and PM periods received modest savings with the two-system interconnect, while the MID period benefitted slightly more using the one-system coordination plan.

5.3.3 VISSIM Analysis

Tables 5.13 - 5.15 illustrate the percent change for the arterial and network delay between the one-system and two-system interconnects for the three time periods. The bolded values indicate the Synchro percent differences.

Table 5.13. VISSIM Interconnect Comparison, AM Peak Period

AM Peak Period	Arterial Total Delay (veh-hr)				Network Total Delay (veh-hr)			
	SYNCHRO	TEAPAC	PASSER	TRANSYT	SYNCHRO	TEAPAC	PASSER	TRANSYT
Two-System	42.6	38.7	41	37.8	101.8	103.6	116.6	106.9
One-System	42.5	43.8	42.1	39.9	102.7	104.5	115.8	113.9
Percentage Difference	**-0.2%**	13.0%	2.5%	5.7%	**0.8%**	0.9%	-0.7%	6.5%

*shaded values indicate statistically insignificant at a 95% confidence interval

Table 5.14. VISSIM Interconnect Comparison, MID Peak Period

MID Peak Period	Arterial Total Delay (veh-hr)				Network Total Delay (veh-hr)			
	SYNCHRO	TEAPAC	PASSER	TRANSYT	SYNCHRO	TEAPAC	PASSER	TRANSYT
Two-System	46.9	45.3	42.9	55.2	109	130.5	171.5	158.3
One-System	46.7	47.3	46.1	54.8	112	128.3	133.8	150.9
Percentage Difference	**-0.5%**	4.5%	7.4%	-0.8%	**2.8%**	-1.7%	-22.0%	-4.6%

*shaded values indicate statistically insignificant at a 95% confidence interval

Table 5.15. VISSIM Interconnect Comparison, PM Peak Period

PM Peak Period	Arterial Total Delay (veh-hr)				Network Total Delay (veh-hr)			
	SYNCHRO	TEAPAC	PASSER	TRANSYT	SYNCHRO	TEAPAC	PASSER	TRANSYT
Two-System	70	64.1	67.6	65.5	155	170.7	189.3	176.3
One-System	66.9	65.6	65.5	67.9	149.6	172	169.6	188.5
Percentage Difference	**-4.4%**	2.3%	-3.1%	3.6%	**-3.5%**	0.8%	-10.4%	6.9%

*shaded values indicate statistically insignificant at a 95% confidence interval

Neither system provided consistent arterial or network delay benefits. The only observation that can be made by these comparisons is the two systems provide similar delay time.

5.3.4 Summary of Results

When dealing with many scenarios and comparisons, it is easy to lose focus on the objective the data is to represent. This is the case when comparing several time of day plans, four signal timing packages, and three simulation software packages. However, some patterns that can be recognized when looking at the three simulation packages collectively. The methodology behind using three simulation packages is to remove any bias, caused by a particular models logic.

Based on the two coordination strategies, it was evident that some signal optimization programs provided more benefits than others. Synchro consistently provided the most benefits for both strategies followed by TEAPAC. In addition, Synchro was the most user friendly program to use and provided several positive features, such as calculating actuated green time and providing an easy to use graphical interface.

The comparison between the two interconnect strategies did not yield overwhelming support for either strategy. Depending on the time of day, one strategy provided slightly more benefits over the other strategy, however, the savings obtained were minimal or insignificant.

6.0 Alternative Communication Media

This chapter provides an overview of the types of plausible interconnect communication media. Data communication methods can fit into three categories: wireless, cable, or fiber. Wireless communications are referred to those technologies that utilize line of sight through radio or microwave systems. Cable consists of copper based connectivity, such as twisted pair or coaxial. Fiber are simply glass based cables. This section will describe some of the individual methods from each category and look at the disadvantages and advantages of each. The next section will summarize components and estimated costs of these systems.

6.1 Wireless

Wireless communications use data transceivers to send a signal at a preset frequency to enable communication between two devices (traffic controllers). An obvious advantage of this method is there is no need for additional infrastructure, such as conduit or innerduct. In addition, there are many frequency options available when choosing a wireless system. Reliability and security are the two main factors to consider when choosing the appropriate frequency.

6.1.1 Types of Wireless Systems

- Radio – requires the use of a transceiver at each data point and typically operates at frequencies ranging from 300Khz to 300Mhz
- Microwave – directional method of signal transmission that operates at frequencies ranging from 300Mhz to 300Ghz (line-of-sight is required)
- Optical – operates at very high frequencies, used mostly for very high data rate applications

6.1.2 Frequency Ranges

Today's radio transceivers can operate in a variety of frequency ranges. Higher frequencies allow higher data rates but shorten the operational distance between antennas. Lower frequencies are better suited for lower data rates and can allow a greater distance between antennas. Also, transmission reliability increases with lower frequencies. On the downside, there are more communication devices available (such as cordless phones) that use the lower frequencies, which can increase the likelihood of interference.

6.1.3 Licensed vs. Non-Licensed

A licensed system is more desirable where long-term reliability is an issue. The FCC issues the user a dedicated frequency to eliminate problems from the radio emissions of others. The downside of a licensed system is a few month delay while the frequency search is performed, preliminary notices are filed, and the FCC license is issued. Additionally, there are annual fees involved for the system.

Spread spectrum (unlicensed) is available in 900Mhz, 2.4Ghz, 3.5Ghz, 5.8Ghz and 24Ghz frequencies. Spread spectrum is suitable where some infrequent interference may be acceptable; or if the structures are very close together or in a very remote area. It should be noted that remoteness and close proximity of antennas might not always overcome all interference. The advantage of the spread spectrum system is that it may be unlicensed so operation can begin immediately.

6.1.4 Advantages/Disadvantages

The advantages of wireless communication include connecting devices that are separated by existing structures or land features. Future expansion of the network can also be done at relatively low costs. The disadvantages are the higher initial cost of the equipment and the dependability of the signal. Line-of-site, environmental factors, and interference from other non-licensed systems may affect the performance of the system.

6.1.5 Components

The wireless system chosen for the comparison is a spread-spectrum microwave system. This system was chosen because the system was the most integrated from the group of vendors solicited.

Typically a site-survey will be conducted prior to the installation. Since spread-spectrum microwave is an unlicensed frequency for systems, there may be interference caused by existing communication devices. A site survey will verify any interference prior to installation. If interference is determined, adjustments in the frequency may eliminate the interruption. The wireless vendor has agreed to provide the site survey equipment for a preliminary survey.

The components needed for wireless installation consist of a modem, communication cables, and antennas. Labor costs were not included for installation of the modem since additional items would be included in the actual installation of the modem. At a minimum, the following components were used to estimate installation costs:

- Modem - Encom Model 5100S
- Antenna - Encom Omni Directional, Base Station
- Antenna - Encom Yagi, Directional

6.1.6 Estimated Costs

Tables 6.1 and 6.2 provide cost estimates for adding one signalized intersection to each of the current signal interconnects using wireless communications. Demers Ave would be added to the 5th Ave N to 2nd Ave N interconnect while 13th Ave S would be added to the 17th Ave S to 32nd Ave S interconnect.

Table 6.1. Wireless Estimates between 17th Ave S and 13th Ave S

Description	Measure	Quantity	Unit Price Materials	Unit Price Labor	Unit Price Materials & Labor	Ext. Price - Materials & Labor
Encom Model 5100S, Wireless Interconnect Unit, RS232 Version Shelf Mount. 4 WIRE FSK option, and Wall Cube Power Supply	EA	2	$2,139.00		$2,139.00	$4,278.00
Encom CB-1018 - RF jumper, 6ft., Rev.TNC to N M	EA	2	$40.00		$40.00	$80.00
Encom CB-1045 Coax Cable - LMR400, 45'	EA	2	$90.00		$90.00	$180.00
Encom AN-159 OMNI Directional, Base Station Antenna 6 dB gain, 902-928 MHz	EA	1	$228.00		$228.00	$228.00
Encom AN-140 Yagi Antenna, Directional, 8.5 dB gain, 900 MHz	EA	1	$123.00		$123.00	$123.00
Encom MT-PEL-1 Antenna Horizontal Mount Kit	EA	2	$275.00		$275.00	$550.00
Encom Y-Cable	EA	1	$200.00		$200.00	$200.00
						$5,639.00

Table 6.2. Wireless Estimates between Demers Ave and 2nd Ave N

Description	Measure	Quantity	Unit Price Materials	Unit Price Labor	Unit Price Materials & Labor	Ext. Price - Materials & Labor
Encom Model 5100S, Wireless Interconnect Unit, RS232 Version Shelf Mount. 4 WIRE FSK option, and Wall Cube Power Supply	EA	2	$2,139.00		$2,139.00	$4,278.00
Encom CB-1018 - RF jumper, 6ft., Rev.TNC to N M	EA	2	$40.00		$40.00	$80.00
Encom CB-1045 Coax Cable - LMR400, 45'	EA	2	$90.00		$90.00	$180.00
Encom AN-159 OMNI Directional, Base Station Antenna 6 dB gain, 902-928 MHz	EA	1	$228.00		$228.00	$228.00
Encom AN-140 Yagi Antenna, Directional, 8.5 dB gain, 900 MHz	EA	1	$123.00		$123.00	$123.00
Encom MT-PEL-1 Antenna Horizontal Mount Kit	EA	2	$275.00		$275.00	$550.00
Encom Y-Cable	EA	1	$200.00		$200.00	$200.00
						$5,639.00

6.2 Cable

Cable communication requires a physical connection between two modems that send the signal across the connection. Reliability is greater with this type of communication but the installation expense can also be much higher.

6.2.1 Types of Cable

- Twisted Pair – a type of cable that consists of two independently insulated wires twisted around one another. One wire carries the signal while the other wire is grounded and absorbs signal interference.

- Coaxial – a type of cable that consists of a center wire surrounded by insulation and then a grounded shield of braided wire. Not typical of interconnect systems.

6.2.2 Advantages/Disadvantages

The main advantage of twisted pair cable is that it is relatively inexpensive. Disadvantages of these types of media, however, include increased susceptibility to electromagnetic interference, possibility of cross talk among signals, lower available bandwidth (compared to fiber), and the signal strength fades as transmission distances increases. In addition, coaxial is not typically used for this type of application and is more expensive than twisted pair.

The cable system chosen for the comparison is an unshielded twisted pair, CAT 5. This type of interconnect is being phased out due to limited bandwidth and system integration. A comparison is only provided to illustrate the marginal cost of fiber.

6.2.3 Components

The components needed for cable installation consist of a modem and cable. The existing interconnect signal can be delivered via the RS-232 port on the existing fiber modem and converted to the 9600 baud modem over twisted pair. At a minimum, the following components were used to estimate installation costs:

- Modem - Naztec 9600A
- Cable - unshielded, 4 - twisted pair, CAT5

6.2.4 Estimated Costs

Tables 6.3 and 6.4 provide cost estimates for adding one signalized intersection to each of the current signal interconnects using cable communications. Demers Ave would be added to the 5th Ave N to 2nd Ave N interconnect while 13th Ave S would be added to the 17th Ave S to 32nd Ave S interconnect.

Table 6.3. Cable Estimates between 17th Ave S and 13th Ave S

Description	Measure	Quantity	Unit Price Materials	Unit Price Labor	Unit Price Materials & Labor	Ext. Price - Materials & Labor
UTP, CAT 5	LF	1889	$0.05	$0.75	$0.80	$1,511.20
Naztec 9600 Baud Modem	EA	2	$500.00		$500.00	$1,000.00
						$2,511.20

Table 6.4. Cable Estimates between Demers Ave and 2nd Ave N

Description	Measure	Quantity	Unit Price Materials	Unit Price Labor	Unit Price Materials & Labor	Ext. Price - Materials & Labor
Bore - 1-2" Innerduct	LF	1744	$0.53	$10.00	$10.53	$18,364.32
4" Casing (AS NEEDED)	LF		$13.00	$3.60	$16.60	-
Warning Tape	LF	1.744	$12.78		$12.78	$22.29
UTP, CAT 5	LF	1744	$0.05	$0.75	$0.80	$1,395.20
Naztec 9600 Baud Modem	EA	2	$500.00		$500.00	$1,000.00
Vault/Hand Hole	EA	4	$622.80	$400.00	$1,022.80	$4,091.20
						$24,873.01

6.3 Fiber

A fiber optic cable consists of a bundle of glass threads, each of which is capable of transmitting messages modulated onto light waves.

6.3.1 Types of Fiber

Fiber can be separated into two types, multimode and single mode. Multimode fiber is used for shorter distances and is less expensive and thus single-mode fiber is used for transmitting data longer distances and is more expensive. Single-mode fiber is usually used for telecommunications whereas multimode is used more often for ITS applications.

Multimode fiber allows light to travel in multiple modes, where a mode is referred to as an independent light path through a fiber. Typical core/cladding size is 62.5/125 m. Single-mode fiber thus allows light to travel in one mode. The fiber has a small core diameter, typically 8.3 m.

Fiber can also have additional features, such as armor. Armor is additional protection under the outer jacket of the fiber to provide protection against the elements.

6.3.2 Advantages/Disadvantages

Advantages of fiber include low interference and high available bandwidth. Fiber is generally more dependable than other types of communication media. The disadvantage of fiber is a high initial cost for materials and installation.

Fiber installation costs are very market driven. Since the slow down of infrastructure development of the telecom companies, fiber prices have lowered significantly. Likewise, installation costs are associated with contractor availability. The cost estimate provided here is based on existing information provided by a consultant for the NDDOT.

It is important to note that existing conduit between 17th Ave S and 13th Ave S is assumed to be in good condition and usable. Conduit that has been placed for several years may experience water infiltration and fail. If the conduit is in poor condition, additional cost may be incurred due to replacement or repair of the existing conduit.

The fiber that was chosen for this comparison is a standard fiber cable used in typical interconnect systems. A six-strand fiber estimate was provided for the interconnects, allowing for four additional unlit fibers. Additional fibers allow for future expansion of the network to include additional components or replacement of failed fibers. Possible ITS applications utilizing the additional fiber include VMS or video transmission for traffic management.

6.3.3 Components

The components needed for fiber installation consist of protective conduit, fiber, and a fiber modem. Additional components will be needed for proper termination of the fiber inside the cabinet, e.g. splice boxes. Labor costs were not included for installation of the modem since additional items would be included in the actual installation of the modem. At a minimum, the following components were used to estimate installation costs:

- Modem - FO400 Fiber Optic Modem, Traffic Fiber Systems
- Fiber Cable - ALTOS/LST™ Cable, 6 strand, multimode fiber, Siecor (Corning Cable Systems)
- Innerduct, orange plastic, or city standard

6.3.4 Estimated Costs

Tables 6.5 and 6.6 provide cost estimates for adding one signalized intersection to each of the current signal interconnects using fiber optic communications. Demers Ave would be added to the 5th Ave N to 2nd Ave N interconnect while 13th Ave S would be added to the 17th Ave S to 32nd Ave S interconnect.

Table 6.5. Fiber Estimates between 17th Ave S and 13th Ave S

Description	Measure	Quantity	Unit Price Materials	Unit Price Labor	Unit Price Materials & Labor	Ext. Price - Materials & Labor
Fiber - 6 Strand, Multimode, Armored	LF	1889	$1.00	$0.75	$1.75	$3,305.75
FO400 170/Internal Fiber Optic Modem	EA	1	$235.00		$235.00	$235.00
						$3,540.75

Table 6.6. Fiber Estimates between Demers Ave and 2nd Ave N

Description	Measure	Quantity	Unit Price Materials	Unit Price Labor	Unit Price Materials & Labor	Ext. Price - Materials & Labor
Bore - 1-2" Innerduct	LF	1744	$0.53	$10.00	$10.53	$18,364.32
4" Casing (AS NEEDED)	LF		$13.00	$3.60	$16.60	-
Warning Tape	LF	1.744	$12.78		$12.78	$22.29
Fiber - 6 Strand, Multimode, Armored	LF	1744	$1.00	$0.75	$1.75	$3,052.00
FO400 170/Internal Fiber Optic Modem	EA	1	$235.00		$235.00	$235.00
Vaults/Hand Holes	EA	4	$622.80	$400.00	$1,022.80	$4,091.20
						$25,764.81

6.4 Interconnect Communication Alternatives

This section will provide information on plausible alternatives for expanding the current interconnect areas. As per the recommendation in *Technical Memorandum II*, the segment between 17th Ave S and 13th Ave S and the segment between Demers Ave and 2nd Ave N will be investigated. Wireless, cable, and fiber options will be discussed, with estimated costs for each segment.

Each system includes an estimation of the actual cost and has not included what are considered minor expenses associated with the installation of cabinet components. Labor costs are provided only for the installation of innerduct and cable/fiber between the intersections and are based on estimates for the Fargo-Moorhead area. It is assumed the labor costs are equivalent between the systems at the controller cabinet, such as installing modems and terminations. Each estimate was based on the lowest quote received by vendors or most integrated system design.

A combination of the systems will provide the most cost efficient system. Wireless may provide additional savings over traditional conduit placed cable or fiber.

6.4.1 One-System Interconnect

This section provides an estimated cost for a one-system interconnect. *Technical Memorandum II* did not recommend interconnecting the two systems, however, estimated cost are provided for comparison. Some advantages can be realized by having a one-system interconnect, such as only needing one master controller. Table 6.7 summarizes a complete fiber connection between 17th Ave S and 2nd Ave N. Table 6.8 summarizes a combination of fiber and wireless, utilizing the existing innerduct between 17th Ave S and 13th Ave S. This combination of communication technologies results in a cost savings of approximately $52,000.00.

Table 6.7. One-System Interconnect, Fiber Estimates between 17th Ave S and 2nd Ave N

Description	Measure	Quantity	Unit Price Materials	Unit Price Labor	Unit Price Materials & Labor	Ext. Price - Materials & Labor
Bore - 1-2" Innerduct	LF	4395	$0.53	$10.00	$10.53	$46,279.35
4" Casing (AS NEEDED)	LF		$13.00	$3.60	$16.60	-
Warning Tape	LF	6.284	$12.78		$12.78	$80.31
Fiber - 6 Strand, Multimode, Armored	LF	6284	$1.00	$0.75	$1.75	$10,997.00
FO400 170/Internal Fiber Optic Modem	EA	2	$235.00		$235.00	$470.00
Vault/Hand Hole	EA	6	$622.80	$400.00	$1,022.80	$6,136.80
						$63,963.46

Table 6.8. One-System Interconnect, Wireless & Fiber Estimates between 17th Ave S and 2nd Ave N

Description	Measure	Quantity	Unit Price Materials	Unit Price Labor	Unit Price Materials & Labor	Ext. Price - Materials & Labor
Encom Model 5100S, Wireless Interconnect Unit, RS232 Version Shelf Mount. 4 WIRE FSK option, and Wall Cube Power Supply	EA	3	$2,139.00		$2,139.00	$6,417.00
Encom CB-1018 - RF jumper, 6ft., Rev.TNC to N M	EA	3	$40.00		$40.00	$120.00
Encom CB-1045 Coax Cable - LMR400, 45'	EA	3	$90.00		$90.00	$270.00
Encom AN-159 OMNI Directional, Base Stateion Antenna 6 dB gain, 902-928 MHz	EA	1	$228.00		$228.00	$228.00
Encom AN-140 Yagi Antenna, Directional, 8.5 dB gain, 900 MHz	EA	2	$123.00		$123.00	$246.00
Encom MT-PEL-1 Antenna Horizontal Mount Kit	EA	3	$275.00		$275.00	$825.00
Encom Y-Cable	EA	2	$200.00		$200.00	$400.00
Fiber - 6 Strand, Multimode, Armored	LF	1889	$1.00	$0.75	$1.75	$3,305.75
FO400 170/Internal Fiber Optic Modem	EA	1	$235.00		$235.00	$235.00
						$12,046.75

6.4.2 Two-System Interconnect

The two-system interconnect would be accomplished by a combination of Table 6.2 and Table 6.5 estimated costs and components. There is substantial savings using a wireless connection between Demers Ave and 2nd Ave N of approximately $20,000. Total cost for the two-system interconnect including fiber for 17th Ave S - 13th Ave S and wireless for Demers Ave - 2nd Ave N is approximately $9,200.00. Installing fiber for both systems would increase the cost to approximately $29,300.00.

6.5 Summary of Results

This section provided a review of alternative communication media for the Washington Street interconnect area. Three alternative communication systems were reviewed for interconnect systems, including wireless, cable, and fiber. A minimum set of components and estimated costs were provided for each system.

Wireless communications were estimated using a typical spread-spectrum system. The vendor used for this comparison is Encom Wireless Data Solutions, Inc. This systems consists of modems and antennas that transmit the signal from the existing fiber interconnect to the outlying intersection(s). Interconnect is achieved by spitting the signal from the fiber modem to the wireless modem.

Several benefits can be realized by choosing a wireless system over a hardline connection. Wireless can be easier to install and have less expensive installation costs. The main disadvantage of a wireless system is possible interference with additional spread-spectrum systems in the area. Therefore, a site survey must be performed to determine if the system would experience any interference. A cost savings of approximately $20,000 is realized for selecting wireless instead of fiber for the connection between Demers Ave and 2nd Ave N. Total cost for wireless communication between 17th Ave S and 13th Ave S and Demers Ave and 2nd Ave N is $5,639.00. The costs are equal for the two segments since the systems require the same components.

Twisted pair cable (copper) was investigated as a comparison for incremental costs for fiber. Since the existing systems are already fiber, placement of twisted pair is not preferred. Additional hardware is required to convert the interconnect signal from the fiber to the twisted pair system. There may be other limitations in bandwidth for additional features.

Fiber communications were estimated using the same model of fiber modems and typical fiber for traffic interconnect applications. The fiber quoted is a multimode, 6 strand armored cable. While only two fibers are required for interconnect, the remaining fibers can be used for future applications.

Installation (labor) costs are the highest for the placement of innerduct and fiber. The cost of fiber is approximately $1.00/ft, and is based on market values. The placement of innerduct between 17th Ave S and 13th Ave S is very advantageous for the placement of fiber for expanding the existing interconnect system. Fiber can be blown into the conduit at a cost approximately $2,000 less than the wireless system. Total cost for fiber installation between 17th Ave S and 13th Ave S is $3,540.75, whereas the cost between Demers Ave and 2nd Ave N is $25,764.81.

Total cost for the two-system interconnect including fiber for 17th Ave S - 13th Ave S and wireless for Demers Ave - 2nd Ave N is approximately $9,200.00. If the one-system interconnect was implemented, a combination of wireless and fiber would cost approximately $12,000 ($70,00 if only fiber was used). The proposed communication alternative is illustrated in Figure 6.1.

6.6 Communication Tips

When adding communication infrastructure to an existing system, several factors must be addressed by the agency and communication vendor. An inventor of the current system components must be performed to ensure system compatibility. Some specific questions that must be answered for the Washington Street corridor include the following:

- What type of fiber is currently being used (single- or multi-mode)
- What is the current condition and size of existing innerduct
- Can communication be made to existing cards or expansion ports at 17th Ave S and 2nd Ave N
- What are the type of port connections on existing modems (ST, FC, or SC)
- Has the daisy-chain reached its limit

Since it was recommended to use wireless communication along part of the corridor, a site survey should be performed to determine if the technology can be used. If interference is caused by existing communication devices, adjustments can be made to eliminate the interruption.

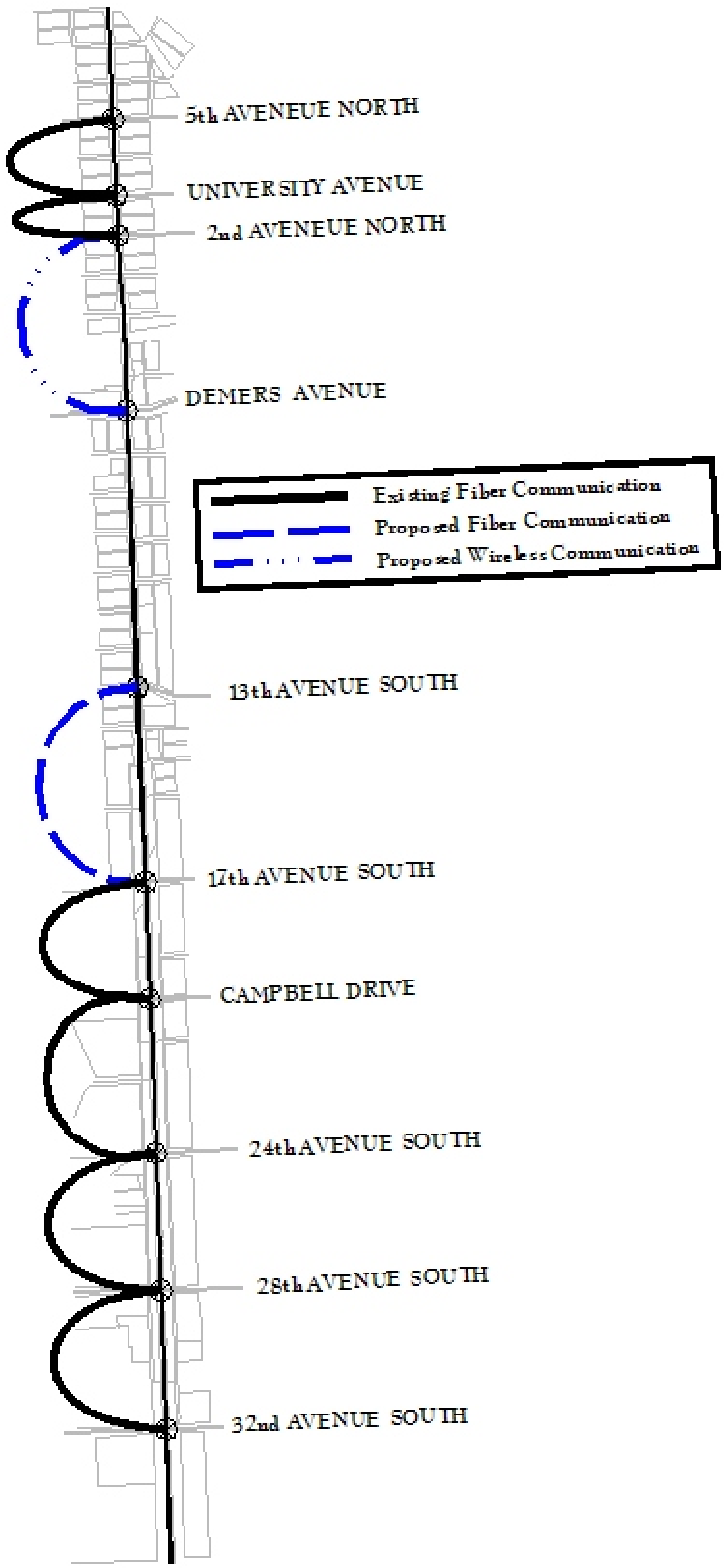


Figure 6.1. Proposed Communication Alternative

7.0 Recommendations

Based on the analyses, our recommendation is to use the Synchro software for signal timing studies. Synchro provided the most user-friendly interface for input parameters and signal timing optimization. In addition, Synchro promotes better organization of traffic signal plans, since intersections and corridors can be merge into one file which reduces the probability of data entry errors and improves signal timing updates. It should be mentioned that minor adjustments are typically necessary to improve the performance or traffic flow after implementing the signal plans. This practice is needed when using any signal analysis tool because driving behavior or traffic patterns may have changed since the traffic data were collected.

The evaluation between the one- and two-system coordination strategies provided inconclusive results. Since the cycle length differences between each zone of the two-system were only five seconds on average, we recommend using the one-system coordination strategy, which uses a common cycle length along the entire corridor. Although the distance between 13th Ave S and Demers Ave is approximately one-half mile, some progression between the two intersections should be realized. The results from the before/after field travel time studies indicate the corridor is benefitting from the updated traffic signal plans and a one-system coordination scheme.

Our recommendation is to expand the current the two-system interconnects to include the intersections of Demers Ave and 13th Ave N. Since two master controllers are already being used at University Ave and 24th Ave S, the two systems do not need to be connected. Our recommendation for alternative communication strategy is to install fiber between 17th Ave S and 13th Ave S and a wireless system between Demers Ave and 2nd Ave N. This configuration would be the most cost effective at a total cost of approximately $9,200, not considering labor costs for installation of components in the traffic controller cabinet. It should also be mentioned that these recommendations did not take into account potential future uses of communications along the corridor, such as adding video monitoring or other ITS technologies.

Appendix A: Signal Optimization Program Information

Synchro

Trafficware Corporation
1009B Solano Ave
Albany, CA 94706
Phone: (510)526-5891
Fax: (510)526-5199
www.trafficware.com

Version 5, Build 321 NOV01

TEAPAC

Strong Concepts
1249 Shermer Road, Suite 100
Northbrook, Illinois U.S.A. 60062-4540
Phone: (847) 564-0386
Fax: 564-0394
www.strongconcepts.com

TEAPAC 2000 Interface
Version 5.00 25SEP01

SIGNAL2000/TEAPAC
Version 2.70 25SEP01 Build 10

NOSTOP/TEAPAC
Version 4.40 25SEP01 Build 10

PREPASSR/TEAPAC
Version 1.60 25SEP01

PRETRANSYT/TEAPAC
Version 2.70 25SEP01

PASSER

Texas Transportation Institute
Texas A&M University System
3135 TAMU
College Station, Texas 77843-3135
Phone: (979)845-1713
Fax: (979)845-9356
http://tti.tamu.edu/

PASSER II-90
Version 2 DEC90

TRANSYT

McTrans Center, University of Florida
P.O. Box 116585
Gainesville FL 32611-6585
Phone: (352)392-0378
Fax: (352)392-6629
http://mctrans.ce.ufl.edu/

TRANSYT-7F
Release 9.4 JAN02

Appendix B: Traffic Simulation Model Information

CORSIM

Federal Highway Administration
Office of Operations Research, Development and Technology
Contract No. DTFH61-95-C-00125

McTrans Center
PO Box 116585
Gainesville, FL 32611-6585
Phone: (352)392-0378
Toll Free: (800)226-1013
Fax: (352)392-6629
mctrans@ce.ufl.edu

Version 5.0

SimTraffic

Trafficware Corporation
1009B Solano Ave
Albany, CA 94706
Phone: (510)526-5891
Fax: (510)526-5199
www.trafficware.com

Version 5, Build 321 NOV01

VISSIM

Innovative Transportation Concepts
1128 NE 2nd St., Suite 204
Corvallis, OR 97330
Phone: (541)754-6836
Fax: (541)754-6837
www.itc-world.com

Version 3.6 - 03

Appendix C: Updated Traffic Signal Timing Plans

AM Peak

Intersection	Volumes											
	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
32nd Ave S	69	133	79	17	336	147	300	354	12	39	215	176
28th Ave S	47	23	26	31	34	92	25	593	14	30	360	45
24th Ave S	121	156	14	45	166	150	47	734	39	63	422	87
Campbell Dr.	32	7	15	12	14	32	28	818	7	14	578	29
17th Ave S	132	149	30	48	225	131	65	720	26	46	557	87
13th Ave S	67	46	32	76	120	79	42	1008	19	26	530	23
Demers Ave	146	670	78	239	507	139	169	702	318	65	426	152
2nd Ave N	9	17	28	28	38	18	136	805	19	13	538	25
University Ave	42	190	102	101	190	26	312	559	72	36	402	25
5th Ave N	1	10	4	17	8	1	17	593	8	6	394	4
Gateway Dr.	107	587	49	157	716	125	79	112	66	138	251	188

Intersection	Level of Service			
	EB	WB	NB	SB
32nd Ave S	C	C	C	B
28th Ave S	D	C	A	A
24th Ave S	C	D	B	B
Campbell Dr.	D	C	A	A
17th Ave S	C	D	B	B
13th Ave S	D	E	A	A
Demers Ave	D	C	B	B
2nd Ave N	C	D	A	A
University Ave	C	C	A	B
5th Ave N	D	D	A	A
Gateway Dr.	C	C	C	C

AM Peak

	32nd Ave S	28th Ave S	24th Ave S	Campbell Dr.	17th Ave S	13th Ave S	Demers Ave	2nd Ave N	University Ave	5th Ave N	Gateway Dr.
Cycle Length	100	100	100	100	100	100	100	100	100	100	100
Offset	40.6	5.6	0	64.6	45	4	28	11	92	32.6	
f 1											
Max Split	21	20	13		15	13	20		30		20.3
Min Green	3	3	3		5	5	4		3		3
Yellow	3.5	3.6	3		3	3.5	3.5		3		3.5
Red	1.2	1.3	1		1	1	1.2		1		1
f 2											
Max Split	28.4	44.2	42.6	55.4	41	42	32	64.3	28.8	52.5	34.8
Min Green	8	13	8	8	8	12	10	12	15	10	7
Yellow	3.9	3.9	3.6	3.6	3.6	4	3.2	3.5	3.5	4	3.2
Red	2.1	2.4	3.2	3	2.4	2	2.5	1	2.2	1	3.1
f 3											
Max Split	13		13		13	20	15		13		20.2
Min Green	3		3		3	8	4		3		3
Yellow	3		3		3	3.5	3.5		3		3.5
Red	1		1		1	1	2		1		1
f 4						**f 9**	**f 4**				
Max Split	37.6	35.8	31.4	44.6	31	25	33	35.7	28.2	47.5	24.7
Min Green	8	5	8	8	8	4	8	9	8	8	8
Yellow	3.9	3	3	4	3	2	3.6	3.5	3.2	3.5	3.2
Red	2.7	3.8	4.4	2.6	3	0	2.1	1.2	2	1	3
f 5											
Max Split	13	20	13		13	13	13	24			20.3
Min Green	3	3	3		3	5	4	2			3
Yellow	3	3.6	3		3	3.5	3.5	3.5			3.5
Red	1	1.3	1		1	1	1.2	1.2			1
f 6											
Max Split	36.4	44.2	42.6	55.4	43	42	39	40.3	58.8	52.5	34.8
Min Green	8	13	8	8	8	8	10	12	15	10	8
Yellow	3.9	3.9	3.9	3.6	3.6	4	3.2	4	3.5	4	3.2
Red	2.1	2.4	2.8	3	2.4	2	2.5	1	2.2	1	3.1
f 7											
Max Split	13		13		13	20	16				20.2
Min Green	3		3		3	8	4				11
Yellow	3.5		3		3	4	3.5				3.5
Red	1.2		1		1	1	2				1
f 8											
Max Split	37.6	35.8	31.4	44.6	31		32	35.7	41.2	47.5	24.7
Min Green	8	5	8	8	5		8	9	8	8	8
Yellow	3.5	3	3	4	3		3.9	3.5	3.2	3.5	3.2
Red	3.6	3.8	4.4	2.6	3		1..9	1.2	2	1	3

Midday Peak

Intersection	Volumes											
	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
32nd Ave S	315	182	148	7	213	47	151	166	11	52	282	328
28th Ave S	59	30	35	32	44	40	26	507	22	58	603	67
24th Ave S	158	145	7	32	141	73	50	657	29	141	843	108
Campbell Dr.	60	10	42	6	16	27	61	721	12	25	833	33
17th Ave S	204	154	54	90	144	66	48	714	74	75	876	123
13th Ave S	120	72	49	170	143	66	54	1121	40	70	1103	20
Demers Ave	199	508	129	414	478	76	161	653	363	96	753	140
2nd Ave N	9	24	73	38	17	18	64	639	14	4	630	17
University Ave	34	135	143	83	171	26	175	494	65	34	433	31
5th Ave N	5	8	14	14	7	5	22	577	12	7	524	9
Gateway Dr.	106	464	111	171	465	109	88	137	94	102	166	170

Intersection	Level of Service			
	EB	WB	NB	SB
32nd Ave S	C	D	C	B
28th Ave S	D	C	A	A
24th Ave S	D	D	B	B
Campbell Dr.	C	C	A	A
17th Ave S	D	D	B	B
13th Ave S	D	E	A	A
Demers Ave	D	D	B	C
2nd Ave N	C	D	A	A
University Ave	C	C	A	B
5th Ave N	D	D	A	A
Gateway Dr.	C	C	C	B

Midday Peak

	32nd Ave S	28th Ave S	24th Ave S	Campbell Dr.	17th Ave S	13th Ave S	Demers Ave	2nd Ave N	University Ave	5th Ave N	Gateway Dr.
Cycle Length	105	105	105	105	105	105	105	105	105	105	100
Offset	32.7	9	0	72	39	101	21	8	98	18	
f 1											
Max Split	15	22	13		13	13	15		26		20.3
Min Green	3	3	3		5	5	4		3		3
Yellow	3.5	3.6	3		3	3.5	3.5		3		3.5
Red	1.2	1.3	1		1	1	1.2		1		1
f 2											
Max Split	30	45.2	47.6	57.4	44	43	38	67.3	33	53.5	34.8
Min Green	8	13	8	8	8	12	10	12	15	10	7
Yellow	3.9	3.9	3.6	3.6	3.6	4	3.2	3.5	3.5	4	3.2
Red	2.1	2.4	3.2	3	2.4	2	2.5	1	2.2	1	3.1
f 3											
Max Split	14		13		13	24	18		19		20.2
Min Green	3		3		3	8	4		3		3
Yellow	3		3		3	3.5	3.5		3		3.5
Red	1		1		1	1	2		1		1
f 4						**f 9**	**f 4**				
Max Split	46	37.8	31.4	47.6	35	25	34	37.7	27	51.5	24.7
Min Green	8	5	8	8	8	4	8	9	8	8	8
Yellow	3.9	3	3	4	3	2	3.6	3.5	3.2	3.5	3.2
Red	2.7	3.8	4.4	2.6	3	0	2.1	1.2	2	1	3
f 5											
Max Split	14	23	22		14	13	13	21			20.3
Min Green	3	3	3		3	5	4	2			3
Yellow	3	3.6	3		3	3.5	3.5	3.5			3.5
Red	1	1.3	1		1	1	1.2	1.2			1
f 6											
Max Split	31	44.2	38.6	57.4	43	43	40	46.3	59	53.5	34.8
Min Green	8	13	8	8	8	8	10	12	15	10	8
Yellow	3.9	3.9	3.9	3.6	3.6	4	3.2	4	3.5	4	3.2
Red	2.1	2.4	2.8	3	2.4	2	2.5	1	2.2	1	3.1
f 7											
Max Split	26		13		17	24	23				20.2
Min Green	3		3		3	8	4				11
Yellow	3.5		3		3	4	3.5				3.5
Red	1.2		1		1	1	2				1
f 8											
Max Split	34	37.8	31.4	47.6	31		29	37.7	46	51.5	24.7
Min Green	8	5	8	8	5		8	9	8	8	8
Yellow	3.5	3	3	4	3		3.9	3.5	3.2	3.5	3.2
Red	3.6	3.8	4.4	2.6	3		1..9	1.2	2	1	3

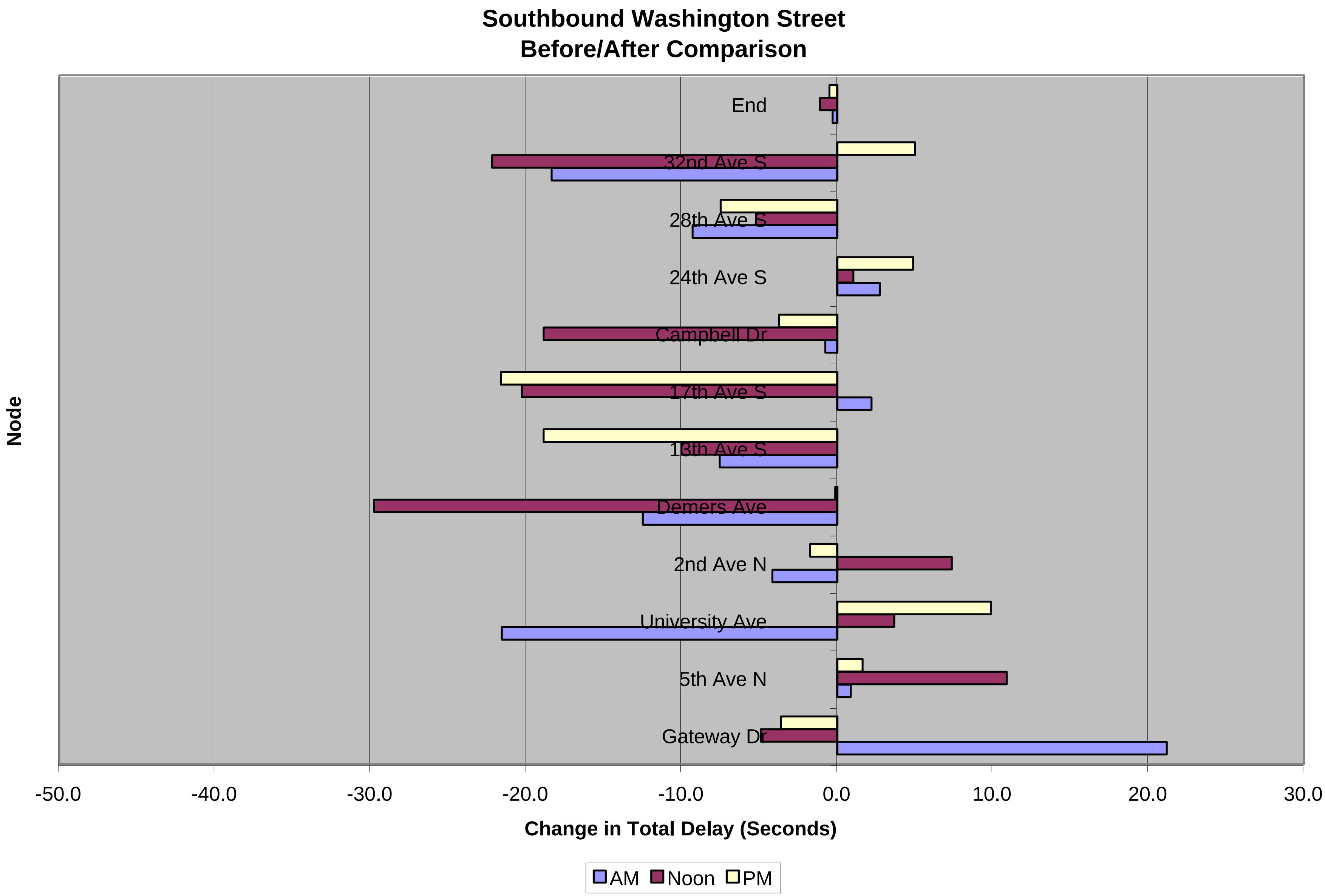
PM Peak

Intersection	Volumes											
	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
32nd Ave S	421	290	289	17	276	69	285	304	38	74	427	271
28th Ave S	66	62	55	37	48	39	60	648	27	86	731	33
24th Ave S	258	199	39	75	201	27	43	1050	30	127	1139	184
Campbell Dr.	58	117	30	22	108	19	77	648	13	43	609	18
17th Ave S	239	274	41	87	241	70	121	924	93	117	1102	140
13th Ave S	135	182	106	188	159	66	72	1533	46	40	1558	77
Demers Ave	323	1017	289	606	724	76	158	893	491	229	1083	176
2nd Ave N	15	40	108	54	24	16	35	879	19	7	1025	6
University Ave	43	158	204	107	199	30	190	594	91	31	699	35
5th Ave N	3	13	22	19	7	9	30	618	30	12	637	2
Gateway Dr.	103	774	131	205	625	131	15	254	118	169	112	129

Intersection	Level of Service			
	EB	WB	NB	SB
32nd Ave S	C	D	D	C
28th Ave S	D	D	B	A
24th Ave S	D	D	C	C
Campbell Dr.	D	D	C	A
17th Ave S	D	D	D	C
13th Ave S	F	F	A	A
Demers Ave	F	F	C	F
2nd Ave N	C	D	A	A
University Ave	C	C	A	B
5th Ave N	D	D	A	A
Gateway Dr.	C	C	C	C

PM Peak

	32nd Ave S	28th Ave S	24th Ave S	Campbell Dr.	17th Ave S	13th Ave S	Demers Ave	2nd Ave N	University Ave	5th Ave N	Gateway Dr.
Cycle Length	115	115	115	115	115	115	115	115	115	115	100
Offset	59.3	25.6	0	86.6	47	5	34	17	3	68.6	
f 1											
Max Split	20	24	13		15	13	13		23		20.3
Min Green	3	3	3		5	5	4		3		3
Yellow	3.5	3.6	3		3	3.5	3.5		3		3.5
Red	1.2	1.3	1		1	1	1.2		1		1
f 2											
Max Split	29	52.2	56.6	59.4	50	50	40	78.3	46.8	61.5	34.8
Min Green	8	13	8	8	8	12	10	12	15	10	7
Yellow	3.9	3.9	3.6	3.6	3.6	4	3.2	3.5	3.5	4	3.2
Red	2.1	2.4	3.2	3	2.4	2	2.5	1	2.2	1	3.1
f 3											
Max Split	13		13		13	27	21		15		20.2
Min Green	3		3		3	8	4		3		3
Yellow	3		3		3	3.5	3.5		3		3.5
Red	1		1		1	1	2		1		1
f 4						**f 9**	**f 4**				
Max Split	53	38.8	32.4	55.6	37	25	41	36.7	30.2	53.5	24.7
Min Green	8	5	8	8	8	4	8	9	8	8	8
Yellow	3.9	3	3	4	3	2	3.6	3.5	3.2	3.5	3.2
Red	2.7	3.8	4.4	2.6	3	0	2.1	1.2	2	1	3
f 5											
Max Split	16	27	16		15	13	16	20			20.3
Min Green	3	3	3		3	5	4	2			3
Yellow	3	3.6	3		3	3.5	3.5	3.5			3.5
Red	1	1.3	1		1	1	1.2	1.2			1
f 6											
Max Split	33	49.2	53.6	59.4	50	50	37	58.3	69.8	61.5	34.8
Min Green	8	13	8	8	8	8	10	12	15	10	8
Yellow	3.9	3.9	3.9	3.6	3.6	4	3.2	4	3.5	4	3.2
Red	2.1	2.4	2.8	3	2.4	2	2.5	1	2.2	1	3.1
f 7											
Max Split	29		14		19	27	23				20.2
Min Green	3		3		3	8	4				11
Yellow	3.5		3		3	4	3.5				3.5
Red	1.2		1		1	1	2				1
f 8											
Max Split	37	38.8	31.4	55.6	31		39	36.7	45.2	53.5	24.7
Min Green	8	5	8	8	5		8	9	8	8	8
Yellow	3.5	3	3	4	3		3.9	3.5	3.2	3.5	3.2
Red	3.6	3.8	4.4	2.6	3		1..9	1.2	2	1	3


Southbound Washington Street
Before/After Comparison
End
32nd Ave S
28th Ave S
24th Ave S
Campbell Dr
17th Ave S
13th Ave S
Demers Ave
2nd Ave N
University Ave
5th Ave N
Gateway Dr
Node
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
10.0
20.0
30.0
Change in Total Delay (Seconds)
AM
Noon
PM